TRANSPORT
ISSN 1648-4142 print / ISSN 1648-3480 online
2012 Volume 27(3): 307–319
doi:10.3846/16484142.2012.724448

THE MODEL OF EVALUATING THE CRITERIA, DESCRIBING THE QUALITY OF ORGANIZATION AND TECHNOLOGY OF TRAVEL BY INTERNATIONAL TRAIN

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Submitted 5 March 2012; accepted 22 August 2012

Abstract. The significance of the criteria describing various aspects of travel by train, e.g. passenger transportation comfort, safety, travel time, price of a journey, etc., differs considerably. The quality of particular trains, track sections and staff performance can be successfully evaluated by a single number, using the comprehensive quality index (CQI). The paper offers an additive model to calculate the normalized weight coefficients of particular criteria for CQI calculation. A multi-criteria mathematical model, which may be used for evaluating the significance of the criteria describing organization and technology of travel by train for determining its quality, is also presented. Based on the nineteen adopted criteria (the criteria of group B), reflecting the organization and technology of travel by train, the quantitative estimate K_B is obtained. Case studies of calculating the comprehensive quality index K_B, describing the organization and technology of travel by the train 'Vilnius–Moscow', which show the real quality of these processes, are presented. Finally, the conclusions based on the research results are provided.

Keywords: comprehensive quality index, quality evaluation, multicriteria model, survey of experts, transportation.

1. Introduction

Major evaluation criteria of rail transport are related to traffic safety, environmental protection, competitiveness, as well as embracing quality and diversity of services provided to clients, etc. To ensure traffic safety, the control systems of the railway track and trains, as well as signalling and communication systems are being introduced (TCRP Report 130… 2009) and the influence of the track and train parameters on rail traffic safety is investigated (Cherkashin, Pogorelov 2010). The roughness of the track and longitudinal forces, acting on the train, have been found to be the main unfavourable factors, influencing its travel. Assessing the possibility of train derailing, the main factors causing this accident and the role of track roughness in this process are determined (Zharov 2010). The models for evaluating operational characteristics of the railway embankment under the moving loads are being developed. The embankment thickness and speed of the train were evaluated in this context in (Huang *et al.* 2009a). Railway accidents, abnormal loading of wagons and aging of railways and their infrastructure require that technical railway inspection should be improved. To detect railway track and wheelset defects, ultrasound waves from 20 kHz to 1 MHz and non-contact technical inspection are used. Theoretical research into the propagation of ultrasound waves in the semi-conducting track base, using the finite elements' method was performed in California University, San Diego (Coccia *et al.* 2009). The reliability of research results ranges from 75% to 100%. In testing the railway track, the climatic conditions (e.g. rain, wind) were taken into account. The sealing of the railway joints with high-quality epoxy adhesives was also investigated (Peltier, Barkan 2009). The laboratory characteristics of the polluted railway track ballast were described in (Huang *et al.* 2009b) and various types of rail lubricating oil were tested (Markov 2011). After measuring the wheels and rails, it was found that the wear of even new lateral surface was very small, when there was oil between the wheel flange and the rail. The modelling and analysis of ground vibration caused by a moving train, based on the use of the finite elements' method (Hall 2003), the validation of empirical models (With *et al.* 2006) and the dynamic analysis of wind effect on the train moving across the bridge (Xia *et al.* 2008), as well as the dynamic analysis of the spatial (three-dimensional) model of the interaction between the bridge – fast train (rail – wheelset) (Dinh *et al.* 2009) were performed. Special attention should be paid to traffic safety by the countries with specific climatic conditions. For example, the peat ground is found in regions of the northwestern France. Ground surface near the railway should have high load-carrying capacity to be safe for the movement of fast trains, such as T.G.V. (*train grand vites* – in French). To achieve this, the assessment and prediction of ground vibration caused by passing trains was made (Picoux, Houédec 2005). The dynamic pressure caused by a passing train on the railway embankment Qinghai-Tibet with the ground in the frozen condition was investigated in (Zhu *et al.* 2011).

Now, when the prices of oil, electricity and gas are growing, the ways of reducing expenses should be sought. The investments in solving technical, organizational and technological problems are made, management is improved, the alternative power sources are used, macroeconomic indices of transport infrastructure development are evaluated (Macheret *et al.* 2010), the maintenance costs of freight locomotives are analysed and methods of their reduction are suggested (Bureika 2011). The mathematical models of forming trains are made, allowing for optimizing the trains for any route and the type of traction (Dailydka, Lingaitis 2012; Dailydka 2012). The Revenue Management system is widely used in the US, West European countries and Russia. The use of long-distance passenger trains and the models for passenger transportation resulted in the income increase of about 10÷12% (Miroshnichenko *et al.* 2010). Thus, railway transport is becoming a leader and promoter of novel economic development, based on intensification of activities and productivity in the sector, supplemented with the creation and development of new routes (for fast passenger and freight trains) (Lapidus, Macheret 2011).

Many works, focussing on the problems of passenger transportation as a social service or the related issues have appeared in the years of crisis. The environment protection problems are emphasized by researchers and ordinary people in the world, while railway transport is considered to be most environmentally-friendly and safe means of transport. To attract more passengers, transportation services should be improved. For this purpose, researchers are trying to determine the criteria, describing the quality of passenger transportation by rail transport and their significance (Sivilevičius, Maskeliūnaitė 2010), while new advanced methods of evaluating and improving its quality are being sought. Multicriteria decision-making methods are used for evaluating the risks of the projects (Zavadskas *et al.* 2010), choosing the projects of residential environment improvement (Tupėnaitė *et al.* 2010), making construction contracts (Podvezko *et al.* 2010), creating the construction knowledge management system (Lin *et al.* 2011), selecting the best borehole installation method (Lashgari *et al.* 2011), giving preference to the local government construction projects (Aghdaie *et al.* 2012). These methods are also successfully applied to modelling transport system management (Tica *et al.* 2011), and assessing the risks of dangerous goods transportation (Dzemydienė, Dzindzalieta 2010). The weights and ranks of the criteria are determined. An original multicriteria additive mathematical model, allowing for the evaluation the quality of an operating asphalt mixing plant, which is based on nine criteria and their normalized weight coefficients is developed (Sivilevičius *et al.* 2008; Sivilevičius 2011). The criterion variables, obtained by comparing their actual (real) and the specified permissible, as well as the best and the worst values, are calculated by using the above model. In the present paper, the considered principle is applied to the evaluation of the quality of travel by trip.

The aim of the present paper is to suggest an original multicriteria mathematical model, allowing for the evaluation of the significance of 19 criteria describing the organization and technology of travel by train, as well as their significance to the comprehensive quality index (CQI) and to validate the results by considering a numerical example of calculating the quantitative quality index for the international train 'Vilnius–Moscow'.

