VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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THE MODEL FOR MULTICRITERIA EVALUATION OF THE QUALITY OF PASSENGER TRANSPORTATION BY INTERNATIONAL TRAINS

SUMMARY OF DOCTORAL DISSERTATION

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VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

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TARPTAUTINIO KELEIVIŲ VEŽIMO GELEŽINKELIAIS PROCESO KOKYBĖS TYRIMO DAUGIATIKSLIS MODELIS

DAKTARO DISERTACIJOS SANTRAUKA

TECHNOLOGIJOS MOKSLAI,
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Introduction

The research problem

Can it happen that in the 21st century the sector of passenger transportation by railway will disappear? Some time ago this scenario seemed unreal. However, now, when Lithuania is the EU member-state, it is becoming true. Now, the company lacks finances for renewing the locomotive park for passenger transportation, though this is necessary for ensuring the required quality of services provided to passengers. When the companies providing cheap flights emerged, some passengers chose air transport because the fare was not much higher than that for a railway trip, but the time of travel was much shorter. It is believed that to make passenger transportation by rail profitable, the fare should be increased by 6 times or the train should be filled up to 100 %. To make passenger transportation by rail competitive on the transportation market, the quality of passenger transportation should be improved.

The dissertation presents the criteria describing the quality of passenger transportation by international trains (CQPTIT). The significance (weight) of the criteria and their groups is determined by expert evaluation. The multipurpose mathematical model for calculating the influence of 49 criteria, describing the trip by train, on the quality of passenger transportation and expressing it by one value (a comprehensive quality evaluation index K) is offered.

The relevance of the work

The analysis of the literature has shown that there is a lack of methods and means for objective evaluation of the quality of the trip by international trains.

To maintain and increase the competitiveness of the railway company on the market so that it could compete successfully with companies representing other means of transport, the railway company should search for the methods of increasing the comfort and safety of the railway trip. For this purpose, it is necessary to determine the criteria describing the quality of the railway trip, which are significant for passengers, and to improve them. The above factors (criteria) differently influence the comfort, safety, time and cost of the trip, as well as the pleasure gained by passengers. It is convenient to evaluate the quality of the particular trains, routes and the service staff by a single value, i.e. by a comprehensive quality evaluation index K.

The object of the research

The object of the research is the process of passenger transportation by railway and its parameters (criteria).

The aim of the work

The aim of the work is to present a system of criteria describing the quality of passenger transportation by international trains and the multipurpose models for their evaluation.

The tasks of the work

To achieve the aim of the research, the following tasks should be fulfilled:

1. To define and classify the criteria, influencing the quality of passenger transportation by railway on international trains and to determine their weight.

2. To determine the significance (rank) of each criterion group and the criteria included in it.

3. To offer an original mathematical model, allowing the quality of passenger transportation by international trains to be expressed by a single-valued quantitative criterion.

4. Based on the data obtained in the experimental research, to check the validity of the suggested model and to determine the influence of the criterion variation on the comprehensive quality evaluation index K.

5. To provide the scientifically grounded conclusions and recommendations for increasing the quality of passenger transportation by international trains.

The methodology of the research

The research methods used in the investigation are based on the analysis of the research works in this field. The experimental research, mathematical statistics and multicriteria evaluation methods are used in the work and the comparison of the results and expert evaluation data is performed. The data obtained by conducting a survey in the international train Vilnius–Moscow and by measuring the temperature in the railway car and the axle boxes and the parameters of the Lithuanian railways by track geometry car EM-140, are used in the work.

The scientific novelty of the work

In fact, the quantitative parameters characterizing the quality of passenger transportation by international trains have not been investigated, therefore, in performing the present research, the following results which have not been known to transport engineering were obtained:

1. By using the quantitative methods, the significance of the quality of passenger transportation by international trains has been determined.

2. The objective numerical values of the significance of the criteria, describing the quality of passenger transportation by international trains and their groups, have been obtained by processing the data of the questionnaire survey of the respondents belonging to various categories (including the service staff of the train and the ad-

ministration staff of the AB "Lietuvos geležinkeliai") as well as passengers of the train, with the help of the method, known as *Analytic Hierarchy Process* (AHP).

3. An original multipurpose mathematical model, allowing to determine the influence of the criteria describing the railway trip quality on the passenger transportation and to comprehensively evaluate the quality of the trips by various international trains by a single value, i.e. the comprehensive quality evaluation index K, has been offered. The validity of the model has been experimentally checked and confirmed by the calculation data. The influence of the criterion variation on the comprehensive quality evaluation index K, i.e. the sensitivity of the model, has been determined.

4. For the first time, the qualitative parameters of passenger transportation by railway have been evaluated based on the use of ranking, pairwise comparison and multicriteria evaluation methods.

The practical value of the work

1. The criteria (parameters), influencing the quality of international passenger transportation by rail, have been defined and classified and the significance of these criteria and their groups has been determined. The research results may be used for improving the particular criteria and the process of passenger transportation by international trains as a whole.

2. An original additive model for calculating the comprehensive quality evaluation index K on the particular international route was created and its sensitivity was determined. Its validity was checked in evaluating the index K for the international train Vilnius–Moscow.

Defended propositions

1. The quality of passenger transportation by train, depending on many factors, may be assessed by a single value with the help of an additive model. Applying the additive model, various routes of an international train may be compared.

2. The model of the comprehensive quality evaluation index includes four summands calculated by summing up the products of the normalized weight of the criterion and its value. Not all the criteria, describing the quality of the trip by train, are equally important for passengers, the train service staff and the administration.

3. It is expedient to determine the normalized weights of the criteria and their significance (ranks) of their groups by using expert evaluation methods, AHP and Rank Correlation.

