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RESEARCH ON THE QUALITY OF PASSENGER TRANSPORTATION BY RAILWAY

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Abstract. The transportation of passengers by railroads is a dynamic process because setting, wherein the process takes place, undergoes continuous changes observed at technical, technological and transportation process planning levels. Every passenger has different needs and aims and can afford different possibilities. Therefore, the conception of quality differs in each individual case. In order to be able to plan a railway trip process in a proper manner, it is important to become familiarized with passenger needs and preferences and eliminate any existing deficiencies. To this end, it is reasonable to conduct passenger surveys. The paper provides an affinity diagram of railway transportation quality factors, the elements whereof correspond to the structure of the survey questionnaire. For determining the level of the quantitative significance (weight) of indicators, there was applied the method of *Analytic Hierarchy Process* (AHP) developed and introduced by the American scientist T. Saaty. The scope of research work carried out by the authors covered the determination of the highest eigenvalue, the compatibility ratio, the concordance correlation coefficient, the estimated and critical value of *chi-square* values (the examples of estimations are presented in the paper) as well as the classification and processing of the surveyed data on passenger questionnaire and the analysis of respondents' opinion. The closing part of the paper presents conclusions drawn based on the findings of the survey and respective recommendations for quality improvements in passenger transportation by Lithuanian railways.

Keywords: quality of passenger carriage, quality evaluation, respondent survey, ranking, consistency of opinions, coefficient of concordance, AHP method.

1. Introduction

Transport is an integral part of the Lithuanian economic and social infrastructure designed for the purpose of meeting public needs. At present, five types of transport are operated in Lithuania: railway, road, sea, air and inland water transport. Railway transport represents a promising and competitive area of activity which plays an important role in reducing the increasingly growing traffic of motor vehicles minimizing environmental pollution, enhancing the safety of road traffic and solving other problems encountered by the transport system.

Many countries have reformed their transportation policies for the sake of environmental and economical considerations (Akgungor, Demirel 2007).

In the last decade, marked by global developments in the economic life of Lithuania, the growth of automobilisation level and the changing patterns of population needs as well as the number of people travelling by railway transport has significantly decreased. Last year, for example, the flows of travelling people increased, however, those who chose travelling by train were rather small in number. Based on the data of the Department of Statistics for 2007, the number of passengers per all modes of transport made up 471.75 ml which indicates an increase in 3.7% compared to 2006. The majority of passengers (98.2%) traveled by road transport, 1.1% prefered railways, 0.5% used inland water transport and the remaining 0.2% took advantage of the airline services provided by Lithuanian operators. However, the share of railway passengers in 2007 appeared to be 16.3% smaller than that recorded in 2006.

The dynamics of passenger transportation in 1991–2007 is illustrated in Fig. 1. The peak of passenger flows (34.9 ml) fell to the year 1991, whereas the lowest flow of passengers (5.2 ml) was recorded in 2007.

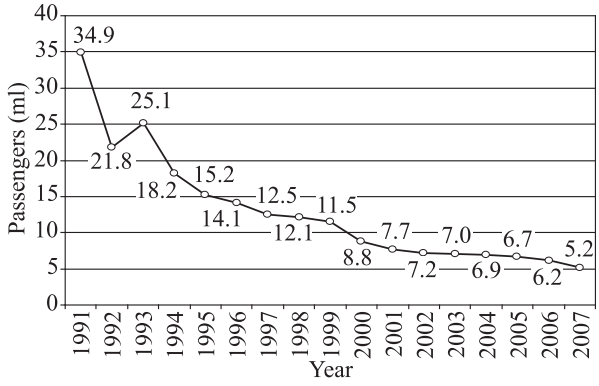


Fig. 1. Dynamics of passenger flows, 1991–2007 (ml)

Thus, railways do not appear to be the most attractive mode of transport and passenger transportation can hardly be viewed as the most promising area of activities conducted by the AB 'Lietuvos geležinkeliai' (Joint-Stock Company *Lithuanian Railways*).

The services of passenger transportation by railroads provided at an affordable price are loss-making to the State. Therefore, making passenger transportation is a profitable task of vital importance. Various calculations are used to optimize this process (Lingaitienė, Lingaitis 2006).

Trains, as a mode of passenger transport, are not yet favoured very much in terms of their attractiveness among people basically due to the insufficient level of comfort they may offer, a comparatively limited speed they are able to develop and poor dynamic characteristics of railway and rolling-stock (Keršys, Bazaras 2001; Bureika 2008; Lata 2008; Dailydka *et al.* 2008; Magyla 2002).

To increase the capacity of railways so that they could compete with other modes of transport and make railway transport an integral part of the extended European transport system, it is necessary to build an up-to-date railway infrastructure, renovate the existing rolling-stock and implement up-to-date information management systems (Povilaitienė *et al.* 2006; Gailienė *et al.* 2008).

Butkevičius (2000) envisages the following major research-based policies to be pursued in developing the activities of passenger carriage by railways: an increase in speed level, an improvement in the ticketing system, the renovation of car park and better financing of railway carriage operations.

The requirements to be complied with the European railway infrastructure are formulated based on the guidelines for railway transport policy and strategy. Infrastructure represents a factor of vital importance as it provides facilities necessary to enable the performance of railway transport operations (Butkevičius, Jaržemskis 2000).

The national priorities with respect to improving the infrastructure of railway transport in Lithuania include an increase in railway network technical level and, more importantly, its upgrade to the level maintained in the European Union. A new construction, however, is envisaged only in an exceptional case. A gradual increase in speed up to the level of 160 km/h, the continued upgrade and expansion of cross-border railway stations and the capital overhaul of the main railway lines also make a part of the national plan. (Sakalauskas, Rezgaitis 2000).

General task for the railway transport sector is to provide decision-makers both at the European and national levels with knowledge and means enabling achievement in the treasured mobility, the building of the integrated European transport system and an increase in its productive, economic and financial efficiency so that railways could enhance their competitiveness and complement other modes of transport (Baublys 2000).

Practice shows that in order to attract more passengers, it is necessary to improve the services of transportation which is only possible given the availability of high quality rolling-stock and expanding the presence of staff having necessary skills to operate railway equipment and assess the technical condition thereof as well as to improve and develop services provided on trains, boost the quality of passenger attendance, eliminate imperfections and enhance the image of railway transport. The identification of passenger needs is also indispensable (Огинская, Толкачева 2006; Пастухов 2008). To this end, it would be reasonable to carry out a comprehensive research into the quality of passenger transportation. Butkevičius (2001) presents a research methodology designed for investigating passenger flows developed by him and approved by numerous research studies conductet since 1994.