2. The Development and Description of the Model of Travel by Train

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 work (Maskeliūnaitė *et al.* 2009), 49 QTT 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 (P – passengers and experts, including service staff of the train – ST and the administration staff of Joint-Stock Company 'Lithuanian Railways' (AB 'Lietuvos geležinkeliai') – AS) provided their judgements. The mean weight coefficient $\overline{Z}_B^*$ shows the significance of the criteria of group B (when the number of the respondents and experts in each category differs). This coefficient is calculated as follows:

$$\overline{Z}_B^* = \frac{Z_{B,P} \cdot n_P + Z_{B,ST} \cdot n_{ST} + Z_{B,AS} \cdot n_{AS}}{n_P + n_{ST} + n_{AS}}, \qquad (1)$$

where: $Z_{B,P}$, $Z_{B,ST}$, $Z_{B,AS}$ are weight coefficients given to the criteria of group B by the respondents (experts) of categories P, ST, AS; n_P, n_{ST}, n_{AS} – show the number of the respondents (P) and experts (ST, AS).

The significance estimates (in points), provided to the criteria of group *B* by passengers (*P*), service staff of the train (*ST*) and the administration staff (*AS*) are presented in Table 1.

Table 1. The significance (weight) of the criteria of group *B* describing travel by train

Category of respondents and experts	Number of questionnaires	Weight
Passengers (*P*)	21	$Z_{B,P} = 0.2619$
Service staff of the train (*ST*)	20	$Z_{B,ST} = 0.1900$
Administration staff of Joint-Stock Company 'Lithuanian Railways' (*AS*)	9	$Z_{B,AS} = 0.2333$
The average estimate value of all respondents and experts in their categories	50	$\bar{Z}_B^* = 0.228$

Trains made up for various routes have cars of different types and technical state 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 indicator *K*, allowing the quality of travel on a particular route to be expressed by a single number, were developed ($K = K_A + K_B + K_C + K_D$, $K = 0 \div 1$). The model for calculating the criteria describing organizational and technological aspects of travel by train, which are based on the mean weight coefficient $\bar{Z}_B^*$ 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:

$$K_B = \bar{Z}_B^* \cdot \left(\bar{Q}_{B1} \cdot x_{B1} + \bar{Q}_{B2} \cdot x_{B2} + ... + \bar{Q}_{B19} \cdot x_{B19} \right), \quad (2)$$

where: K_B is comprehensive quality index (CQI) of the international train (ranging from 0 to $\bar{Z}_B^*$); $\bar{Z}_B^*$ is the mean weight coefficient, reflecting respondents' and experts' estimates of the significance of group *B* criteria; $\bar{Q}_{B1}, ..., \bar{Q}_{Bm}$ denote mean weight values of *j*-th criterion of group *B* criteria 1, ..., *m*, determined by expert evaluation method (Sivilevičius, Maskeliūnaitė 2010; Maskeliūnaitė, Sivilevičius 2011); $x_{B1}, ..., x_{Bm}$ are the variables of *j*-th criterion of group *B* criteria 1, ..., *m*, whose estimates are used for determining the real criterion value, ranging from 0 to 1.

3. The Model of Evaluating the Criteria, Describing Organizational and Technological Aspects of Travel by Train

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.

3.1. Departure and arrival of trains according to schedule. Train traffic is organized according to schedule, which should be kept by all railway departments. Meeting a schedule is one of the most important criteria describing the quality of railway operation. In the case of a failure to meet the schedule due to a technical failure or natural calamity, the staff members of all departments should take measures to ensure that the delaying passenger and freight locomotives would be running to schedule again because traffic safety depends on it, read more in the 'Guiding principles of technical use of railways' (Techninio geležinkelių naudojimo nuostatai 1996). Trains should arrive in time not only to the terminal but to intermediate stations as well. If the train is up to 5 minutes behind schedule, the report is not written. Therefore, such cases are considered to be permissible. In terms of schedule, any station is considered from the perspective of four schedule maintenance alternatives (for every intermediate station) (Fig. 1):

1. the train arrives at the station before schedule;
2. the train departs from the station before schedule (when the stoppage time of the train is cut down because of its arrival at the station behind schedule). It is possible, but not permitted;
3. the train arrives at the station behind schedule;
4. the train departs from the station behind schedule.

The train cannot depart from the station *A* before schedule, though it can depart behind schedule (Fig. 2).

The train can arrive at the destination station *C* some time behind or before schedule because of various obstacles on the way. There can be four combinations of train's arrival at an intermediate station and departure from it with respect to the schedule (Fig. 3):

1–2 denote the arrival before schedule and departure before schedule (not permitted);

1–4 denote the arrival before schedule and departure behind schedule;

3–4 denote the arrival behind schedule and departure behind schedule;

3–2 denote the arrival behind schedule and departure before schedule (not permitted).

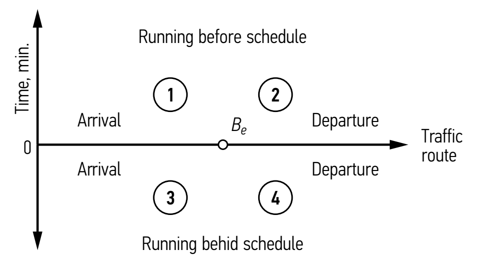

Fig. 1. The model of passenger train's keeping to schedule at the intermediate station *B*

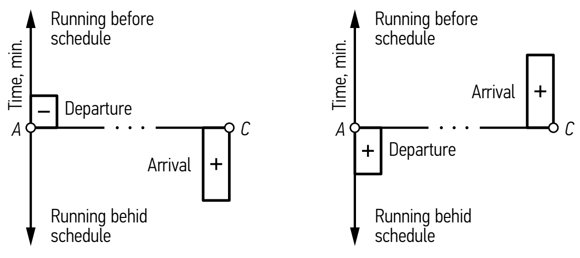

Fig. 2. The model of passenger train's keeping to schedule, when departing from the station *A* and arriving at the station *C*

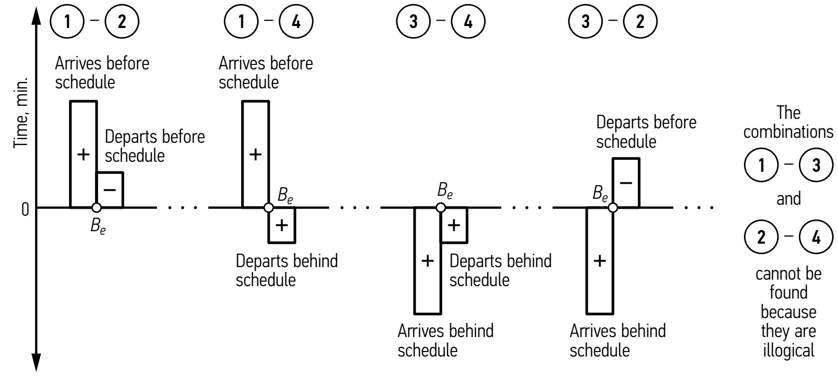

Fig. 3. The combinations of passenger train's arrival (departure) at the intermediate station B before (behind) schedule

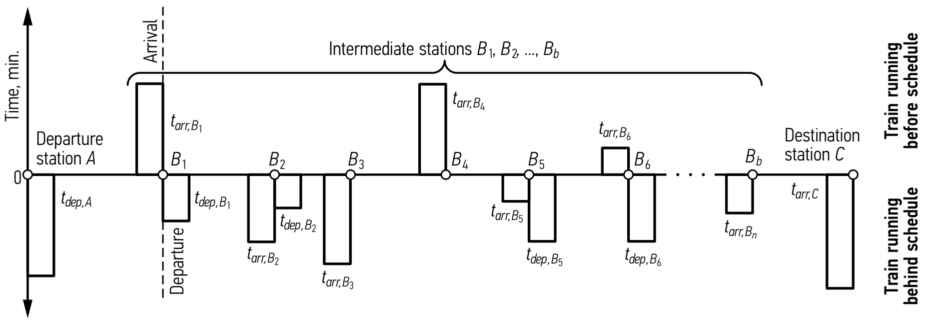

Fig. 4. Various available combinations of train's keeping to schedule on the route

The available combinations of the train's keeping to schedule over the whole route (distance from the departure to the destination station) are shown in Fig. 4.