4. The criteria variables, ranging from 0 to 1, are considered to be most important because their influence on the value of the index K is the strongest.

The scope of the work

The dissertation consists of the Introduction, four chapters, general conclusions, the list of references as well as the author's publications on the topic of the thesis and annexes. The length of the dissertation is 165 pages and includes 38 figures, 22 tables and 12 annexes.

1. The analysis of the works devoted to the investigation of the quality of passenger transportation by railway and the documents regulating it

Railway transport competing with other means of transport on the market is developing rapidly. The speed, level of comfort and safety of transportation are growing. There is an optimistic view on the development of this branch of industry because most of the countries in the world give preference to railway transport for freight and passenger transportation. Railway transportation market is stable because there are the eternal problems associated with traffic jams in the cities, the need for quick transportation, lots of heavy trucks on highways, etc., which compel people to choose rail transport.

In this chapter, the documents specifying the quality of passenger transportation by railway in Lithuania and other EU member-states are analysed. The research works carried out by Lithuanian and foreign scientists and devoted to the study and evaluation of railway infrastructure, trains and quality of passenger transportation by railway are considered.

2. The criteria describing the quality of passenger transportation by railway and models of this process

Social expenses on railway transport consist of the maintenance costs of railways (infrastructure), the costs of renewal of the rolling stock (the repair of the old and purchasing of the new locomotives) (Fig. 1) and its maintenance, as well as the expenses of passengers on the trips. The costs of passenger transportation services differ, depending on their quality.

An increase in the quality of rolling stock and railways decreases the costs of travelling. Due to an increase in speed, travel time and chances to be involved in a railway traffic accident are reduced (which helps one avoid medical and insurance expenses).

The costs of the railway maintenance and development are associated with its construction, repair and maintenance. The expenses on stock renewal, purchasing, repair and maintenance (including the cost of fuel, electric power, spare parts, oil, workers' payment, etc.) make the major part of these costs.
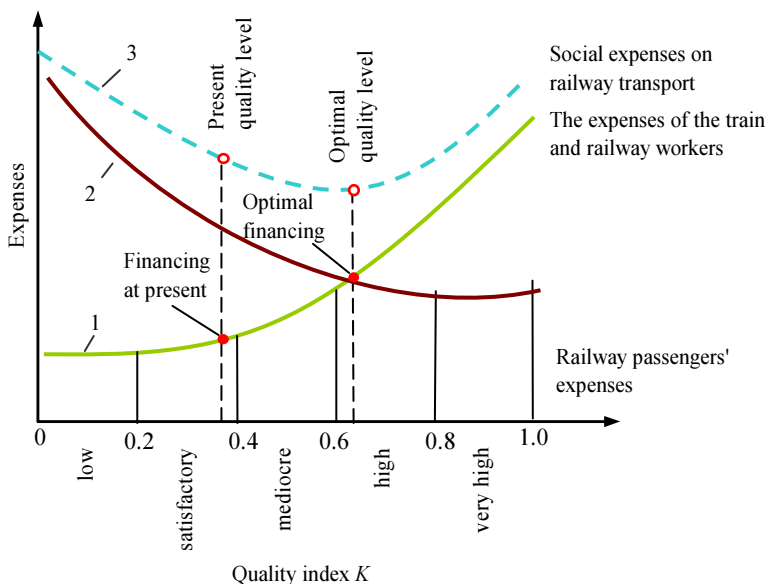
Fig. 1. The model of the dependence of the costs of passenger transportation by railway on the level of the trip quality: 1 expenses of the train and railway staff; 2 passengers' expenses; 3 (total) social expenses

The expenses of railway transport users are associated with the fare losses experienced due to the delays of the trip, traffic accidents, environment pollution and lack of comfort in the trip.

By increasing the costs of the railway staff to some extent, the total expenses of passengers and society can be decreased. When the variation curves of the railway staff and passengers cross each other, social expenses are the smallest, i.e. the optimal quality level is achieved. The lack of investment to infrastructure and rolling stock results in low quality of a railway trip or makes trains unattractive to passengers.

To attract more passengers, the quality of transportation should be improved: in addition to high-quality rolling stock, there should be a highly qualified staff. Therefore, the problems associated with theoretical and practical knowledge of employees have been in the focus of the researchers from various countries for several decades.

Quality can hardly be described and measured by a single criterion. It may be defined by a set of criteria. In Fig. 2, the criteria groups A, B, C and D describing the quality of the trip by train are schematically presented.

THE CRITERIA OF RAILWAY TRIP QUALITY

A. The criteria describing the train elements and the technical state of rails (railway track)

A1. Roughness of railway track
A2. Speed of train travel (trip duration)
A3. State of coach exterior (whether it is clean has no deformations or damage)
A4. Noise reduction measures (noise insulation)
A5. Passenger coach interior
A6. Operation of ventilation, air conditioning, cooling and lighting systems in terms of their timely switch on/off
A7. Temperature required inside a passenger car
A8. Type (simple or vacuum) and condition of sanitary units (lavatories)
A9. Construction of plank-beds (safety belts of upper level plank-beds), special facilities for the disabled
A10. Availability of regularly operating shower
A11. Special compartments for transporting bicycles
A12. Smoking places
A13. Radio broadcasting unit and its centralized operation (switching on/off)
A14. Dining-car (buffet-car)
A15. Possibility of calling an attendant to a passengers' compartment in emergency cases
A16. Possibility of using tools (hairdryer, iron, etc.)