The quality of passenger transportation may be defined as the totality of transportation process characteristics that bear on its ability to satisfy passenger needs. Improvement in passenger railway transportation quality is a complex problem requiring knowledge and practice-based professionalism, intellect and the regular generation of new ideas.

In managing complex processes, it is necessary to perform a comprehensive analysis of activities, tasks and objectives as well as of methods and measures enabling achievement thereof. The potential effect of various factors on the efficiency and quality of work must be also assessed. Moreover, to be able to take right decisions, it is necessary to refer to expert estimates (Kendall 1970).

Expertise, as a method for obtaining information, has always been a part of the decision-making process (Kendall 1970). Expert investigations carried out on different subject matters of technological and social sciences were applied by researchers, too (Sivilevičius 2001 and 2002; Ustinovičius, Zavadskas 2004; Zavadskas *et al.* 2005, 2008; Podvezko 2005, 2007; Sivilevičius *et al.* 2008; Su *et al.* 2006; Zavadskas, Kaklauskas 2007; Brauers *et al.* 2008; Ginevičius *et al.* 2008; Šelih *et al.* 2008; Susnienė, Jurkauskas 2008; Morkvėnas *et al.* 2008; Magyla 2001).

The process of going by train is not sufficiently investigated. The research effort aimed at surveying and investigating railway transport passenger flows is very scarce in Lithuania.

Therefore, the purpose of the present study is to disclose the significance of researching the quality of passenger transportation, to provide a scientifically grounded methodology for weighting the quality criteria of passenger transportation by Lithuanian railways, to present data on a respective passenger survey and to propose methods for improving the quality of passenger transportation.

2. Expert Methods Applied in Researching the Quality of Passenger Transportation by Railway

For performing research on the quality of passenger transportation by railway, the most widely recognized and accepted method of pairwise comparison developed by the outstanding American scientist T. Saaty (1980 and 2005) was selected.

The carried out work included the identification and ranking of criteria defining the quality of a railway trip, drafting survey questionnaires suitable for application in this method and their distribution to the respective respondents (passengers). The affinity diagram of railway trip quality factors (corresponding to the structure of the questionnaire) is presented in Fig. 2. The questionnaire is available in English and Russian.

The questionnaire-based survey of passengers conducted on the train Vilnius–Moscow–Vilnius extended from 3 September 2007 to 16 January 2008. Totally, 32 questionnaires were distributed to passengers. Among the respondents, there were 18 nationals from Lithuania, 9 from Russia, 1 from the USA, 1 from Spain, 1 from Italy, 1 from Germany and 1 from Great Britain.

Data on completed and collected questionnaires was processed, thoroughly analyzed, classified and further referred to making respective recommendations on specific measures aimed at improving the quality of passenger transportation.

Fig. 2. The affinity diagram of railway trip quality factors

3. Rating the Weight of Criteria for the Quality of Railway Trip on the basis of the Pairwise Comparison Method

In applying the system of decision-making, rating indicator weights is extremely important. At present, the most widely recognized and accepted method used for rating the weight of indicators is the method of pairwise comparison worked out by T. Saaty (1980 and 2005) and known under the title of *Analytic Hierarchy Process* (AHP). In this method, the weight of indicators standing on a particular level of hierarchy is measured against the indicators of a higher level; it also enables rating weights for hierarchically non-structured indicators. The method is based on the matrix of pairwise comparison used by experts for comparing with each other the indicators (criteria) being weighed, i.e. R_i and R_j (i, j =1, ..., m), where m stands for the number of indicators being compared (Saaty 1980 and 2005; Ginevičius *et al.* 2004 and 2008; Su *et al.* 2006).

This method is very convenient as it is much easier to compare indicators taken pair by pair than to compare them all at one time. The comparison of indictors, as such, is not a sophisticated process as it simply indicates the extent, to which one indicator carries more weight than the other. Moreover, the method concerned makes it possible for the expert to transform a qualitative evaluation of indicators into the quantitative one. As the outcome of comparison is produced in the form of the square matrix $\mathbf{P} = \|p_{ij}\|(i, j = 1, ..., m)$, the evaluation process, as proposed by T. Saaty, shall be carried out using a five-score scale (1-3-5-7-9) widely applied in practice.

The elements of matrix **P** shall be completed in compliance with the following requirements (Saaty 1980; Ginevičius *et al.* 2004): first, when both indicators being compared carry equal weight with respect to the phenomenon (object) of the study, i.e. when both are equally important, the elements of matrix **P** must be $p_{ij} = 1$. In such a case, all the elements of the main diagonal must be $p_{ii} = 1$ ($i = 1,...,m$) as each indicator is compared with itself; second, when indicator R_i carries a higher weight than indicator R_j, the elements of matrix **P** must be $p_{ij} = 3$; third, when indicator R_i carries a much higher weight than indicator, R_j, the elements of matrix **P** must be $p_{ij} = 5$; fourth, when indicator R_i carries a substantially higher weight than indicator R_j, the elements of matrix **P** must be $p_{ij} = 7$; fifth, when indicator R_i carries a comparatively higher weight than indicator R_j, the elements of matrix **P** must be $p_{ij} = 9$.

The estimates of even order ($p_{ij} = 2;4;6;8$) are used as intermediary and compromise variants; generally, they are applied when the situation being investigated based on the opinion of the expert diverges from a typical one.

Matrix **P** elements p_{ij} may be treated as the ratio of indicator R_i and R_j values, and after the values have been normalized – as the ratios between the unknown weights of indicators. In such a case, the scale of elements p_{ij} would represent a set of all rational numbers. The comparison matrix for the expert evaluation of indicators is read as follows:

$$\mathbf{P}=\begin{pmatrix} p_{11} & p_{12}\cdots & p_{1m} \\ p_{21} & p\cdots & p_{2m} \\ \vdots & \ddots & \vdots \\ p_{m1} & p_{m2\cdots} & p_{mn} \end{pmatrix}=\begin{pmatrix} \frac{\omega_1}{\omega_1} & \frac{\omega_1}{\omega_2}\cdots & \frac{\omega_1}{\omega_m} \\ \frac{\omega_2}{\omega_1} & \frac{\omega_2}{\omega_2}\cdots & \frac{\omega_2}{\omega_m} \\ \vdots & \ddots & \vdots \\ \frac{\omega_m}{\omega_1} & \frac{\omega_m}{\omega_2}\cdots & \frac{\omega_m}{\omega_m} \end{pmatrix}. \quad (1)$$

Thus, it is evident that in an ideal case, where elements p_{ij} represent the ratios of unknown weighs, matrix **P** is reciprocal, i.e. $p_{ij}=1/p_{ij}$. Subsequently, the matrix sections which may be completed appear to be located either above or below the main diagonal. Matrix **P** contains m(m-1)/2 number of nonrecurring elements.