When a train is from 60 to 120 min behind schedule or when the run is cancelled, passengers can require compensation from the company, which is provided for in the 'General rules of passenger transportation…' (AB „Lietuvos geležinkeliai" bendrosios… 2011). The influence of the train's arrival at and departure from a station on the (CQI) can be determined by the train's conductor or some other person (e.g. the senior attendant).

The value of the CQI component K, depending on K_B, which describes the organization and technology of travel by train, and the variable x_{B1} of the product $\overline{Q}_{B1} \cdot x_{B1}$, showing how the train keeps to schedule when arriving at or departing from the stations, is calculated by the formula:

$$x_{B1} = 1 - \frac{par}{\beta(2+b)t^2_{arr,\,l}};$$

$$par = \gamma \cdot \left(\left(t_{dep,\,l} + t_{dep,\,A}\right)^2 - t^2_{dep,\,l} + \left(t_{arr,\,l} + t_{arr,\,C}\right)^2 - t^2_{arr,\,l} \right) + (1-\gamma)\sum_{e=1}^{b}\left(\left(t_{arr,\,l} + t_{arr,\,B}\right)^2 - t^2_{arr,\,l} + \left(t_{dep,\,l} + t_{dep,\,B}\right)^2 - t^2_{dep,\,l} \right)_e, \quad (3)$$

where: $t_{dep,\,A}$ is the delay time of the train's departure from station A, min; $t_{arr,\,C}$ is the delay time of the train's arrival at the destination station C, min; $t_{arr,\,B}$ is the delay time of the train's arrival at intermediate station e, min; $t_{dep,\,B}$ is the delay time tolerance of the train's departure from intermediate station e, min; $t_{arr,\,l} = t_{dep,\,l}$ means the delay time of the train's arrival to or departure from the departure, destination or intermediate station (taken as 5 min because this delay time does not require any report writing); e is the number of intermediate stations on the route, $e = 1, 2, ..., b$; β is a coefficient depend on the number of intermediate stations on the route; γ is weight coefficient of the train's delay of departing from the departure station A and to arrive at the destination station C, depending on the ratio of the number of passengers, taking the train and descending from it, to the whole number of the train's passengers: when the obtained number N_{A+C} of passengers, taking the train at the departure station and travelling to the destination station, is divided by the total number N_{total} of passengers, taking the train at the departure and intermediate stations and descending from it at intermediate or terminal stations (not the number of cases of taking the train and descending from it):

$$\gamma = \frac{N_{A+C}}{N_{total}}. \quad (4)$$

3.2. The provision of passengers with a ration included in the ticket price: 0 means that the ration is not included in the ticket price for travel in the considered car and, therefore, is not provided to passengers, 1 means that the ration is included in the ticket price of travelling in this car and is provided to passengers. The CQI component K_B, evaluating the significance of the criterion, describing this service, is calculated by the formula:

$$x_{B2} = \frac{\sum_{c=1}^{n_{car}} \frac{PP_{fc}}{PP_{\max}}}{n_{car}}, \quad (5)$$

where: x_{B2} is the variable of the second criterion of group B, based on which the actual criterion value, ranging from 0 to 1, is calculated; PP_{fc} is the actual evaluation in points (0 or 1) of ration provision in the c-th car; $PP_{\max}$ is the maximum number of points (1) given to ration provision; n_{car} is the number of railway cars in the train.

3.3. Availability of bedclothes in the car, their state and making the bed for passengers: 0 means that bedclothes are not available in the considered car and passengers should have their own bedclothes, 1 means that bedclothes are not packed, therefore, there is no guarantee that they have not been used; a passenger should pay for bedclothes in cash and the attendant should not make the bed for him/her, 2 shows that bedclothes are packed, i.e. not used, clean and ironed, but car attendant should not make the bed for passengers, 3 means that bedclothes are packed, their provision is included in the ticket price but the attendant should not make the bed for passengers, 4 means that bedclothes are packed, their provision is included in the ticket price and car attendant should make the bed for passengers if they so please, 5 shows that bedclothes (of dubious cleanness) are included in the ticket price and car attendant should make the bed for passengers of the upper berths if they so please, 6 means that the provision of bedclothes is included in the ticket price, the lower berths are covered with clean and ironed bedclothes and car attendant should make the bed for the passengers of the upper berths if they so please, 7 means that the provision of bedclothes is included in the ticket price and the upper and lower berths are covered with bedclothes (of dubious cleanness), 8 shows that the provision of bedclothes is included in the ticket price and the lower and upper berths are covered with clean and ironed bedclothes, 9 means that the provision of bedclothes is included in the ticket price, while the only (lower) berths in the car are covered with bedclothes (of dubious cleanness), 10 means that the provision of bedclothes is included in the ticket price, while the only (lower) berths in the car are covered with bedclothes of the best quality. The value of the CQI component K_B, evaluating the provision of bedclothes to passengers, their state and making the bed for passengers is calculated by the formula:

$$x_{B3} = \frac{\sum_{c=1}^{n_{car}} \frac{AB_{fc}}{AB_{\max}}}{n_{car}}, \quad (6)$$

where: x_{B3} is the variable of the third criterion of group B, used for calculating the actual criterion value ranging from 0 to 1; AB_{fc} is the estimate of the considered service in points (0, 1, 2, 3, 4, 5, 6, 7, 8, 9 or 10 points); $AB_{\max}$ is the highest possible estimate of the considered service (10 points); n_{car} is the number of railway cars in the train.

3.4. The possibility of ordering food and drinks from the dining car to be delivered to the compartment (via car attendant): 0 means that this service is not available on the train and passengers should go to the dining car themselves, 1 shows that only passengers of two-seat compartments of the first-class cars can order food and drinks to be delivered from the dining car, 2 means that only passengers of two- or four-seat compartments of the first-class cars can order food and drinks to be delivered from the dining car, 3 means that passengers of all railway cars can order food and drinks to be delivered from the dining car. The CQI component K_B, evaluating the considered service (criterion), is calculated as follows:

$$x_{B4} = \frac{FD_f}{FD_{\max}}, \quad (7)$$

where: x_{B4} is the variable of the fourth criterion of group B, used for calculating the actual criterion value ranging from 0 to 1; FD_f is actual estimate of the service in points (0, 1, 2 or 3 points); $FD_{\max}$ is the highest possible estimate of the considered service in points (3 points).