B. The criteria describing the railway trip planning and technology

B1. Departure and arrival of trains at the scheduled time
B2. Delivery of meals included into the ticket price
B3. Delivery of bedclothes, their condition and making up the bed and its condition
B4. Possibility of ordering meals and beverages from the dining car to the compartment (by car attendant)
B5. Onboard distribution of popular press
B6. Possibility to access the Internet
B7. Possibility of buying a ticket on the train (from the train manager)
B8. Possibility of reserving a seat in the dining-car
B9. Possibility of calling a taxi
B10. Possibility of settling for onboard services by payment cards
B11. Onboard sales of souvenirs
B12. Music broadcast and information in conformity with passenger requests
B13. Safekeeping of passenger luggage and personal items
B14. Possibility of acquiring a health insurance card valid abroad
B15. Possibility of obtaining a visa at the cross-border station
B16. Exterior appearance of service staff (uniform, footwear, hairstyle, identification card)
B17. Communication culture of service staff (with passengers and colleagues)
B18. Foreign language skills of service staff
B19. Competence, impersonality and communication culture of customs and cross-border station officers while dealing with passengers

C. The criteria describing the price of the trip ticket and the provided services

C1. Price of a ticket
C2. Price of meals served in the dining-car and their quality
C3. Price of newspapers and magazines
C4. Price of health insurance card valid abroad
C5. Price of visa
C6. Delivery of meals (included into the ticket price) to passengers travelling in the first-class double compartment

D. Criteria describing the safety of railway trip

D1. Availability of fire safety equipment and its condition
D2. Availability of first medical aid
D3. Possibility of calling an ambulance
D4. Operational state of axle-box overheat and fire alarm system
D5. Availability of emergency exits
D6. Condition of handrails, stairs, tambours, doors and locks
D7. Operational state of the hand brake and the emergency brakes
D8. Possibility of calling the police

Fig. 2. The criteria groups A, B, C, D describing railway trip quality

The quality of travel by train (QTT) is described by both qualitative and quantitative criteria. It would be convenient to quantitatively evaluate the significance of all the criteria for QTT by a single number. The significance of particular criteria differs to some extent. In the present work, 49 QTQ criteria belonging to four various groups (A, B, C, D) are considered. Their average weights are determined by using the expert evaluation method. The weights of 19 criteria belonging to group B, which describe the organization and technology of travel by train, are found from the survey of experts, when three categories of respondents (K – passengers and experts, consisting of P – service staff of the train and A – the administration staff of the company AB "Lietuvos geležinkeliai") provided their judgements. The mean weight coefficient $\overline{Z}_B^*$ shows the significance of the criteria of group B.

Trains made up for various routes have cars of various types and in different technical condition and are serviced by staff members, having different work experience and education. The quality of passenger transportation by any train can be determined only roughly, subjectively and intuitively. Therefore, to evaluate it more accurately, a qualitative method and the index K, allowing the quality of travel on a particular route to be expressed by a single value, were developed ($K = K_A + K_B + K_C + K_D$, $K = 0$–1).

The model for calculating the criteria describing organizational and technological aspects of travel by train, which is based on the mean weight coefficient $\overline{Z}_B^*$ and mean weight of each criterion, expressing the estimates of the significance of group B criteria, elicited from all three categories of respondents and experts, is determined by the formula:

$$K_B = \overline{Z}_B^* \cdot \left(\overline{Q}_{B1} \cdot x_{B1} + \overline{Q}_{B2} \cdot x_{B2} + ... + \overline{Q}_{B19} \cdot x_{B19} \right), \tag{1}$$

where K_B is the comprehensive quality index (CQI) of the international train (ranging from 0 to 1); $\overline{Z}_B^*$ is the mean weight coefficient, reflecting the respondents' and experts' estimates of the significance of group B criteria; $\overline{Q}_{B1}$, ..., $\overline{Q}_{Bm}$ denote mean weight values of j-th (from 1 to m) criterion of group B, determined by expert evaluation method; x_{B1}, ..., x_{Bm} are the variables of j-th (from 1 to m) criterion of group B, whose estimates are used for determining the real criterion value, ranging from 0 to 1.

To calculate the comprehensive quality index, evaluating the significance of organization and technology of travel by train, the variables of any criterion x_{B1}, ..., x_{B19}, serving as a basis for calculating the real criterion value, ranging from 0 to 1, should be determined.

The calculation formula of K_B, describing the organization and technology of the railway trip (Sivilevičius *et al.* 2012) is written as follows:

$$K_B = \overline{Z}_B^* \cdot \left(\overline{Q}_{B1} \cdot \left(1 - \frac{\gamma \cdot \left(\left(t_{i\check{s}v,l} + t_{i\check{s}v,A} \right)^2 - t_{i\check{s}v,l}^2 + \left(t_{atv,l} + t_{atv,C} \right)^2 - t_{atv,l}^2 \right) + \left(1-\gamma\right) \cdot \sum_{e=1}^{b} \left(\left(t_{atv,l} + t_{atv,B} \right)^2 - t_{atv,l}^2 + \left(t_{i\check{s}v,l} + t_{i\check{s}v,B} \right)^2 - t_{i\check{s}v,l}^2 \right)_e}{\beta \cdot \left(2+b\right) \cdot t_{atv,l}^2} \right) + $$

$$\overline{Q}_{B2} \cdot \frac{\sum_{c=1}^{V} \left(\frac{MD_f}{MD_{\max}} \right)_c}{V} + \overline{Q}_{B3} \cdot \frac{\sum_{c=1}^{V} \left(\frac{P_f}{P_{\max}} \right)_c}{V} + \overline{Q}_{B4} \cdot \frac{MU_f}{MU_{\max}} + \overline{Q}_{B5} \cdot \frac{SP_f}{SP_{\max}} + $$