In an ideal case, the reciprocity of matrix **P** comes plain: for instance, if one object is three times heavier than the other, then the latter one, naturally, is three times lighter than the first one or, to say in other words, its weight makes up 1/3 of the first indicator's weight. In such a case, the respective elements of any two columns will be proportionate. It means that the ratios between the elements of the respective columns will be identical. For example, the ratio between the elements of the first and the second columns will appear as follows:

$$\frac{p_{i1}}{p_{i2}}=\frac{\frac{\omega_i}{\omega_1}}{\frac{\omega_i}{\omega_2}}=\frac{\omega_2}{\omega_1}\ (i=1,...,m).$$

Similarly, the elements of any two rows will be proportionate, too.

It is very important to ensure the consistency of the comparison matrix (Saaty 1980; Ginevičius *et al.* 2004). Matrix **P** will be consistent if it contains the required minimal number of elements based on which the remaining elements may be obtained. For instance, if element R_1 is three times more important than element R_2 and element R_2 is two times more important than element R_3, then element R_1 is six times more important than element R_3. The elements contained in the columns (and rows) of the consistent matrix will be proportionate. The essential condition for the consistency of the comparison matrix lies in the transitivity of the weight carried by its elements: if element A is more important than element B and element B is more important than element C, then element A is more important than element C.

The condition on the consistency of the comparison matrix may as well be expressed in the form of a mathematical equation. In a truly ideal case, if we multiply matrix **P** by the column of weights $\omega=(\omega_1, \omega_2,..., \omega_m)^T$ and apply equation (1), the result we obtain will be $P\omega=m\omega$, i.e., in fact, this is a well-known mathematical exercise dealing with the matrix **P** eigenvectors ω with eigenvalue $\lambda=m$:

$$P\omega=\lambda\omega, \quad (2)$$

where: m stands for the range of matrix **P** or the number of indicators being compared.

It is known that the maximum eigenvalue of the reciprocal matrix of range m is $\lambda_{max}=m$ (Saaty 1980). In an ideal case, given the matrix is consistent and the elements of columns are proportionate, $\lambda_{max}\geq m$ and the consistency of the matrix are defined in terms of difference $\lambda_{max}-m$, where m stands for the range of matrix **P**. The consistency index S_I is defined using the following equation:

$$S_I=(\lambda_{max}-m)/(m-1). \quad (3)$$

The lower is the value of S_I, the higher is the consistency of the matrix. In an ideal case, $S_I=0$. In practice, however, such a matrix is very rarely generated, even though condition on the transitivity of elements may be fully satisfied. The consistency degree of the quantitative reciprocal matrix may be determined by comparing the computed consistency index of the evaluation matrix with the consistency index of the randomly generated (within the 1–3–5–7–9 scale) reciprocal matrix of the same range. Ratio S_A between the consistency index of the matrix and the mean of the random index is referred to as the ratio of consistency showing the consistency degree of the matrix (Saaty 1980):

$$S_R=\frac{S_I}{S_A}. \quad (4)$$

The matrix will be consistent if the value of ratio S_R is equal to 0.1 or lower.

Equation (2) makes it obvious that the weights in T. Saaty's (1980) comparison AHP method are the normalized components of the eigenvector corresponding to the maximum eigenvalue λ_{max}.

The ratio of consistency S_R makes it possible to determine the consistency of each individual expert judgment. The opinions of different experts may appear to diverge. Consistency within a group of experts can be achieved only if all group members reconcile their opinions through a compromise and come up with a single consistent comparison matrix. However, this appears to be a long and complex process. The consistency of the expert group may be determined using the concordance coefficient W. The application of the concordance coefficient, however, is subject to one essential condition requiring ranking indicators to be performed by all experts of the group. The indicators shall be ranked prior to being compared in pairs so that it would be possible to start a comparison of indicators in the order of their priority. The exercise of distributing indicators and determining their weight is rather easy: the arrangement of indicators in a decreasing order according to their values shows the ranks of indicators. Thus, the estimation of the concordance coefficient is based on the following matrix: $\mathbf{C}=\|c_{ik}\|, i=1, ..., ; k=1, ..., r$ (where m stands for the number of indicators and r refers to the number of experts). If hence the estimated value of the concordance coefficient validates the con-

sistency of expert opinions, the weight of indicators will be the mean of all weights as per ratings of all experts.

The consistency of two expert opinions may be quantified by the correlation coefficient. If the number of experts exceeds two, the consistency level of the expert group will be shown by the concordance coefficient *W*. However, certain issues related to the concordance coefficient and the possibilities of applying it in practice still need to be further elaborated and these include requirements for expert judgments, the best and worst values of the coefficient, the application of theoretical probability distribution χ^2 marginal expectation, the effect of equally rated indicator ranks on the value of the concordance coefficient, relation to T.Saaty's AHP (*Analytic Hierarchy Process*) method and the methods of direct expert evaluation and the dependence of experts consistency level on the selected object evaluation method and scale (Podvezko 2005).

The dispersive concordance coefficient was defined by M. Kendall (1970).

The group consisting of *r* experts performs a quantitative evaluation of *m* objects (indicators). The judgments c_{ij} (i=1, ..., m; j=1, ..., r) are presented in the form of table (matrix) **C** containing *m* number of rows and *r* number of columns. The experts may choose to estimate the expected value c_{ij} in different ways. Estimation may be performed using any measuring scale expressed, for instance, in indicator units, percent shares, unit elements; a 10-score scale or the Saaty's pairwise comparison scale may be also applied. For the estimation of the concordance coefficient, however, only the expert rated ranks of indicators may be applied. If expert estimations have been expressed in any other form, it will be required to carry out their preliminary ranking. Ranking is a procedure whereby the first most important indicator is assigned rank 1, the second one – rank 2 etc. and the least important indicator is assigned rank *m* where *m* stands for the number of indicators being compared. Equivalent indicators are assigned identical value expressed as the arithmetic mean of ordinary ranks. Thus, if we have two consecutive indicators which, based on the order of ranking, should be assigned rank 6 and rank 7 respectively, but, as believed by the expert, they carry equal importance, they will be assigned equal rank 6.5.