3.5. Access to popular newspapers and magazines on the train: 0 means that popular newspapers and magazines are not available on the train, 1 shows that passengers can buy popular newspapers and magazines on the train, 2 shows that some free-of-charge and paid newspapers are available on the train, 3 means that all newspapers and magazines on the train are free of charge. The CQI component K_B, evaluating the considered service (criterion), is calculated by the formula:

$$x_{B5} = \frac{NM_f}{NM_{\max}}, \quad (8)$$

where: x_{B5} is the variable of the fifth criterion of group B, used for calculating the actual criterion value, ranging from 0 to 1; NM_f is actual service estimate in points (0, 1, 2 or 3 points); $NM_{\max}$ is the highest possible service estimate (3 points).

3.6. Internet access on a train is one of the most often discussed subjects in the modern railway industry. More and more railway companies (especially those which operate suburban trains) provide a free wireless connectivity (WiFi) service. In this way, these companies ensure the satisfaction of their existing customers during the trips and attract even more customers. The implementation of similar services is often difficult due to ineffectiveness of the employed technologies and incompatibility with the rules of the Internet connection use in the public space. For example, all the attempts to install Wi-Fi hotspots in the London Underground have been unsuccessful so far. Thus, the passengers are unable to connect to the wireless network although the time they spend on the metro train often exceeds one hour. Unfortunately for passengers, there are usually no other means to pass the time during a trip, so they are forced to listen to conversations of other people and other ambient noise (Geležinkelininkas, 1–15 June, 2011, No 11(433)). *Internet access* (*IA*) on a train is assessed as follows: 0 means the absence of the Internet access on a train, 1 means the presence of paid Internet access on a train, 2 means the presence of free Internet access on a train. The CQI component K_B, evaluating the considered service on a train, is calculated by the formula:

$$x_{B6} = \frac{IA_f}{IA_{\max}}, \tag{9}$$

where: x_{B6} is the variable of the sixth criterion of group *B*, the value of which is used for calculating the actual criterion value, ranging from 0 to 1; IA_f is the actual service estimate in points (0, 1 or 2 points); $IA_{\max}$ is the highest possible service estimate (2 points).

3.7. The possibility of buying a ticket on the train (from the train conductor): 0 means that this service is not provided on the train, 1 means that the considered service is available in an ordinary sleeping (sitting) car, 2 shows that the considered service is provided in the sleeping car with four-seat compartments, 3 means that the service is provided in an ordinary sleeping or sitting car and in the sleeping car with four-seat compartments, 4 means that the service is available in an ordinary sleeping (sitting) car, a sleeping car with four-seat compartments and a first-class car with two-seat compartments, 5 shows that the considered service is provided in all types of cars. The CQI component K_B, evaluating the considered service (criterion), is calculated by the formula:

$$x_{B7} = \frac{BT_f}{BT_{\max}}, \tag{10}$$

where: x_{B7} is the variable of the seventh criterion of group *B*, used for calculating the actual criterion value, ranging from 0 to 1; BT_f is actual service estimate in points (0, 1, 2, 3, 4 or 5 points); $BT_{\max}$ is the highest possible estimate (5 points).

3.8. The possibility to reserve a table in the dining car: 0 means that this service is not provided on the train, 1 denotes that tables in the dining car may be reserved only for passengers of the first-class cars with two-seat compartments, 2 means that tables in the dining car may be reserved for passengers of the first-class cars with two- and four-compartments, 3 shows that tables in the dining car may be reserved for passengers of all types of railway cars. The CQI component K_B, evaluating the considered service (criterion), is calculated by the formula:

$$x_{B8} = \frac{RDC_f}{RDC_{\max}}, \tag{11}$$

where: x_{B8} is the variable of the eighth criterion of group *B*, used for calculating the actual criterion value, ranging from 0 to 1; RDC_f is the actual estimate of the considered service in points (0, 1, 2 or 3 points); $RDC_{\max}$ is the highest possible service estimate (3 points).

3.9. The possibility of ordering a taxi for a passenger at a particular station from the train via the car attendant and the train conductor: 0 means that the service is not provided on the train, 1 shows that there is a possibility to call a taxi for a passenger at the terminal (train formation) station, but it is a paid service, 2 means that there is a possibility to call a taxi for a passenger at the terminal (train formation) station and this service is provided free of charge, 3 denotes that there is a possibility to call a taxi for a passenger at the terminal (train formation or destination) station, but it is a paid service, 4 means that it is possible to call a taxi for a passenger at the terminal (train formation or destination) station and this service is provided free of charge, 5 shows that the considered service can be provided at any station, where the train stops, but it is a paid service, 6 means that the service can be provided at any station, where the train stops, and it is free of charge. The CQI component K_B, evaluating the considered service (criterion), is calculated by the formula:

$$x_{B9} = \frac{OT_f}{OT_{\max}}, \tag{12}$$

where: x_{B9} is the variable of the ninth criterion of group *B*, used for calculating the actual criterion value, ranging from 0 to 1; OT_f is the actual estimate of the considered service (criterion) in points (0, 1, 2, 3, 4, 5 or 6 points); $OT_{\max}$ means its highest possible estimate (6 points).

3.10. The possibility of paying with a payment card on the train: 0 means that this service is not provided on the train, 1 denotes that the service is provided on the train, but a passenger should go with the train conductor to the dining car, where a scanner of electronic cards is installed, 2 means that the considered service is provided, while the scanner of electronic cards is located at the train conductor's workplace, 3 shows that the considered service is provided on the train, with the scanner equipped in every railway car. The CQI component K_B, evaluating the considered service (criterion), is calculated by the formula:

$$x_{B10} = \frac{PC_f}{PC_{\max}}, \tag{13}$$

where: x_{B10} is the variable of the tenth criterion of group *B*, used for calculating the real criterion level, ranging from 0 to 1; PC_f is the actual criterion estimate in points (0, 1, 2 or 3 points); $PC_{\max}$ is the highest possible service (criterion) estimate (3 points).

3.11. The sale of souvenirs on the train: 0 means that souvenirs are not sold on the train; 1 shows that souvenirs are sold on the train. The CQI component K_B, evaluating this service (criterion), is calculated by the formula:

$$x_{B11} = \frac{SS_f}{SS_{\max}}, \tag{14}$$

where: x_{B11} is the variable of the eleventh criterion of group *B*, used for determining the real criterion level, ranging from 0 to 1; SS_f is the actual service (criterion) estimate in points (0 or 1 points); $SS_{\max}$ is the highest possible service estimate (1 point).