$$\overline{Q}_{B6} \cdot \frac{IP_f}{IP_{\max}} + \overline{Q}_{B7} \cdot \frac{BP_f}{BP_{\max}} + \overline{Q}_{B8} \cdot \frac{VRR_f}{VRR_{\max}} + \overline{Q}_{B9} \cdot \frac{TI_f}{TI_{\max}} + \overline{Q}_{B10} \cdot \frac{MK_f}{MK_{\max}} + $$

$$\overline{Q}_{B11} \cdot \frac{PS_f}{PS_{\max}} + \overline{Q}_{B12} \cdot \frac{\sum_{k=1}^{n_K} \left(\frac{TMK_f}{TMK_{\max}} \right)_k}{n_K} + \overline{Q}_{B13} \cdot \frac{BA_f}{BA_{\max}} + \overline{Q}_{B14} \cdot \frac{MID_f}{MID_{\max}} + $$

$$\overline{Q}_{B15} \cdot \frac{IV_f}{IV_{\max}} + \overline{Q}_{B16} \cdot \frac{\sum_{k=1}^{n_K} \left(\frac{API_f}{API_{\max}} \right)_k}{n_K} + \overline{Q}_{B17} \cdot \frac{\sum_{k=1}^{n_K} \left(\frac{APB_f}{APB_{\max}} \right)_k}{n_K} + $$

$$\overline{Q}_{B18} \cdot \frac{\sum_{P=1}^{n_P} \left(\frac{UK_f}{UK_{\max}} \right)_p}{n_P} + \overline{Q}_{B19} \cdot \frac{\sum_{k=1}^{n_K} \left(\frac{MPK_f}{MPK_{\max}} \right)_k}{n_K} \right). \tag{2}$$

Using the considered model as well as real research data and the allowable or best values of each criterion, the significance of the criteria of group *B* for evaluating the quality of passenger transportation by train, expressed by a single value, may be obtained.

3. The analysis of the significance of the criteria and their groups, describing the quality of passenger transportation by railway, based on experimental methods

Criteria describing the quality of passenger transportation by railway (a railway trip) were determined and grouped (Fig. 2). The conducted analysis was based on the application of the AHP method. Criteria describing the quality of the railway trip were collected and the appropriate survey questionnaires were prepared and later distributed among the respondents (passengers) and experts (service staff and representatives of the Passenger Transportation Directorate of the join-stock company *Lietuvos geležinkeliai*). The criteria for establishing the quality of railway trips are divided into groups A, B, C and D (the structure of the questionnaire) and presented in Fig. 2. The questionnaire was translated into the English and Russian languages. Thirty two questionnaires were distributed among the passengers representing eighteen citizens of Lithuania, nine of Russia, one of the USA, one of Spain, one of Italy, one of Germany and one of Great Britain. However, only 10 questionnaires were completed by the passengers (3 from Lithuania, 4 from Russia, 1 from the USA, 1 from Germany and 1 from Italy) and actually used in the survey because the remaining 22 questionnaires were found to be inconsistent and, therefore, rejected. Moreover, 17 questionnaires were given to experts (i.e. service staff) and only 11 of those were used in the survey. Four questionnaires were handed over to the managers of department of passenger transportation of the joint-stock company *Lietuvos geležinkeliai* and only three of those were applied in the survey. Meanwhile, one completed questionnaire was rejected for the reason described above.

All RTQ criteria were divided into the criteria groups A, B, C and D (Fig. 2), using AHP (*Analytic Hierarchy Process*) technique. The respondents, belonging to three categories, i.e. passengers of the train (category K), service staff (category P) and administration staff (category A) as well as experts filled in the questionnaires. The respondents and experts had to compare the criteria in each group thus determining the weight (significances) of the criteria at a particular hierarchical level with respect to a higher hierarchical level or to non – structured criteria. The largest eigenvalue λ_{max}, *C.I.* (consistency index) and *C.R.* (consistency ratio) were calculated for each questionnaire. The questionnaires with inconsistent evaluation data were rejected. The estimates of RTQ criteria found in the properly completed questionnaires were assigned particular ranks.

When grouping the criteria describing passenger transportation by railway (railway trip) and establishing their weight (significance), the preference order or ranks of the criterion groups A, B, C and D was determined.

Twenty one passengers of the train Vilnius–Moscow and 29 experts (including 20 service staff members of the train and 9 members of the administration staff of the company *Lietuvos geležinkeliai*), competent in describing the structure and the constituent parts of the train, the technical condition of the railway, management and technology of a railway trip, provisions for trip safety and requirements for the quality of transportation, were given questionnaires and asked to assign ranks according to the importance of the above issues and considering the criterion groups A, B, C and D describing the quality of the railway trip.

The significance (weight) Z_{gz} and mean weight coefficients $\overline{Z}_g$ $\overline{Z}_g^*$ are shown in Fig. 3 by the broken lines.
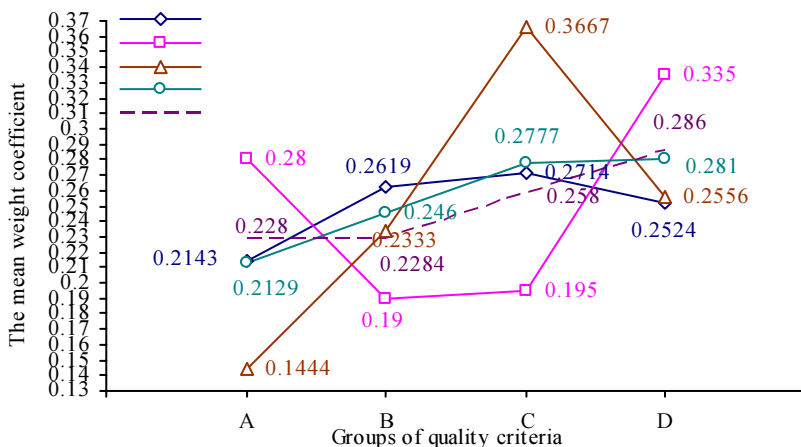