The concept of the concordance coefficient relates to the sum of ranks per each indicator (c_i) with respect to all experts (Podvezko 2005 and 2007):

$$c_i = \sum_{j=1}^{r} c_{ij} \left(i = 1, \ldots, m\right), \tag{5}$$

or, to be more specific, it relates to the deviation of values c_i from the total (general) mean $\overline{c}$ by the sum of squares S (the analogue of variance):

$$S = \sum_{i=1}^{m} \left(c_i - \overline{c}\right)^2. \tag{6}$$

The total (general) mean (c_i) is calculated using the following formula:

$$\overline{c} = \frac{\sum_{i=1}^{m} c_i}{m} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{r} c_{ij}}{m}. \tag{7}$$

If the ranks of all indicators as per all expert ratings were identical, the first most important indicator would have rank 1 and the sum of all expert ranking values for this indicator would be equal to *r* , for the second one – *2r* etc. and for the least important indicator – *m*. With respect to the consistency of expert opinions, this is an ideal case. The sum of ranking values attached by *r* number of experts to *m* number of indicators:

$$\sum_{i=1}^{m} c_i = \frac{1}{2} rm\left(m+1\right), \tag{8}$$

and the total mean:

$$\overline{c} = \frac{1}{2} rm\left(m+1\right), \tag{9}$$

depend only on values *m* and *r*; no dependence on the level of consistency is observed here. Using (Podvezko 2005 and 2007) the formulas of *m* natural numbers and the sums of their squares $\left(\sum_{i=1}^{m} i = \frac{\left(1+m\right)m}{2}, \sum_{i=1}^{m} i^2 = \frac{m\left(m+1\right)\left(2m+1\right)}{6}\right)$, it is easy to prove that the sum of squares S calculated based on formula (6) in this particular case of ideal consistency is equal to:

$$S_{\max} = \sum_{i=1}^{m}\left(ri - \frac{1}{2} r\left(m+1\right)\right)^2 = \frac{r^2 m\left(m^2-1\right)}{12}. \tag{10}$$

This maximum possible value of *S* is obtained when the opinions of all experts come in absolute consistency, i.e. the estimations of all experts are equal. We will have the opposite, or the worst, case when expert estimations appear to be absolutely inconsistent, i.e. when each object is rated using all possible ranks from 1 to *m* , in which case the sum of ranking values per each indicator is the same and coincides with the total mean of ranking values. In this particular case, the value of *S* is 0, though in practice it occurs very seldom and therefore could be assumed as representing a theoretical or marginal value. If *S* is the real sum of squares computed based on formula (6), then the concordance coefficient is defined as the ratio between the computed *S* and the respective $S_{\max}$:

$$W = \frac{12S}{r^2 m(m^2-1)}. \tag{11}$$

If expert opinions are consistent, the value of the concordance coefficient *W* will approximate 1 and if expert estimations diverge, the value of *W* will stand close to 0.

The concordance coefficient may be applied in practice provided that its marginal value, at which expert estimations may be still deemed consistent, has been determined. M. Kendall (1970) has proved that if the number of objects is $m>7$, the significance of the concordance coefficient may be determined using the criterion χ^2.

The random value

$$\chi^2 = Wr(m-1) = \frac{12S}{rm(m+1)} \quad (12)$$

is distributed according to the probability distribution χ^2 with $\nu=m-1$ degree of freedom. Critical value $\chi^2_{\alpha y}$ is derived from the table of probability distribution χ^2 with $\nu=m-1$ degree of freedom according to the selected significance level α (in practice, it generally stands at 0.05 or 0.01). If the value of χ^2 as computed based on formula (12) appears to be higher than $\chi^2_{\alpha\nu}$, it means that expert estimations are consistent.

When the number of indicators (objects) being compared (m) ranges from 1 to 7, the application of probability distribution χ^2 should be exercised with care as the critical value $\chi^2_{\alpha\nu}$ of probability distribution may be higher than the computed one, even though the level of consistency for expert opinions may still be tolerable. In such a case, the probability tables of the concordance coefficient or the tables of critical values S (with $3m \le m \le 7$) may be applied (Kendall 1970).

The number of probability distribution χ^2 degrees of freedom (ν) does not depend on the number of experts (r) because only the difference between the sums of indicator ranking values is taken into account. It is also possible to substitute probability distribution χ^2 by the Fisher distribution F which has two degrees of freedom and depends on the number of objects (m) and the number of experts (r).

Below please find an example of computing the data as per one respondent pairwise comparison questionnaire.

In this particular case, the task was to determine the weight of 16 criteria defining the quality of passenger transportation by railways and related to train elements and the technical state of rails (railway track). To this end, the respondents (passengers) were asked to complete the respective questionnaire of pairwise comparison. The sample of the completed comparison matrix is presented in Table 1.

In this case, a task is to obtain the eigenvector that may be estimated using four different methods (Saaty 1980; Шикин и Чхартишвили 2000).

In our research study, we chose to apply the fourth method, the procedure whereof covers the following steps: first, the elements of each row shall be multiplied and hence the obtained result entered in a column; then, the root of n-degree shall be extracted from each element of the column entered; finally, the elements of this column shall be added up and each element subdivided by the obtained sum.

All four estimation methods mentioned before, given we have a case of the ideal matrix, produce precisely the same result (Saaty 1980; Шикин, Чхартишвили 2000).

Now, from the data contained in the above Table 1, we will derive the eigenvector using the fourth method.

Thus, the eigenvector is already known:
$\omega_1 = 0.0204$, $\omega_2 = 0.0916$, $\omega_3 = 0.0216$, $\omega_4 = 0.0247$, $\omega_5 = 0.0201$, $\omega_6 = 0.1381$, $\omega_7 = 0.1381$, $\omega_8 = 0.1479$, $\omega_9 = 0.0182$, $\omega_{10} = 0.1083$, $\omega_{11} = 0.0186$, $\omega_{12} = 0.0186$, $\omega_{13} = 0.0195$, $\omega_{14} = 0.0733$, $\omega_{15} = 0.0212$, $\omega_{16} = 0.0195$. Next, we need to obtain the maximum eigenvalue λ_{max} for this matrix: $\lambda_{max} = 16.86$.

