THE NUMERICAL EXAMPLE FOR EVALUATING THE CRITERIA DESCRIBING THE QUALITY OF THE TRIP BY INTERNATIONAL TRAIN

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Introduction

The main criteria, describing the development of railway systems refer to traffic safety, sustainability, competitiveness as well as quality and variety of services provided to passengers.

In the new age of railway transportation, the main task is to ensure a safe use of railway infrastructure, which should meet the requirements of safety standards. A set of programmes most suitable for ensuring railway track safety were developed [26]. A bottleneck optimization model to increase the carrying capacity by reasonably arranging routes and turnouts, and considering proportionality and minimization of total occupation time was offered [12]. A simplified approach to assessing the initial fire development and spread in passenger rail vehicles was suggested [16], and the development of the next generation of intercity corridor bi-level equipment with crash energy management was described [13]. The hunting stability and derailment analysis of a carriage model of a railway vehicle system was performed [1], and a short-range prediction model for track quality index was offered [27].

The economic impacts of intercity passenger rail service (evidence from passenger surveys) [23] and optimal train operation for minimum energy consumption, considering track alignment speed limit, and schedule adherence were analysed [7]. Cluster analysis of intercity rail passengers in emerging high-speed rail corridor was performed [24] and rail transit travel time reliability and estimation of passenger route choice behaviour (the analysis using

automatic fare collection data) were described [25]. The value for railway capacity, assessing the efficiency of operators in Great Britain was determined [20], and the development of base train equivalents to standardize trains for capacity analysis was described [9]. A comprehensive decision support framework of strategic railway capacity planning was developed [8]. Over the preceding years, transit agencies in the United States have been building light rail transit (LRT) or bus rapid transit (BRT) systems to provide an effective and reliable high-speed transit service. However, the selection between LRT and BRT has been controversial for many years, with no suitable closure. A cost estimating model was developed for LRT and bus rapid transit BRT systems to better aid transportation planners and decision makers in the selection [6].

Public rail transport planning is a highly complex task, and it is divided into several steps: analysis of demand, line planning, train scheduling planning, planning of rolling stock, and crew management. A train routing model combined with a train scheduling problem, which is a 0–1 mixed-integer nonlinear programming problem, was offered [10]. Transportation infrastructure management is a decision-making process concerning the allocation of resources for maintenance, rehabilitation, and reconstruction of facilities composing transportation systems. Numerical experiments were presented to examine the effects of economic and functional interdependencies on network optimization and demonstrate the validity of the proposed model [4]. The railway blocking problem (RBP) solution is important for freight

railway companies. A mathematical model was presented for the RBP by Iran Railways. Solving the blocking problem considerably reduces the operational cost of railways and saves time in moving the freights [28]. The configuration of service facilities, such as ticket vending machines, staffed ticket booths, automatic fare gates, and escalators, is an important issue for planning and design of rail transit stations. Reasonable configuration of service facilities is based on thorough understanding of passenger traffic characteristics of these service facilities, which are affected by passenger characteristics, station types, and facility performance. The traffic characteristics of service facilities were analysed and the influencing factors (for example, station types, passenger gender, and passenger experience) were considered [11].

Also, it is very important to control complicated processes, the analysis of activities, aims and tasks, as well as methods of their fulfilment, in order to be performed. The influence of various factors on work efficiency and quality should be also evaluated. To make effective decisions in technological and management, engineering economics areas, etc., AHP, TOPSIS and TOPSIS grey, FAHP [31], [32], [5], [29], [30], SAW and COPRAS [18] method are commonly used.

2. Passenger Services

In 2012, joint-stock company (JSC) "Lithuanian Railways" (AB "Lietuvos geležinkeliai" – "LG") passenger trains operated on 52 domestic lines and on 18 international lines: 183 trains on domestic lines and 4 trains (made up by the company) on international lines. A total of 22 trains of the railway undertakings from other countries came to Lithuania or passed the territory of this country in transit.

Compared to 2011, passenger revenues had risen by 5.9% in 2012 (Fig. 1) [17].

Fig. 1:	Passenger revenues in 2011–2012 (mil)
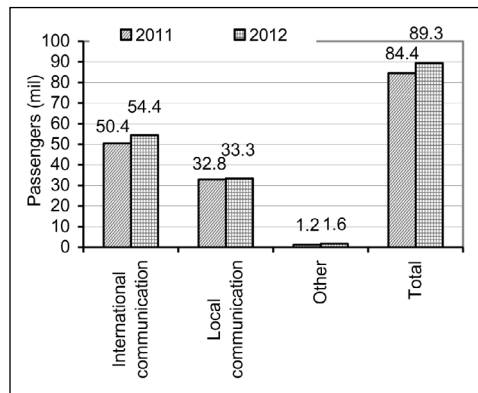
Source: Metinė ataskaita. (Annual report) 2012

Within the framework of the passenger loyalty programme different discounts on tickets were offered and campaigns conducted in 2012: a 20% discount was applied during holidays (Cristmas, Easter, St. John's Day etc.), and a 30% discount on tickets was applied during a campaign targeted at the young people aged 10–26 to travel by train at reduced prices [17].