Fig. 3. The weights of the groups of railway trip quality criteria A, B, C and D (shown by the broken lines) which were assigned by 1) passengers (K); 2) the train service staff (P); 3) the administration staff of "Lietuvos geležinkeliai" (A); 4) all experts and residents ($n = 50$), based on their mean estimate $\overline{Z}_g$; 5) all experts and residents ($n = 50$), based on the mean estimate $\overline{Z}_g^*$ of all experts and residents and taking into account their number in a category

Based on the considered data, it may be concluded that the parameters of the railway and the train (group of criteria A) are least important for all categories of respondents and experts, while the parameters of traffic safety (group of criteria D) are most important for them.

4. The application of models for evaluating the quality of passenger transportation by railway

A general model for calculating a comprehensive index K, evaluating the railway trip quality with normalized weight coefficients of the criteria and their groups calculated by the expert method, is obtained from the formula:

$$
\begin{aligned}
K = \sum_{g=1}^{M}\left[\overline{Z}_g^* \cdot \left(\sum_{j=1}^{m}\overline{Q}_{gj} \cdot x_{gj}\right)\right] &= \overline{Z}_A^* \cdot \left(\overline{Q}_{A1} \cdot x_{A1} + \overline{Q}_{A2} \cdot x_{A2} + \ldots + \overline{Q}_{A16} \cdot x_{A16}\right) + \\
&\overline{Z}_B^* \cdot \left(\overline{Q}_{B1} \cdot x_{B1} + \overline{Q}_{B2} \cdot x_{B2} + \ldots + \overline{Q}_{B19} \cdot x_{B19}\right) + \\
&\overline{Z}_C^* \cdot \left(\overline{Q}_{C1} \cdot x_{C1} + \overline{Q}_{C2} \cdot x_{C2} + \ldots + \overline{Q}_{C6} \cdot x_{C6}\right) + \\
&\overline{Z}_D^* \cdot \left(\overline{Q}_{D1} \cdot x_{D1} + \overline{Q}_{D2} \cdot x_{D2} + \ldots + \overline{Q}_{D8} \cdot x_{D8}\right).
\end{aligned}
\tag{3}
$$

where K is the index value for the international train (K ranges from 0 to 1); $\overline{Z}_A^*$, $\overline{Z}_B^*$, $\overline{Z}_C^*$, $\overline{Z}_D^*$ denote the mean normalized weight coefficient for the criteria groups; $\overline{Q}_{A1}$, $\overline{Q}_{B1}$, $\overline{Q}_{C1}$, $\overline{Q}_{D1}$, ..., $\overline{Q}_{Am}$, $\overline{Q}_{Bm}$, $\overline{Q}_{Cm}$, $\overline{Q}_{Dm}$ denote the normalized weight coefficient of j-th ($j = 1, 2, ..., m$) criterion of g-th group determined by the expert method; x_{A1}, x_{B1}, x_{C1}, x_{D1}, ..., x_{Am}, x_{Bm}, x_{Cm}, x_{Dm} denote the variable of j-th ($j = 1, 2, ..., m$) criterion of g-th group, based on which the real criterion level, ranging from 0 to 1, is calculated by a particular formula.

The formulas for calculating the summands of the comprehensive quality evaluation index K, showing the influence of each group (A, B, C and D) of criteria, were derived. Based on these formulas, the value of each variable summand x_j is determined by considering the real data and comparing them with the data taken from the standards, technical documentation, surveys, measurements, etc. The values of K with the medium ($x_j = 0.5$), the best ($x_j = 1$) and the worst ($x_j = 0$) values were also calculated. The calculations were made for the international train Vilnius–Moscow.

Based on the real data, the value of the comprehensive index K evaluating the quality of the trip by the train Vilnius–Moscow was $K = 0.641$, while, based on the mean values, it was $K = 0.497$, i.e. about 0.5 (which indicated a very small error).

Using the *Excel* program, sensitivity of the comprehensive railway trip quality evaluation index was determined, which showed the influence of the change of one variable on K value. The influence of the variation of the argument on the change of the function (the index K) was calculated in the fractions of unity. K_0 was calculated for the cases, when the criterion variable is $x_j = 0$,

while that of the other criteria – $x_j = 0.50$ (the first zero level). K_1 was also calculated, when one criterion variable was $x_j = 1$, while that of the other criteria – $x_j = 0.50$ (the second ideal level). Finally, the change $\Delta K = K_1 - K_0$ between K_1 and K_0 was calculated as well.

The influence of particular criteria on the comprehensive index K was determined, based on the change ΔK. The larger the change ΔK, the higher the influence of the considered criterion on the value of the comprehensive index K evaluating the railway trip quality (Fig. 4).