Table 1. An example of the pairwise comparison of indicators related to train elements and the technical state of railway track as per one respondent questionnaire

Indicator No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	1/7	1	1	1	1/5	1/5	1/7	1	1/5	1	1	1	1/3	1/3	1
2	7	1	7	7	7	3	3	3	7	3	7	7	7	3	7	7
3	1	1/7	1	1	1	1/5	1/5	1/5	1	1/5	1	1	1	1/5	1	1
4	1	1/7	1	1	3	1/5	1/5	1/5	3	1/5	1	1	1	1/5	1	1
5	1	1/7	1	1/3	1	1/5	1/5	1/5	1	1/5	1	1	1	1/5	1	1
6	5	1/3	5	5	5	1	1	1	7	3	9	9	7	3	7	7
7	5	1/3	5	5	5	1	1	1	7	3	9	9	7	3	7	7
8	7	1/3	5	5	5	1	1	1	9	3	9	9	7	5	7	7
9	1	1/7	1	1/3	1	1/7	1/7	1/9	1	1/7	1	1	1	1/5	1	1
10	5	1/3	5	5	5	1/3	1/3	1/3	7	1	9	9	9	3	7	9
11	1	1/7	1	1	1	1/9	1/9	1/9	1	1/9	1	1	1	1/5	1	1
12	1	1/7	1	1	1	1/9	1/9	1/9	1	1/9	1	1	1	1/5	1	1
13	1	1/7	1	1	1	1/7	1/7	1/7	1	1/9	1	1	1	1/5	1	1
14	3	1/3	5	5	5	1/3	1/3	1/5	5	1/3	5	5	5	1	5	5
15	3	1/7	1	1	1	1/7	1/7	1/7	1	1/7	1	1	1	1/5	1	1
16	1	1/7	1	1	1	1/7	1/7	1/7	1	1/9	1	1	1	1/5	1	1

It is known that the maximum eigenvalue of the reciprocal matrix of range m is $\lambda_{max} \geq m$. In our particular case, the range of the matrix or the number of the indicators being compared is m=16. As 16.86>16, it implies that the condition to be complied with is satisfied.

Now, it is very easy to compute the index of consistency which is defined in the following way:

$$S_I = (\lambda_{max} - m)/(m-1) = (16.86-16)/(16-1) = 0.057.$$

Then, we calculate the consistency ratio S_R based on which we determine the consistency degree of the matrix (Saaty 1980):

$$S_R = \frac{S_I}{S_A} = \frac{0.057}{1.73} = 0.0332.$$

As the value of ratio S_R appears to be lower than 0.1, we may state that our matrix is consistent.

The consistency level of respondent and expert opinions is determined by the concordance coefficient W.

The ranking of criteria related to the price of a trip ticket as per ten respondent questionnaires is presented in Table 2 below.

The total sum of all indicators calculated based on formula (8) or the sum of the last elements presented in Table 2 is $\sum_{i=1}^{m} c_i = 210$, the mean of object rankings computed in accordance with formula (9) is $\overline{c}$= 35 or, if calculated otherwise, $\overline{c}$=210/6=35. The sum of square deviations is S=853.5 and the concordance coefficient is W=0.49.

If we use data as per Table 2 and make calculation according to formula (12), we will obtain the following result: $\chi^2 = 0.49 \cdot 10 \cdot (6-1) = 24.39$ and 11.07 for the critical value $\chi^2_{\alpha\nu}$ derived from the probability distribution table with $\nu = 6-1 = 5$ degree of freedom and $\alpha = 0.05$ level of significance.

The computed value χ^2= 24.39 is significantly higher that the critical one which implies that the opinions of experts are consistent enough.

4. Data Analysis of Questionnaires on Passenger Survey

First, we determined the importance (weight) of criteria included in the questionnaire and to be used in subsequent research into the quality of passenger transportation by Lithuanian railways. The respondents (passengers) were offered the questionnaires designed based on the model of the pairwise comparison of indicators. The data included in the questionnaires was computed using the *Microsoft Excel* spreadsheet program. However, only data on 10 questionnaires completed by passengers (whereof 3 came from Lithuania, 4 from Russia, 1 from the USA, 1 from Germany and 1 from Italy) was actually used in the survey as the remaining 22 were found to be inconsistent and therefore rejected. Based on the opinion of the surveyed respondents, there was determined the importance of criteria related to train elements and the technical state of the railway track, to railway transportation process planning and technology and to the safety of a railway trip.

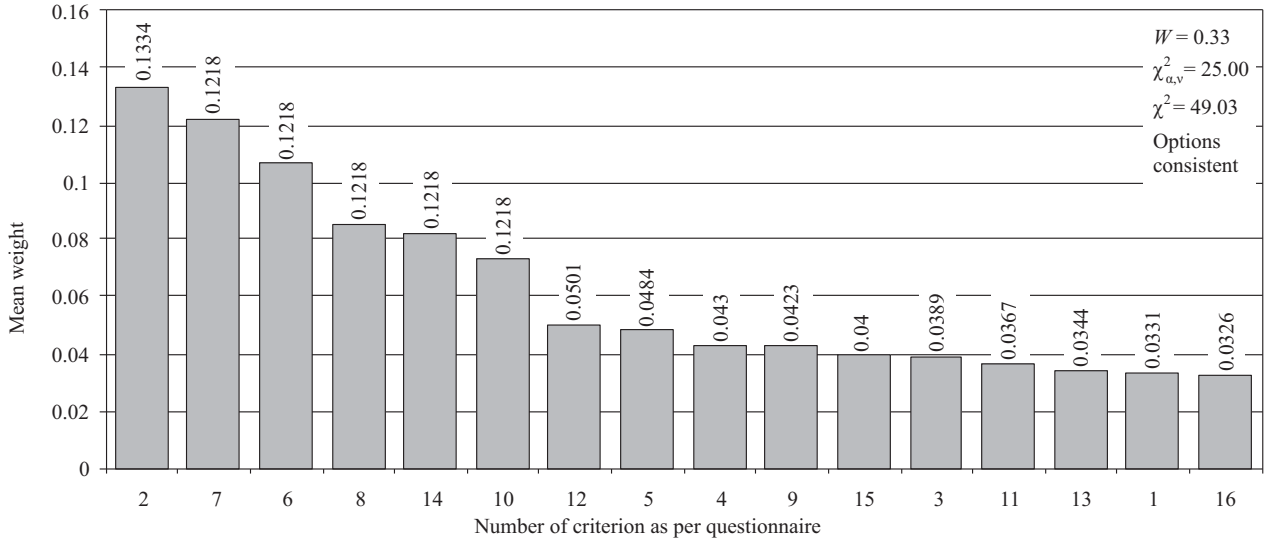
The means of indicator weights computed using T. Saaty's AHP method and the respective positions of indicators as per each questionnaire of the respondent help with determining the importance of criteria defining the quality of passenger transportation by Lithuanian railways.