3.12. Evaluating radio broadcasting of music and information on the train according to the wishes of passengers, the opinions of passengers should be taken into account. For this purpose, the surveys of passengers were conducted. In a specially prepared questionnaire, passengers had to give the points as follows: 0 very poor, 1 poor, 2 satisfactory, 3 very good, 4 excellent. The CQI component K_B, evaluating this service (criterion), is calculated by the formula:

$$x_{B12} = \frac{\sum_{p=1}^{n_p} \frac{RB_{fp}}{RB_{\max}}}{n_p}, \quad (15)$$

where: x_{B12} is the variable of the twelfth criterion of group *B*, used for calculating the actual criterion level, ranging from 0 to 1; RB_{fp} is the actual estimate (in points) given to the considered service by the *p*-th respondent (passenger) (0, 1, 2, 3 or 4 points); $RB_{\max}$ is the highest possible criterion (service) estimate (4 points); n_p is the number of respondents (passengers), evaluating the considered service in points.

3.13. The protection of passenger luggage and other valuable things on the train: 0 means that the passenger's luggage, documents and other things are not protected on the train. A passenger himself should be responsible for their protection, 1 shows that the luggage is not protected, while the documents and other valuable things on the train are protected for the specified payment, 2 means that the passenger's luggage is not protected, while documents and other valuable things on the train are protected free of charge, 3 means that the passenger's luggage, documents and other things on the train are protected for the specified payment, 4 denotes that there are locked containers for passenger's luggage on the train, therefore, his/her luggage and other things are protected. The CQI component K_B, evaluating this service (criterion), is calculated by the formula:

$$x_{B13} = \frac{PL_f}{PL_{\max}}, \quad (16)$$

where: x_{B13} is the variable of the thirteenth criterion of group *B*, used for calculating the actual criterion level, ranging from 0 to 1; PL_f is the actual service (criterion) estimate in points (0, 1, 2, 3 or 4 points); $PL_{\max}$ is the highest possible service estimate (4 points).

3.14. The possibility to get a foreign health insurance policy on the train: 0 means that the service is not provided on the train, 1 means that the service is provided on the train, 2 denotes that there is no need to get a foreign health insurance policy because the health of a passenger going abroad is insured when he/she gets a visa. The CQI component K_B, evaluating this service (criterion), is calculated by the formula:

$$x_{B14} = \frac{HIP_f}{HIP_{\max}}, \quad (17)$$

where: x_{B14} is the variable of the fourteenth criterion of group *B*, used for calculating the actual criterion level, ranging from 0 to 1; HIP_f is the actual service (criterion) estimate in points (0, 1 or 2 points); $HIP_{\max}$ is the highest possible service estimate (2 points).

3.15. The possibility to get a visa at the frontier post: 0 means that there is no such possibility during the trip by train, 1 means that the considered service may be provided, but a passenger should interrupt the trip and, after getting a visa, take another train to continue travel, 2 implies that a passenger can get a visa and continue the travel on the same train. The CQI component K_B, evaluating this service (criterion), is calculated by the formula:

$$x_{B15} = \frac{GV_f}{GV_{\max}}, \quad (18)$$

where x_{B15} is the variable of the fifteenth criterion of group *B*, used for calculating the actual criterion level, ranging from 0 to 1; GV_f is the actual service (criterion) estimate in points (0, 1 or 2 points); $GV_{\max}$ is the highest possible service estimate (2 points).

3.16. Evaluating the appearance of service staff members (uniform, shoes, hairstyle, identification card), the opinions of passengers should be taken into account. For this purpose, a special questionnaire was prepared (Table 2), where a passenger evaluating this criterion could give it the following points: 0 means very poor, 1 indicates poor, 2 means satisfactory, 3 means very good, 4 denotes excellent. The CQI component K_B, evaluating this service (criterion), is calculated by the formula:

$$x_{B16} = \frac{\sum_{p=1}^{n_p} \frac{ASS_{fp}}{ASS_{\max}}}{n_p}, \quad (19)$$

where: x_{B16} is the variable of the sixteenth criterion of group *B*, used for calculating the actual criterion level, ranging from 0 to 1; ASS_{fp} is the actual estimate (in points) given by the *p*-th respondent (passenger) (0, 1, 2, 3 or 4 points); $ASS_{\max}$ is the highest possible criterion estimate (4 points); n_p is the number of respondents (passengers), evaluating the considered criterion in points.

3.17. Communication of the service staff with passengers and each other. Providing various services to passengers, a car attendant should conform to the rules of communication with passengers: to meet passengers in a friendly way, to listen to them attentively and to answer their questions, to be always polite and tactful, to speak to the passengers calmly and express his/her ideas concisely and clearly, read more in the 'The instruction of the passenger car attendant responsibilities' (Keleivinio vagono palydovo pareiginė instrukcija 1999). The car attendant should not be disrespectful to colleagues and superiors, use profanity and make inappropriate remarks, read more in the 'Code of ethics of the staff…' (AB „Lietuvos geležinkeliai" darbuotojų etikos kodeksas… 2008). Evaluating the *communication of the service staff with passengers and each other*, the opinions of passengers should be taken into account. For this purpose, a special questionnaire was prepared (Table 2), where passengers give the following points to the considered issue: 0 means very poor, 1 means poor, 2 denotes satisfactory, 3 means very good and 4 means excellent. The CQI component K_B, evaluating this criterion, is calculated by the formula:

$$x_{B17} = \frac{\sum_{p=1}^{n_p} \frac{CSSP_{fp}}{CSSP_{\max}}}{n_p}, \tag{20}$$

where: x_{B17} is the variable of the seventeenth criterion of group B, used for calculating the actual criterion level, ranging from 0 to 1; $CSSP_{fp}$ is the actual estimate (in points) given by the p-th respondent (passenger) (0, 1, 2, 3 or 4 points); $CSSAP_{\max}$ is the highest possible criterion estimate (4 points); n_P is the number of respondents (passengers), evaluating the considered criterion in points.

3.18. Knowledge of foreign languages by the service staff of the train: 0 means that a person does not know any foreign language, 1 shows that a person knows (to some extent) a foreign language, allowing him/her to communicate with passengers, 2 means that a person knows (to some extent) two foreign languages, 3 means that a person knows (to some extent) three foreign languages, 4 means that a person knows (to some extent) four and more foreign languages. The CQI component K_B, evaluating this criterion, is calculated by the formula:

$$x_{B18} = \frac{\sum_{a=1}^{n_{ST}} \frac{KFL_{fa}}{KFL_{\max}}}{n_{ST}}, \tag{21}$$

where: x_{B18} is the variable of the eighteenth criterion of group B, used for calculating the actual criterion level, ranging from 0 to 1; KFL_{fa} is the actual estimate (in points) given by the a-th respondent (service staff member) (0, 1, 2, 3 or 4 points); $KFL_{\max}$ is the highest possible criterion estimate (4 points); n_{ST} is the number of respondents (train service staff members).

3.19. Competence, objectivity and communication skills of customs officers and frontier guards. These persons represent the country. They should be competent in answering the questions of passengers, as well as polite, tactful and respectful. Evaluating this criterion, the estimates of passengers should be taken into account, which may be expressed as follows: 0 means very poor, 1 means poor, 2 denotes satisfactory, 3 means very good, 4 means excellent. The CQI component K_B, evaluating this criterion, is calculated by the formula:

$$x_{B19} = \frac{\sum_{p=1}^{n_p} \frac{COFG_{fp}}{COFG_{\max}}}{n_p}, \tag{22}$$

where: x_{B19} is the variable of the nineteenth criterion of group B, used for calculating the actual criterion level, ranging from 0 to 1; $COFG_{fp}$ is the actual estimate (in points) given by the p-th respondent (passenger) (0, 1, 2, 3 or 4 points); $COFG_{\max}$ is the highest possible criterion estimate (4 points); n_p is the number of respondents.