The criteria of the groups C and D have the strongest influence on the comprehensive index K: C1 ($\Delta K = 0.084$), C5 ($\Delta K = 0.073$), C4 ($\Delta K = 0.039$) and D4 ($\Delta K = 0.049$), as well as D1 and D7 ($\Delta K = 0.043$), D5 ($\Delta K = 0.037$) because their variation is the highest. The criteria of the groups A and B exert the slightest influence on the index K: A15 ($\Delta K = 0.003$), A11 ($\Delta K = 0.004$), A3 ($\Delta K = 0.007$) and B11 ($\Delta K = 0.004$), B8, B9 ($\Delta K = 0.005$), B5, B12 ($\Delta K = 0.006$).
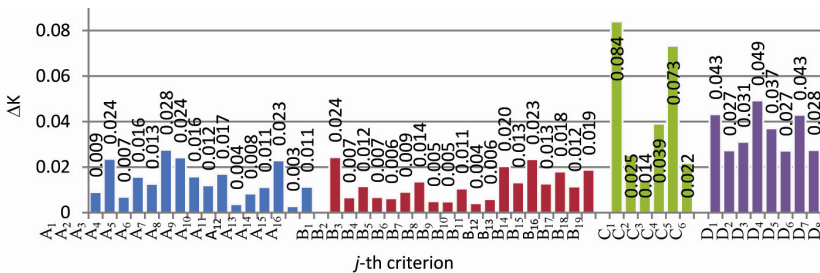

Fig. 4. The change $\Delta K = K_1 - K_0$ of the value K

The relative difference between the strongest and the slightest criterion influence makes 96.4 %.

General conclusions

1. Standards and technical documents, referring to railway transport, evaluate some particular parameters, though a comprehensive multicriteria evaluation methodology has not been developed yet in this area. The analysis of the literature on the problems associated with railway infrastructure, rolling stock and passenger transportation by railway has shown that there are many investigations devoted to their evaluation and improvement. However, the process of travelling by train has practically not been investigated.

2. The method AHP has been used for processing the data of the questionnaires about the significance (weight) of the criteria, which were obtained from the respondents (passengers and experts) of three categories, taking part in the survey. The opinions of the service staff and passengers of the train about the significance of the criteria of all groups have been found to be consistent. The opinions of the administration staff about the significance of the group D criteria have been found to be inconsistent.

3. The significance of the criteria groups A, B, C and D has been determined. The opinions of passengers are inconsistent: the empirical concordance coefficient is 0.038, while the smallest value is 0.180. The judgements of the train service staff and the administration staff are consistent.

4. The multicriteria evaluation model, allowing us to express the quality of the railway trip by a single value and to compare the quality of travel on various international routes, has been developed. Its validity has been checked and confirmed by analysing the quality of the trip by the international train Vilnius–Moscow, based on experiments and calculation data.

5. The influence of the criteria variation on the comprehensive quality evaluation index K has been determined. It has been found that the following criteria of groups C and D exert the strongest influence on K: price of a ticket (the variation is 0.084), price of visa (the variation is 0.073), operational state of fire alarm system for axle-box overheat (the variation is 0.049), availability of fire safety equipment and its condition as well as the operational state of the hand brake and the emergency brakes (the variation is 0.043). Their variation is the highest. The following criteria of the groups A and B have the slightest influence on the comprehensive quality index K: possibility of calling an attendant to a passengers' compartment in emergency cases (the variation is 0.003), special compartments for transporting bicycles (the variation is 0.004), onboard sales of souvenirs (the variation is 0.004), possibility of reserving a seat in the dining-car and possibility of calling a taxi (the variation is 0.005). Their variation is the smallest.

6. The larger the difference, indicated by the variation of the comprehensive quality evaluation index K, the higher the sensitivity of the model with respect to this index, demonstrated by the variation of the criterion value from the worst level (0) to the best level (1). This means that, improving this index, the quality of passenger transportation by international train may be largely increased, but it does not mean that it may be achieved with small investments. The size of investments, when it is desired to reach the maximum value of the index, $x_j = 1$, should be determined in further economic research.

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TARPTAUTINIO KELEIVIŲ VEŽIMO GELEŽINKELIAIS PROCESO KOKYBĖS TYRIMO DAUGIATIKSLIS MODELIS

Problemos formulavimas

Ar gali būti taip, kad XXI amžiuje Lietuvoje išnyks keleivių vežimo geležinkeliais sektorius? Toks scenarijus, kadaise atrodęs nerealus, Lietuvai įžengus į atvirą Europą, virsta realybe. Šiuo metu stinga lėšų keleivinių traukinių riedmenų parkui atnaujinti, kurios yra būtinos keleivių vežimo paslaugos kokybei užtikrinti. Atsiradus pigioms avialinijoms dalis tarptautinių traukinių keleivių pasirinko lėktuvus, kadangi bilieto kaina beveik prilygsta traukinio bilieto kainai, o kelionės tikslas pasiekiamas daug greičiau. Norint, kad keleivių vežimas būtų pelningas, būtina 6 kartus padidinti kainas arba 100 % pripildyti traukinius. Tam, kad geležinkelių transportas rinkoje sėkmingai konkuruotų su kitomis transporto rūšimis, būtina gerinti vežimo proceso kokybę.

Disertacijoje pateikiami tarptautinio keleivių vežimo geležinkeliais kokybės kriterijai (TKVGKK). Ekspertinių vertinimų metodais nustatytas atskirų kriterijų grupių ir jas sudarančių kriterijų reikšmingumas (svoriai). Pateiktas daugiatikslis matematinis modelis, kurį taikant galima apskaičiuoti kelionės tarptautiniu trau-

kiniu 49 kokybės kriterijų įtaką keleivių vežimo kokybei, išreiškiamai vienu parametru (kompleksiniu kokybės vertinimo rodikliu (KKVR) *K*).

Darbo aktualumas

Mokslinėje literatūroje stokojama sprendinių, kuriais remiantis galima objektyviai įvertinti kelionės tarptautiniu traukiniu kokybę.