The survey revealed that passengers' opinions were consistent. Fig. 3 presents a bar diagram showing the importance of criteria related to train elements and the technical state of the railway track determined based on respondents' opinion. The diagram shows that the respondents attach high importance to the speed of train travel (the duration of the trip), the required level of temperature within a passenger coach and the operation of ventilation, air conditioning, cooling and lighting systems and their timely switch on/off. No importance is attached to such criteria as the radio broadcasting unit and its centralized switch on/off, the evenness of the railway track and the possibility of using a hairdryer, iron etc.

We understand that the speed of train travel is important to passengers because it is the factor, upon

Table 2. Ranking ticket price-related criteria as per respondent questionnaires

Criteria	Respondent No.										Sum of rankings
	1	2	3	4	5	6	7	8	9	10	
1	1	1	1	2	1	1	3	1	3	4	18
2	3	5	2	4	4	5.5	3	2	4.5	3	36
3	4	6	4.5	6	6	5.5	6	4	6	6	54
4	5	3	4.5	5	4	3	3	5	2	2	36.5
5	2	2	6	6	2	2	3	3	1	1	23
6	6	6	3	3	4	4	3	6	4.5	5	42.5
Total	21	21	21	21	21	21	21	21	21	21	210



Rank	Number of criterion as per questionnaire	Criteria
1	2	Speed of train travel (trip duration)
2	7	Required temperature inside the passenger coach
3	6	Operation of ventilation, air conditioning, cooling and lighting systems in terms of their timely switch on/off
4	8	Type (simple or vacuum) and condition of sanitary units (lavatories)
5	14	Dining-car (buffet-car)
6	10	Availability of regularly operating shower
7	12	Smoking places
8	5	Passenger coach interior
9	4	Noise reduction measures (measures with noise insulation)
10	9	Construction of plank-beds (safety belts of upper level plank-beds), special measures for the disabled, places for passenger emergency evacuation
11	15	Possibility of calling an attendant to a passenger compartment in emergency cases
12	3	State of coach exterior (whether it is clean, contains any deformation damage etc.)
13	11	Special compartments for transporting bicycles
14	13	Radio broadcasting unit and its centralized operation (switch on/off)
15	1	Evenness of railing (railway track)
16	16	Possibility of using a hairdryer, iron etc.

Fig. 3. The bar diagram showing the importance of criteria related to train elements and the technical state of the railway track determined based on respondents' opinion

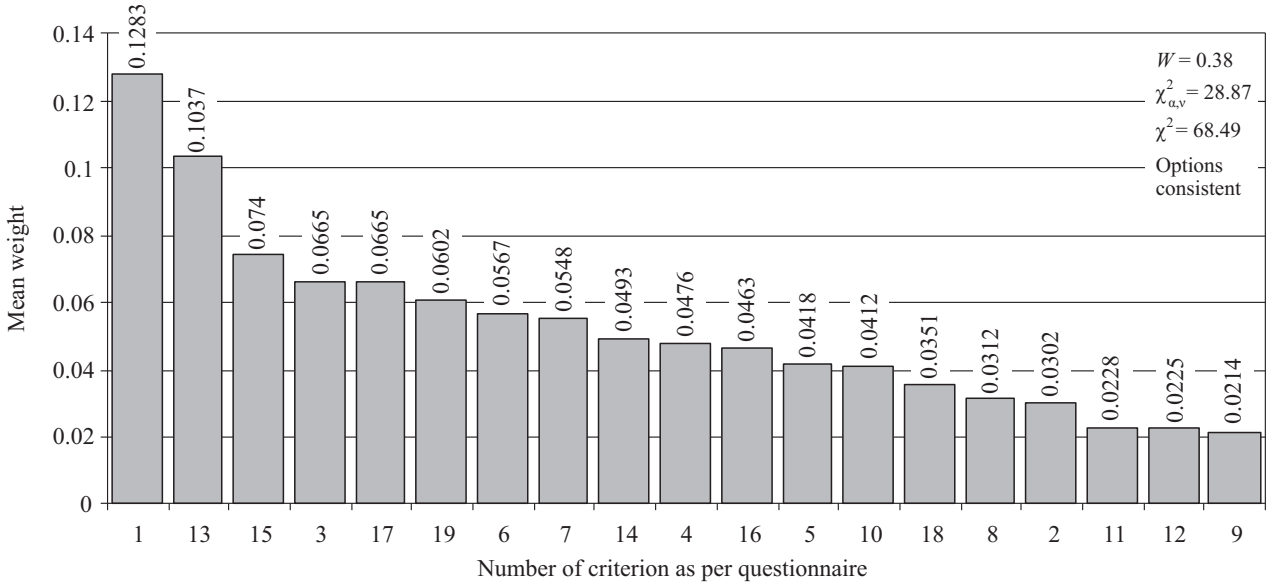
which the duration of the trip (the time of arrival at the destination) depends. The required temperature inside the passenger coach and the operation of ventilation, air conditioning, cooling and lighting systems and their timely switch on/off naturally determine the level of comfort enjoyed during the trip.

We can also see that passengers consider the availability of the radio broadcasting unit and its centralized switch on/off absolutely unimportant as some people may find listening to music undesirable or even annoying, especially if they do not like the music broadcast or it is played too loud. Some passengers prefer taking rest or reading a book while traveling.

The low rating of importance attached to the evenness of rails (railway track) was somewhat unexpected; most probably, passengers are accustomed to the uneven travel of trains, and therefore take it for a matter-of-course and inevitable reality.

Low rating attached by passengers to the possibility of using a hairdryer or iron may be explained by the fact that trips by trains formed in Lithuania are not prolonged (takes only 14 hours to get from Vilnius to Moscow).

Fig. 4 presents a bar diagram showing the importance of criteria related to railway transportation process planning and technology determined based on respondents' opinion.