The corrected formula for calculating the index K_B, evaluating the criteria describing organization and technology of travel by train, is expressed as follows:

$$K_B = \bar{Z}_B^* \cdot \left(\bar{Q}_{B1} \cdot \left(1 - \frac{\gamma \cdot par}{\beta(2+b)t^2_{arr,l}} \right) + \bar{Q}_{B2} \cdot \frac{\sum_{c=1}^{n_{car}} \frac{PP_{fc}}{PP_{\max}}}{n_{car}} + \bar{Q}_{B3} \cdot \frac{\sum_{c=1}^{n_{car}} \frac{AB_{fc}}{AB_{\max}}}{n_{car}} + \bar{Q}_{B4} \cdot \frac{FD_f}{FD_{\max}} + \bar{Q}_{B5} \cdot \frac{NM_f}{NM_{\max}} + \bar{Q}_{B6} \cdot \frac{IA_f}{IA_{\max}} + \bar{Q}_{B7} \cdot \frac{BT_f}{BT_{\max}} + Q_{B8} \cdot \frac{RDC_f}{RDC_{\max}} + \bar{Q}_{B9} \cdot \frac{OT_f}{OT_{\max}} + \bar{Q}_{B10} \cdot \frac{PC_f}{PC_{\max}} + \bar{Q}_{B11} \cdot \frac{SS_f}{SS_{\max}} + \bar{Q}_{B12} \cdot \frac{\sum_{p=1}^{n_p} \frac{RB_{fp}}{RB_{\max}}}{n_p} + \bar{Q}_{B13} \cdot \frac{PL_f}{PL_{\max}} + \bar{Q}_{B14} \cdot \frac{HIP_f}{HIP_{\max}} + \bar{Q}_{B15} \cdot \frac{GV_f}{GV_{\max}} + \bar{Q}_{B16} \cdot \frac{\sum_{p=1}^{n_p} \frac{ASS_{fp}}{ASS_{\max}}}{n_p} + \bar{Q}_{B17} \cdot \frac{\sum_{p=1}^{n_p} \frac{CSSP_{fp}}{CSSP_{\max}}}{n_p} + \bar{Q}_{B18} \cdot \frac{\sum_{a=1}^{n_{ST}} \frac{KFL_{fa}}{KFL_{\max}}}{n_{ST}} + \bar{Q}_{B19} \cdot \frac{\sum_{p=1}^{n_p} \frac{COFG_{fp}}{COFG_{\max}}}{n_p} \right);$$

$$par = \left(\left(t_{dep,l} + t_{dep,A}\right)^2 - t^2_{dep,l} + \left(t^2_{arr,l} + t_{arr,C}\right)^2 - t^2_{arr,l} \right) + (1-\gamma) \cdot \sum_{e=1}^{b} \left(\left(t_{arr,l} + t_{arr,B}\right)^2 - t^2_{arr,l} + \left(t_{dep,l} + t_{dep,B}\right)^2 - t^2_{dep,l} \right)_e . \tag{23}$$

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.

4. Practical application of the model

Based on the formulas suggested in the paper for determining CQI components (19 criteria), evaluating any criterion, their significance may be calculated based on the real data taken from standards, technical specifications, surveys and other reliable sources. The testing was performed on the train 'Vilnius–Moscow'.

4.1. Departure and arrival of the train on time. The test was performed, based on the schedule of the train 'Vilnius–Moscow'. According to schedule, the travel time of the train from the departure station A to the terminal (arrival) station C is 14 h 58 min (898 minutes). At the departure station in Vilnius, 91 passengers took the train. Seventy-seven of them travelled to the terminal station in Moscow. In general, there were 102 passengers on the train. The weight coefficient obtained for the delay of departure of the train from the initial station A and the arrival to the terminal station C was $\gamma = 0.75$. There are 8 intermediate stations on the route 'Vilnius–Moscow'. The train departed from Vilnius on time and arrived at Kena frontier station according to schedule, but departed from it 2 min behind schedule (staying there for 37 min). The train was 2 min late to arrive at Gudagai, stayed there for 38 min (2 min less than provided for in the schedule) and, therefore, departed from it on time. The train arrived at Smorgon and Maladzyechna on time and departed from them on time as well. It was 3 min late to arrive at Minsk and 3 min late to depart from it. The train arrived at Orsha and Smolensk on time and departed from them on time as well. However, it was 5 min late to arrive at Vyazma, stayed there for a shorter time (18 min) than specified and, therefore, departed from it on time. The train arrived at the terminal station, Moscow, according to schedule. Evaluating the travel of the train, formula (3) was used to determine the value of this CQI component. Since the train departed from the departure station on time and the delay time of arrival at or departure from some intermediate stations was not large, the result close to unity, i.e. $x_{B1} = 0.878$, was obtained. When the train meets the schedule, $x_{B1} = 1$ is obtained as an ideal case. We assume that the worst case of the train's delay is the situation, when it departs from the initial station, then stops immediately and stays there for the whole time of the trip to the terminal station. In this case, a new train may be formed, while the first run is considered void. The quality level of the criteria of group B and the respective estimate of the variable x_{Bj}, based on real data, are presented in Table 2.

4.2. The provision of passengers with a ration included in the ticket price. The train 'Vilnius–Moscow' has six cars (not including the dining car). Evaluating this criterion (service), it should be taken into account that, at present, the ration included in the ticket price is provided to the passengers of the first-class two-seat compartment cars of the international trains of the Joint-Stock Company 'Lithuanian Railways'. The CQI component was calculated by formula (5) and $x_{B2} = 0.167$ was obtained.

4.3. Availability of bedclothes in the car, their state and making the bed for passengers. Evaluating this criterion (service), it should be taken into account that in international trains bedclothes (two sheets, a pillow-case and a towel) are included in the ticket price and provided to passengers of the railway cars of all types. Bedclothes should be safely packed. The attendant should make the bed if a passenger so pleases. In the first-class cars with two-seat compartments, the beds are made when the car is being prepared for the trip and passengers have not got on the car yet. The train 'Vilnius–Moscow' has six cars (not including the dining car). The CQI component was calculated by formula (6) and $x_{B3} = 0.50$ was obtained.

4.4. The possibility of ordering food and drinks from the dining car to be delivered to the compartment (via car attendant). Every car of the train has a menu. Car attendant should deliver food and drinks from the dining car to the compartment of passenger, who has made an order. The train 'Vilnius–Moscow' has six cars (not including the dining car). The CQI component was calculated by formula (7) and the maximum $x_{B4} = 1$ was obtained.

4.5. Access to popular newspapers and magazines on the train. In the trains of Joint-Stock Company 'Lithuanian Railways', the newspapers' cost is the same as that in the newsstands. There are some free newspapers as well. The CQI component was calculated by formula (8) and $x_{B5} = 0.667$ was obtained.