Siekdama išlaikyti ir pagerinti vietą konkurencinėje rinkoje su kelių ir oro transportu, geležinkelio įmonė priversta ieškoti būdų, kaip padidinti patogumą, saugumą traukiniuose. Dėl šios priežasties kyla būtinybė nustatyti keleiviui svarbius kelionės traukiniu kriterijus ir juos gerinti. Kelionės traukiniu proceso veiksniai (kriterijai) skirtingai veikia keleivio patogumą, saugumą, važiavimo trukmę, kainą ir pasitenkinimą kelione. Atskirų traukinių, kelionės traukiniu ruožų, aptarnaujančio personalo darbo kokybę patogu vertinti vienu parametru, t. y. KKVR *K*.

Tyrimų objektas

Tyrimų objektas – keleivių vežimo geležinkeliais procesas ir jį rodantys parametrai (kriterijai).

Darbo tikslas

Šio darbo tikslas – pateikti tarptautinio keleivių vežimo geležinkeliais kokybės kriterijų visumą, jų vertinimo daugiatikslius modelius.

Darbo uždaviniai

Darbo tikslui pasiekti reikia išspręsti šiuos uždavinius:

1. Suformuluoti ir susisteminti kriterijus, turinčius įtakos tarptautinio keleivių vežimo geležinkeliais kokybei, nustatyti jų svorį.

2. Nustatyti kiekvienos kriterijų grupės svarbą (pirmumą) ir grupės kriterijų svarbą.

3. Pateikti originalų matematinį modelį, leisiantį įvertinti tarptautinio vežimo kokybės vienareikšmį kiekybinį rodiklį.

4. Eksperimentiniais tyrimų duomenimis patikrinti pateikto modelio korektiškumą ir nustatyti kriterijų kitimo įtaką kompleksiniam kokybės vertinimo rodikliui, išreiškiamam koeficientu *K*.

5. Pateikti moksliniais tyrimais pagrįstas išvadas ir rekomendacijas, leisiančias pagerinti tarptautinio keleivių vežimo geležinkeliais kokybę.

Tyrimų metodika

Tyrimų metodika pagrįsta mokslinių darbų šioje srityje analize. Darbe naudojami ekspertinių tyrimų, matematinės statistikos, daugiakriterio vertinimo metodai, atliktas rezultatų palyginimas ir ekspertinis vertinimas. Panaudoti apklausų,

atliktų LG tarptautinio susisiekimo traukinyje Vilnius–Maskva vagono vidaus ir ašidėžių temperatūros matavimų metu gauti ir kelmačiu EM-140 išmatuoti Lietuvos geležinkelio kelių duomenys.

Darbo mokslinis naujumas

Tarptautinio keleivių vežimo geležinkeliais kokybės (TKVGK) kiekybiniai parametrai beveik netyrinėti, todėl rengiant disertaciją buvo gauti šie transporto inžinerijos mokslui nauji rezultatai:

1. Pasitelkus kiekybinius metodus nustatyta TKVGKK svarba.

2. Analitiniu Hierarchijos Proceso (AHP) metodu atlikus skirtingų kategorijų vertintojų ekspertų (traukinį aptarnaujančio personalo ir AB „Lietuvos geležinkeliai" Keleivių vežimo direkcijos administracijos darbuotojų) ir respondentų (keleivių) anketinę apklausą gauti objektyvūs skaitiniai įverčiai, rodantys TKVGKK ir jų grupių svarbą.

3. Pateiktas originalus daugiatikslis matematinis modelis, kurį taikant galima nustatyti kelionės traukiniu kokybės kriterijų įtaką keleivių vežimo kokybei, kelionės atskirais tarptautiniais traukiniais kokybę vertinti kompleksiškai vienu parametru, t. y. KKVR. Jo adekvatumas (korektiškumas) patikrintas ir patvirtintas remiantis atliktų eksperimentų ir skaičiavimų duomenimis. Nustatyta kriterijų kitimo įtaka KKVR, t. y. modelio jautrumas.

4. Pirmą kartą keleivių vežimo geležinkelių transportu kokybiniai parametrai vertinami taikant rangų, porinio lyginimo ir daugiatikslio vertinimo metodus.

Darbo rezultatų praktinė reikšmė

1. Suformuluoti ir susisteminti kriterijai, turintys įtakos TKVGK, nustatyti jų ir šių kriterijų grupių reikšmingumai. Tyrimų rezultatai gali būti naudojami atskiriems kriterijams ir visam keleivių vežimo tarptautiniu traukiniu procesui gerinti.

2. Sukurtas originalus adityvinis modelis, skirtas atskiro tarptautinio traukinio (maršruto) KKVR skaičiuoti ir nustatytas jo jautrumas. Patikrintas jo korektiškumas vertinant tarptautinio traukinio Vilnius–Maskva KKVR.

Ginamieji teiginiai

1. Keleivių vežimo traukiniu kokybę, priklausančią nuo daugelio kriterijų, galima vertinti vienu parametru, nustatomu iš adityvinio modelio. Taikant adityvinį modelį galima lyginti atskirus tarptautinio traukinio maršrutus.

2. KKVR modelį sudaro skirtingą svorį turintys 4 dėmenys, kurių kiekvienas skaičiuojamas sudedant kriterijaus normalizuoto svorio ir jo kintamosios dalies sandaugas. Ne visi TKVGKK yra vienodai svarbūs keleiviams, traukinį aptarnaujančiam personalui ir administracijos darbuotojams.

3. Kriterijų normalizuotus svorius ir jų grupių pirmumą (svarbą) patogu nustatyti taikant ekspertinių tyrimų metodus: AHP, rangų koreliacijos (angl. *Rank Correlation*).

4. Kriterijai, kurių kintamosios dalies pokytis nuo 0 iki 1 labiausiai keičia KKVR vertę, laikytini svarbiausiais.

Disertacijos struktūra

Disertaciją sudaro įvadas, 4 skyriai, bendrosios išvados, literatūros sąrašas, publikacijų sąrašas ir priedai. Bendra disertacijos apimtis – 165 puslapiai, 38 paveikslai, 22 lentelės ir 12 priedų.