Rank	Number of criterion as per questionnaire	Criteria
1	1	Departure and arrival of trains at the scheduled time
2	13	Safekeeping of passenger luggage and personal items
3	15	Possibility of acquiring a health insurance card valid abroad
4	3	Delivery of bedclothes, their condition and making up the bed
5	17	Communication culture of service staff (with passengers and colleagues)
6	19	Competence, impersonality and communication culture of customs and cross-border station officers while dealing with passengers
7	6	Availability of access to the Internet
8	7	Possibility of buying a ticket on the train (from the train manager)
9	14	Possibility of acquiring a health insurance card valid abroad
10	4	Possibility of ordering meals and beverages from the dining-car and having them delivered to the compartment (through the attendant)
11	16	Exterior appearance of service staff (uniform, footware, hairstyle, identification card)
12	5	Onboard distribution of popular press
13	10	Possibility of settling for onboard services by payment cards
14	18	Foreign language skills of service staff
15	8	Possibility of reserving a seat in the dining-car
16	2	Delivery of meals included in the cost of ticket
17	11	Onboard sales of souvenirs
18	12	Conformity of broadcast music and information to passenger requests
19	9	Possibility of calling a taxi

Fig. 4. The bar diagram showing the importance of criteria related to railway transportation process planning and technology determined based on respondents' opinion

The above diagram indicates that the departure and arrival of trains at the scheduled time, the safekeeping of passenger luggage and personal items as well as the possibility of acquiring a visa at the cross-border office are very important to passengers. No importance seems to be attached to the onboard sales of souvenirs, the conformity of broadcast information to passenger requests or the possibility of calling a taxi. It is extremely important that trains should arrive and depart at the scheduled time. We suppose that the scheduled departure and arrival of trains is important to passengers as any deviations from the schedule may upset their plans (they may miss another train, flight etc.). The safekeeping of passenger luggage and personal items are important issues as the risk of losing documents or personal items exists for passengers and when happen, such situations always entail extra troubles and spoil mood.

If passengers had the possibility of acquiring visas at the cross-border station, this would solve a problem of passenger detraining. For instance, a passenger going from Lithuania to Russia without a Byelorussian transit visa is detrained at the cross-border station on the Byelorussian territory and returned back to Lithuania. The passenger is forced to discontinue the trip and change his/her plans which, naturally, is upsetting. Thus, acquiring visas at the cross-border office would be very convenient. Passengers do not consider the onboard sales of souvenirs being important as they always have the possibility of buying these items in a town or at the railway station. As it has been mentioned before, the sounds of music are not welcomed by all passengers who may always get information related to their trip from the coach attendant or the train manager that may explain why they do not deem the criterion on the conformity of broadcast music and information to their requests being important. We believe that the possibility of calling a taxi does not enjoy popularity among passengers due to the fact that many of them are met at the station of arrival or call taxi services themselves. Passengers who need to go a long way cannot afford going by taxi, and therefore they prefer taking the other means of transport.

Fig. 5 presents a bar diagram showing the importance the respondents have attached to the criterion related to the price of the trip ticket.

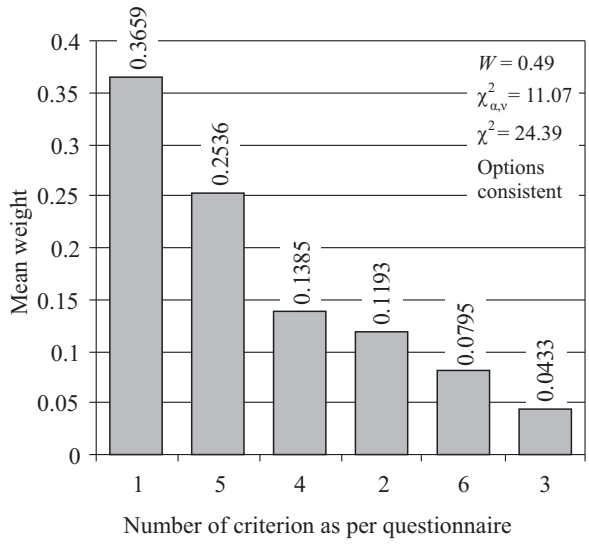
We can notice that the price of the trip ticket as well as the cost of a visa and health insurance card valid abroad is important to passengers. However, such criteria as the price of meals served in the dining-car, the delivery of meals (included into the cost of the ticket) to passengers going in the first class double compartment and the price of newspapers and magazines are rated by passengers as unimportant. Passengers consider the price of the ticket, visa and health insurance card valid abroad important because such situation constitutes the major share of trip expenses. The price of the ticket has particular relevance to those who need to take frequent trips (for e.g., on business purposes).

The price of meals served in the dining-car is not important because visiting this place is not common practice among passengers. The delivery of meals (included into the cost of the ticket) to passengers going in the first class double compartment is not important, either, as the price of the first class tickets is high. The majority of passengers prefer going in cheaper lower class passenger coaches.

The price of newspapers and magazines available on trains and at press kiosks is similar. Moreover, the daily *Respublika* is delivered free of charge. Besides, many passengers take books with them, thus, they can do very well without any press.

Fig. 6 presents a bar diagram showing the importance of criteria related to the safety of the railway trip determined based on respondents' opinion.

We can see that the operation of a hand brake and the availability of fire protection equipment and first medical aid means (stretchers, first aid kit) are



Rank	Number of criterion as per questionnaire	Criteria
1	1	Price of ticket
2	5	Price of visa
3	4	Price of health insurance card valid abroad
4	2	Price of meals served in the dining-car
5	6	Delivery of meals (included into the cost of ticket) to passengers going in the first class double compartment
6	3	Price of newspapers and magazines

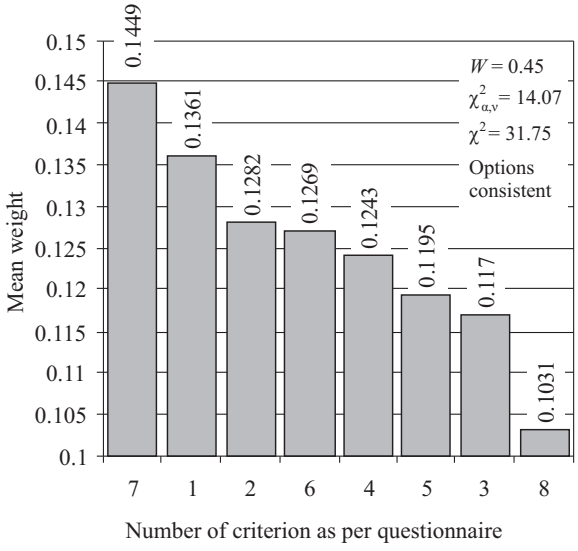
Fig. 5. The bar diagram showing the importance of criteria related to the price of the trip determined based on respondents' opinion

important to passengers. Less important seem to be such indicators as the availability of emergency exits, the possibility of calling an ambulance or the police (militia).