4.6. Internet access (PI). The trains of Joint-Stock Company 'Lithuanian Railways' do not provide this service. The CQI component was calculated by formula (9) and the critically low $x_{B6} = 0$ was obtained.

4.7. The possibility of buying a ticket on the train (from the train conductor). A passenger, who had no time to buy a ticket to the international train 'Vilnius–Moscow' at a booking office, can buy it from the train conductor, who has 5÷8 seats reserved in the sixth car (a sleeping car with four-seat compartments). The service of selling a ticket on the train costs 5.00 Lt (on the local routes this payment is not taken from passengers, getting on the train at the station, where a booking office does not work). The CQI component was calculated by formula (10) and $x_{B7} = 0.50$ was obtained.

4.8. The possibility to reserve a table in the dining car. A passenger can reserve a table in the dining cars of the international trains of the Joint-Stock Company 'Lithuanian Railways'. Passengers rarely use this possibility. A passenger from any car on the train 'Vilnius–Moscow' can reserve the table in the dining car. The CQI component was calculated by formula (11) and the maximum $x_{B8} = 1$ was obtained.

4.9. The possibility of ordering a taxi from the train at the particular station for a passenger. Evaluating this criterion (service), it should be taken into account that it is possible to call a taxi in all trains formed in Lithuania via the car attendant or the train conductor for a passenger before arriving at the terminal (train formation) station. This service is free of charge. A passenger of the train 'Vilnius–Moscow' has a possibility to call a taxi via the car attendant or the train conductor before arriving at the terminal (train formation) station (Vilnius). The CQI component was calculated by formula (12) and $x_{B9} = 0.333$ was obtained.

4.10. The possibility of paying with a payment card on the train. Passengers can pay with a payment card for the provided services, goods and tickets in the international trains. The scanner of electronic cards is located in the train's dining car. The train conductor should accompany a passenger, who wishes to pay with a payment card, to the attendant-barman and perform the required operation for the passenger. Only cash is accepted for the services provided on the local trains. A passenger can pay with a payment card, but, in this case, he/she should go to the dining car, where a scanner of electronic cards is found (1 point). The CQI component was calculated by formula (13) and $x_{B10} = 0.333$ was obtained.

4.11. The sale of souvenirs on the train. Souvenirs are not sold on the trains of the Joint-Stock Company 'Lithuanian Railways'. The CQI component was calculated by formula (14) and the critically low $x_{B11} = 0$ was obtained.

4.12. Radio broadcasting of music and information on the train according to the wishes of passengers. Radio shows, music and information (about the trip duration, intermediate stations, the provided services, etc.) are broadcast on all trains of the Joint-Stock Company 'Lithuanian Railways'. This information is regulated by special rules. The test for evaluating this criterion on the train 'Vilnius–Moscow' was performed based on the data obtained from 20 questionnaires filled in by passengers. The CQI component was calculated by formula (15) and $x_{B12} = 0.575$ was obtained.

4.13. The protection of passenger's luggage and other valuable things on the train. Passengers are responsible for the protection of their luggage, documents and other valuable things during the trip on the train 'Vilnius–Moscow'. The CQI component was calculated by formula (16) and the critically low $x_{B13} = 0$ was obtained.

4.14. The possibility to get a foreign health insurance policy on the train. There is no need to get a foreign health insurance policy on the international trains of the Joint-Stock Company 'Lithuanian Railways' because the health of a passenger going abroad is insured when he/she gets a visa. The CQI component was calculated by formula (17) and the maximum $x_{B14} = 1$ was obtained.

4.15. The possibility to get a visa at the frontier post. Visas are not issued at the frontier posts. Passengers without a visa or having an invalid visa should get off the train at the frontier post. He/she should go to the office, issuing visas, and having got a visa can continue travel on another train. It takes too much time and causes serious problems for passengers. The test was performed for the train 'Vilnius–Moscow', when there was no possibility for passengers to get visas on the frontier post. The CQI component was calculated by formula (18) and the critically low $x_{B15} = 0$ was obtained.

4.16. The appearance of service staff members (uniform, shoes, hairstyle, identification card). All members of the service staff of the trains should wear uniforms during the trip and follow the rules, titled as the 'The rules of wearing the uniform by the service staff members' (AB „Lietuvos geležinkeliai" keleivius aptarnaujančio… 2003). The uniform details, its delivery, period of wearing, maintenance and replacement, as well as wearing of the identification badge and card, are described in these rules, which pay great attention to clothing and accessories of the service staff. The test for evaluating this criterion on the train 'Vilnius–Moscow' was performed based on the data obtained from 20 questionnaires filled in by passengers. The CQI component was calculated by formula (19) and $x_{B16} = 0.813$ is obtained.

4.17. Communication of the service staff with passengers and each other. The test for evaluating this criterion on the train 'Vilnius-Moscow' was performed based on the data obtained from 20 questionnaires filled in by passengers. The CQI component was calculated by formula (20) and $x_{B17} = 0.888$ was obtained.

4.18. Knowledge of foreign languages by the service staff of the train. The train conductor (senior attendant) of an international train should speak a foreign language so that he/she could communicate with passengers and administration of the railway, on which the train runs (The instruction of responsibilities of international passenger train conductor 2003). Car attendant must speak at least one foreign language. The data were obtained from the survey of 11 service staff members (one train conductor and 10 car attendants, questioned by him) of the train 'Vilnius–Moscow'. The CQI component was calculated by formula (21) and $x_{B18} = 0.409$ was obtained.

4.19. Competence, objectivity and communication skills of customs officers and frontier guards. The test was performed on the train 'Vilnius–Moscow' based on the data of 20 questionnaires filled in by passengers. The CQI component was calculated by formula (22) and $x_{B19} = 0.725$ was obtained.

The quality level of the criteria of group B and the respective x_{Bj} value, based on the real data, are presented in Table 2. The quality level, represented by the estimate of the variable x_{Bj}, when based on the highest values of the data, is equal to 1, while based on the lowest values of the data, is equal to 0.

Using the formula (23), the index K_B of the criteria describing organization and technology of travel by train, is calculated as follows:

$$K_B = 0.228 \cdot \big(0.1072 \cdot 0.878 + 0.0293 \cdot 0.167 + 0.0509 \cdot 0.50 + 0.0300 \cdot 1 + 0.0276 \cdot 0.667 + 0.0401 \cdot 0 + 0.0600 \cdot 0.40 + 0.0221 \cdot 1 + 0.0219 \cdot 0.333 + 0.0467 \cdot 0.333 + 0.0180 \cdot 0 + 0.0262 \cdot 0.575 + 0.0898 \cdot 0 + 0.0587 \cdot 1 + 0.1030 \cdot 0 + 0.0560 \cdot 0.813 + 0.0794 \cdot 0.888 + 0.0507 \cdot 0.409 + 0.0826 \cdot 0.725\big) = 0.228 \cdot 0.435 = 0.099.$$

Table 2. Quality level of the criteria of group *B* and the respective value of the variable x_{Bj} based on real data