Pirmajame skyriuje atlikta geležinkelio infrastruktūros, riedmenų ir keleivių vežimo geležinkeliais proceso mokslinių darbų analizė. Taip pat atlikta norminių dokumentų, reglamentuojančių keleivių vežimo geležinkeliais kokybę, analizė.

Antrasis skyrius skirtas AB ,,Lietuvos geležinkeliai" veiklos ir keleivių vežimo rodiklių apžvalgai, kelionės tarptautinio susisiekimo traukiniu kokybės kriterijų formulavimui ir sisteminimui. Sukurtas TKVGK kompleksinis daugiatikslis vertinimo modelis, taikytinas tarptautinio susisiekimo vieno traukinio vežimo kokybei nustatyti.

Trečiasis skyrius skirtas TKVGK kriterijų ir jų grupių svarbos tyrimui. Skyriuje pateikta: apklausos anketų struktūra, anketos duomenų tvarkymo skaitinis pavyzdys, respondentų (keleivių) nuomonių suderinamumo skaitinis pavyzdys, nustatyta vieno eksperto nuomonė apie kriterijų svarbą bei grupės respondentų ar ekspertų nuomonių suderinamumas. Atlikta respondentų ir ekspertų nuomonių apie kriterijų ir jų grupių svarbą analizė.

Ketvirtajame skyriuje pateiktas TKVGK kompleksinio daugiakriterio modelio praktinio pritaikymo vertinimas: nustatytas tarptautinio traukinio Vilnius–Maskva vienareikšmis kiekybinis rodiklis. Atliktas kriterijų kitimo įtakos kompleksiniam kokybės rodikliui tyrimas.

Bendrosios išvados

1. Norminiuose dokumentuose vertinami atskiri parametrai, tačiau nėra kompleksinio daugiakriterio vertinimo metodikos. Atlikus mokslinės literatūros, nagrinėjančios geležinkelio infrastruktūrą, riedmenis ir keleivių vežimo geležinkeliais procesą, analizę nustatyta, kad atliekama daug tyrimų šioms sudėtinėms geležinkelių transporto dalims vertinti ir gerinti, tačiau kelionės traukiniu procesas beveik nenagrinėtas.

2. Kiekvienos iš trijų kategorijų apklaustųjų (respondentų ir ekspertų) atsakymų į kiekvienos anketos klausimus duomenų (kriterijų) svarbumui (svoriui) nustatyti pritaikytas AHP metodas. Nustatyta, kad keleivių ir traukinį ap-

tarnaujančio personalo nuomonės dėl visų grupių kriterijų svarbos yra suderintos. Administracijos darbuotojų nuomonės dėl D grupės kriterijų svarbos yra nesuderintos.

3. Nustatyta A, B, C ir D kriterijų grupių svarba. Keleivių nuomonės yra nesuderintos: empirinis konkordancijos koeficientas 0,038, o mažiausia vertė 0,180. Traukinį aptarnaujančio personalo ir administracijos darbuotojų nuomonės yra suderintos.

4. Sukurtas daugiakriteris vertinimo modelis, leidžiantis vienu parametru vertinti ir palyginti atskirų tarptautinio susisiekimo maršrutų kokybę. Jo adekvatumas (korektiškumas) patikrintas ir patvirtintas remiantis atliktų eksperimentų ir skaičiavimų duomenimis tiriant kelionės tarptautiniu traukiniu Vilnius–Maskva kokybę.

5. Nustatyta kriterijų kitimo įtaka KKVR, rodanti, kad didžiausią įtaką K daro C ir D grupių kriterijai: bilieto kaina (pokytis 0,084), vizų kaina (pokytis 0,073), ašidėžių perkaičio signalizacijos veikimas (pokytis 0,049), gaisro gesinimo priemonių buvimas ir būklė, taip pat rankinio stabdžio būklė ir veikimas, stabdų būklė (pokytis 0,043). Jų pokytis yra didžiausias. Mažiausią įtaką kompleksiniam kokybės vertinimo rodikliui daro A ir B grupių kriterijai: palydovo skubaus iškvietimo į kupė galimybė (pokytis 0,003), specialios kupė dviračiams vežti (pokytis 0,004), prekyba suvenyrais traukinyje (pokytis 0,004), vietų restorano vagone rezervavimo galimybė ir taksi iškvietimo paslauga (pokytis 0,005). Jų pokytis yra mažiausias.

6. Kuo didesnis skirtumas, kurį rodo kompleksinio kokybės vertinimo rodiklio vertės pokytis, tuo kriterijaus vertė, keičiama nuo blogiausios (0 lygmuo) iki geriausios (1 lygmuo), rodo didesnį modelio jautrumą K rodikliui. Tai reiškia, kad gerinant šį kriterijų, galima gauti didžiausią keleivių vežimo tarptautiniu traukiniu kokybės pagerėjimą, bet tai nereiškia, kad jam gerinti reikia mažiausių investicijų. Investicijų dydį, siekiant maksimalios kriterijaus kintamosios dalies, reikėtų nustatyti papildomais ekonominiais tyrimais.

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THE MODEL FOR MULTICRITERIA EVALUATION OF THE QUALITY OF
PASSENGER TRANSPORTATION BY INTERNATIONAL TRAINS

Summary of Doctoral Dissertation
Technological Sciences, Transport Engineering (03T)

Lijana MASKELIŪNAITĖ

TARPTAUTINIO KELEIVIŲ VEŽIMO GELEŽINKELIAIS PROCESO KOKYBĖS
TYRIMO DAUGIATIKSLIS MODELIS

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