The hand brake may be used for stopping the train in emergency cases, for instance, when fire breaks out or the axle-box overheat alarm system goes off etc. Therefore, we believe that such high passenger rating of this particular criterion was prompted namely by the inherent instinct of self-preservation as escaping from the train in a standstill position is obviously less dangerous than attempting to jump off the train in motion. The availability of fire protection equipment ensures fire safety, and since the cases of burns and injuries on trains are rather frequent, the availability of first medical aid means and pharmaceuticals must be important to passengers. Many people do not take pharmaceuticals with them when setting off on a trip. Rather low rating in terms of importance attached by passengers to such criteria as the availability of emergency exits

and the possibility of calling an ambulance or the police (militia) is somewhat unexpected. The availability of emergency exits, in fact, ensures the safe evacuation of passengers in the case of fire or in other emergency situations posing risk to human health and life. Maybe passengers believe that in emergency situations, it is possible to escape through the window or doors, and therefore they do not rate the availability of emergence exits as important.

The bar diagram (Fig. 6) shows that passengers are self-confident in that respect that they do not anticipate to be in any serious need during the trip for medical aid or the interference of the police (militia) officers and that they will be able to handle any problems that may arise during the trip on their own or with the help of service staff. It should be noted that of those 10 respondents, the questionnaires of whose completed correctly, included 3 females and 7 males. This could have determined the results of rating indicating that males usually avoid seeing a doctor or dealing with the police officers.



Rank	Number of criterion as per questionnaire	Criteria
1	7	Operational state of a hand brake
2	1	Availability of fire safety equipment
3	2	Availability of first medical aid means (stretchers, first medical aid kit)
4	6	Condition of handrails, stairs, tambours, doors and locks
5	4	Operational state of axle-box overheat and fire alarm system
6	5	Availability of emergency exits
7	3	Possibility of calling an ambulance
8	8	Possibility of calling the police (militia)

Fig. 6. The bar diagram showing the importance of criteria related to the safety of the railway trip determined based on respondents' opinion

5. Conclusions

1. Following the statistic processing of data as per questionnaires split in four groups (the first one covering 16 criteria for the quality of railway transportation, the second – 19, the third – 6 and the fourth one – 8), there have been determined the key criteria of passenger railway transportation, the importance and weight whereof, rated based on their value enable improvements in passenger transportation by railways.
2. Next, there has been worked out a plan of practical measures and actions on the improvement of the key criteria, the implementation whereof in practice, hopefully, will enhance the attractiveness of railway transport and increase its capacity to compete with other modes of transport so that it could take over from them a part of their passengers.
3. Research has revealed the following advantages and disadvantages of applying the T. Saaty's AHP method in quality surveys on passenger transportation by railways.
4. *Advantages:* the T. Saaty's AHP method of pairwise comparison is convenient in that respect that it allows respondents to compare indicators taken in pairs which has a particular relevance when this exercise is to be carried out on multiple indicators. Another special feature incorporated in the T. Saaty's AHP method is that it accepts prevailing one competent opinion of an expert in terms of its importance over an incompetent opinion of several or even numerous specialists lacking a deeper insight into the matter or a logic mind.
5. *Disadvantages:* when applying this method, it is extremely important for respondents and experts to follow a systematic approach. Therefore, a high level of a logic mind is required. While completing a questionnaire, a respondent or an expert often loses consistency in the logic chain hence rendering the questionnaire itself inconsistent. When the opinions of individual respondents or experts do not come together in concord, for obtaining a representative opinion, the number of opinions offered by respondents or experts must be increased as due to the presence of substantial inconsistencies, some questionnaires have to be rejected or subjected to the minor adjustments of respondent or expert's answers in order to achieve the required ratio of consistency. Moreover, processing such a large scope of data requires the availability of special software as the process of computation using the Microsoft Excel spreadsheets is very time consuming.
6. The hierarchy of criteria by means of the weights and sums of ranking values may contain variations as the weights of two criteria may diverge by only a millesimal, i.e. be nearly identical, yet one criterion

must always have a priority over the other and a different ranking value.

7. We recommend that the following organizational, technical and strategic measures should be prioritized:
   - Train arrival and departure at the scheduled time. It is necessary to take measures aimed at ensuring the traffic of trains strictly in accordance with the schedule, including the introduction of compensations to passengers of international and local route trains payable in case of train delays and, wherever possible, free delivery of meals, should passengers are forced to wait a long time;
   - The price of the ticket. We recommend that there should be introduced more flexible schedules and methods of acquiring tickets, launched more campaigns and implemented customer loyalty programs (offering discounts to loyal customers);
   - First medical aid means (stretchers, first aid kit). The first aid kit should be complemented by the following pharmaceuticals not requiring any special medical knowledge: disinfectants (iodic and peroxide solutions, etc.) preparations intended for treating burns and pain relievers;
   - Speed of train travel (duration of trip). It is necessary to carry out proper and safe maintenance of public railway infrastructure, upgrade the infrastructure and increase its capacities, ensure safe traffic of trains and reduce the standstill time of trains at cross-border stations;
   - The required temperature inside the coach, the operation of ventilation, air conditioning, cooling and lighting systems and their timely switch on/off**.** The renovation and upgrade of the obsolete passenger train park must be continued and, wherever possible, the old rolling-stock replaced by new equipment. Furthermore, it is necessary to ensure quality repair of train faults, whether carried out during the travel or at the time of train formation;
   - Safekeeping of passenger luggage and personal items. We recommend that new coaches as well as those being upgraded should be equipped with video recording cameras. Moreover, safes should be installed in attendant compartments so that passengers could deposit there personal documents and valuables;
   - Some measures, such as, for example, the price of visa, the possibility of obtaining a visa at the cross-border station are of a political nature, therefore, decisions related to these measures should be adopted at the governmental level;
   - We recommend that there should be conducted regular research on the quality of services and surveys on customer preferences and needs.
   - The majority of measures for improving the quality of passenger transportation by railroads will require considerable amounts of investment funds to be raised from all possible sources.

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