Variables x_{Bj} of the criteria of group *B* and the number of the calculation formula	The value of the component	The calculated value x_{Bj}
x_{B1} (3)	$\gamma = 0.75$; $t_{dep,l} = 5$; $t_{dep,A} = 0$; $t_{arr,l} = 5$; $t_{arr,C} = 0$; $\beta = 1.2$; $t_{arr,l_1} = 5$; $t_{arr,B_1} = 0$; $t_{dep,l_1} = 5$; $t_{dep,B_1} = 2$; $t_{arr,l_2} = 5$; $t_{arr,B_2} = 2$; $t_{dep,l_2} = 5$; $t_{dep,B_2} = 0$; $t_{arr,l_3} = 5$; $t_{arr,B_3} = 0$; $t_{dep,l_3} = 5$; $t_{dep,B_3} = 2$; $t_{arr,l_4} = 5$; $t_{arr,B_4} = 0$; $t_{dep,l_4} = 5$; $t_{dep,B_4} = 0$; $t_{arr,l_5} = 5$; $t_{arr,B_5} = 3$; $t_{dep,l_5} = 5$; $t_{dep,B_5} = 3$; $t_{arr,l_6} = 5$; $t_{arr,B_6} = 0$; $t_{dep,l_6} = 5$; $t_{dep,B_6} = 0$; $t_{arr,l_7} = 5$; $t_{arr,B_7} = 0$; $t_{dep,l_7} = 5$; $t_{dep,B_7} = 0$; $t_{arr,l_8} = 5$; $t_{arr,B_8} = 5$; $t_{dep,l_8} = 5$; $t_{dep,B_8} = 0$;	0.878
x_{B2} (5)	$PP_{f1} = 1$; $PP_{f2,...,f6} = 0$; $PP_{\max} = 1$; $n_{car} = 6$	0.167
x_{B3} (6)	$AB_{f1} = 10$; $AB_{f2,...,f6} = 4$; $AB_{\max} = 10$; $n_{car} = 6$	0.50
x_{B4} (7)	$FD_f = 3$; $FD_{\max} = 3$	1
x_{B5} (8)	$NM_f = 2$; $NM_{\max} = 3$	0.667
x_{B6} (9)	$IA_f = 0$; $IA_{\max} = 2$	0
x_{B7} (10)	$BT_f = 2$; $BT_{\max} = 5$	0.40
x_{B8} (11)	$RDC_f = 3$; $RDC_{\max} = 3$	1
x_{B9} (12)	$OT_f = 2$; $OT_{\max} = 6$	0.333
x_{B10} (13)	$PC_f = 1$; $PC_{\max} = 3$	0.333
x_{B11} (14)	$SS_f = 0$; $SS_{\max} = 1$	0
x_{B12} (15)	$RB_f = 2$ (1, 2, 6 – 14, 16, 17*); $RB_f = 3$ (3, 4, 15, 18, 20*) $RB_{f5} = 1$; $RB_{f19} = 4$; $RB_{\max} = 4$; $n_P = 20$	0.575
x_{B13} (16)	$PL_f = 0$; $PL_{\max} = 4$	0
x_{B14} (17)	$HIP_f = 2$; $HIP_{\max} = 2$	1
x_{B15} (18)	$GV_f = 0$; $GV_{\max} = 2$	0
x_{B16} (19)	$ASS_f = 3$ (1–3, 5, 7 – 10, 13, 14, 16 – 20*); $ASS_f = 4$ (4, 6, 11, 12, 15*) $ASS_{\max} = 4$; $n_P = 20$	0.813
x_{B17} (20)	$CSSP_f = 3$ (1, 7 – 10, 14 – 16, 18*); $CSSP_f = 4$ (2 – 6, 11 – 13, 17, 19, 20*) $CSSP_{\max} = 4$; $n_P = 20$	0.888
x_{B18} (21)	$KFL_f = 2$ (1, 2, 6, 9, 10*); $KFL_f = 1$ (3–5, 8, 11*) $KFL_{f7} = 3$; $KFL_{\max} = 4$; $n_{ST} = 11$	0.409
x_{B19} (22)	$COFG_f = 3$ (1–3, 8, 13, 20*); $COFG_f = 2$ (4, 7, 9, 10, 14 – 16, 18*) $COFG_f = 4$ (5, 6, 11, 12, 17, 19*); $COFG_{\max} = 4$; $n_P = 20$	0.725

Notes: $t_{arr,l_1}, t_{arr,l_2}, ..., t_{arr,l_8} = t_{dep,l_1}, t_{dep,l_2}, ..., t_{dep,l_8}$ denote the delay time tolerance of arrival or departure at/from an intermediate station (5 min);
t_{arr,B_1}, t_{arr,B_2}, ..., t_{arr,B_8} denote the delay time of the arrival at the intermediate station *B* (b = 8);
t_{dep,B_1}, t_{dep,B_2}, ..., t_{dep,B_8} denote the delay time of the departure from the intermediate station *B* (b = 8);
*denotes the estimate in points given by the *i*-th respondent.

The obtained index of the set of criteria describing organization and technology of travel by train is K_B = 0.099. The significance of the criteria of other groups (*A*, *C*, *D*) for the CQI component *K* will be determined by using other additive models in further publications of the author. Calculation models of international train routes quality indicator *K* and its constituents K_A, K_C, K_D will be provided in other publications.

5. Conclusions

1. The quality of travel by train is described by a set of criteria, reflecting the parameters of the railway lines and rolling stock (elements of the train) and organization and technology of passenger transportation, as well as the cost and safety of the trip by train. Nineteen out of 49 criteria, making 4 groups, associated with organization and technology of travel by train, which are considered in the present paper.

2. The developed original additive mathematical model is used for calculating the values of each of the 19 criteria based on the criterion's normalized weight coefficient multiplied by its variable, showing the correspondence of the criterion variable to specified, critical, the highest, admissible or the best values. Comparing the real (actual) values of the criterion variable with the specified, critical, the highest, admissible and the best values, the value, showing the closeness of a particular criterion describing the trip by train to the best level sought (when its value is equal to one) and the worst inadmissible level (when its value is about 0), is calculated.
3. The use of a multicriteria model allows for evaluating the quality of travel by train objectively and expressing it in a single value. The value of K_B, calculated based on the values of the real parameters, allows the authors to state that the suggested mathematical model is valid and can be used in practice. The significance of the criteria, describing organization and technology of travel by train for the comprehensive quality index K_B, may be evaluated by determining only the variables x_{Bj} and using them in the suggested mathematical model.
4. The highest quality level, determined by using the real data, was obtained for the criteria $B4$ ($x_{B4} = 1$), $B8$ ($x_{B8} = 1$) and $B14$ ($x_{B14} = 1$). The lowest quality level, determined by using the real data, was obtained for the criteria $B6$ ($x_{B6} = 0$), $B11$ ($x_{B11} = 0$), $B13$ ($x_{B13} = 0$) and $B15$ ($x_{B15} = 0$). The average quality level was determined, based on the real data, for B3 ($x_{B3} = 0.50$). First, the real values of the criteria, whose variables $x_{Bj} = 0$ or are about zero, should be improved.

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