Tab. 1:	Passenger flows in 2008–2012

	Year				
	2008	**2009**	**2010**	**2011**	**2012**
Payload quantity, mil passengers	5.1	4.4	4.4	4.7	4.8
local	4.1	3.5	3.5	3.8	3.8
international	1.0	0.9	0.9	0.9	1.0
Revenue passenger kilometres, mil	397.5	357.0	373.1	389.1	403.2
local	235.3	213.4	225.6	248.5	254.5
international	162.2	143.6	147.5	140.6	148.7
Average distance per passenger, km	78.5	81.6	85.5	83.6	84.0
Average number of trips per inhabitant of the country	2	1	1	1	2

Source: Metinė ataskaita. (Annual report) 2012

As shown in Table 1, the flows of passengers hardly changed.

Passenger revenues accounted for 5.1% in the total revenue structure in 2012, a rise of 5.9% over the previous year. This was due to the increased passenger flows on international lines [17], especially on the route Vilnius–Minsk–Vilnius where passenger flows grew twofold.

3. Practical Application of the Model

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 [15], 49 QTT criteria belonging to four various groups A, B, C, D (Fig. 2) are considered. Their average weights are determined by using the expert evaluation method. The weights of 16 criteria, belonging to group A, and de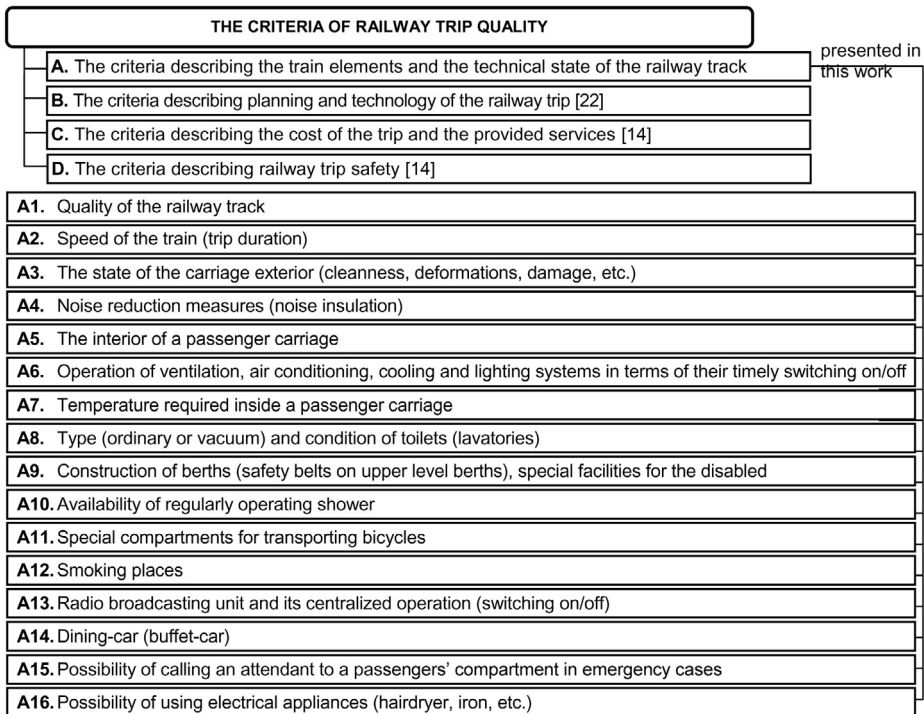scribing the train elements and technical state of rails (railway track), were obtained from the survey of experts, when three categories of respondents – passengers (P) and experts, including the service staff of the train (ST) and the administration staff (AS) of the joint-stock company 'Lithuanian Railways' (AB „Lietuvos geležinkeliai" – "LG"), provided their judgements.

The model for calculating the criteria, describing the train elements and technical state of the railway track based on the mean weight $\bar{Z}_A^*$ and the mean weight of each criterion $\bar{Q}_{Aj}$ (expressing the estimates of the significance of group A criteria, elicited from all three categories of respondents and experts) is expressed by the equation:

$$K_A = \bar{Z}_A^* \, (\bar{Q}_{A1} \times x_{A1} + \bar{Q}_{A2} \times x_{A2} + \dots + \\ + \bar{Q}_{A16} \times X_{A16}), \qquad (1)$$

where K_A is a comprehensive quality index (CQI) of the international train (ranging from 0 to 1); $\bar{Z}_A^*$ is the mean weight, reflecting the

Fig. 2: Components of quality criteria groups A, B, C, D, describing the railway trip quality

THE CRITERIA OF RAILWAY TRIP QUALITY

presented in this work

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

B. The criteria describing planning and technology of the railway trip [22]

C. The criteria describing the cost of the trip and the provided services [14]

D. The criteria describing railway trip safety [14]

A1. Quality of the railway track

A2. Speed of the train (trip duration)

A3. The state of the carriage exterior (cleanness, deformations, damage, etc.)

A4. Noise reduction measures (noise insulation)

A5. The interior of a passenger carriage

A6. Operation of ventilation, air conditioning, cooling and lighting systems in terms of their timely switching on/off

A7. Temperature required inside a passenger carriage

A8. Type (ordinary or vacuum) and condition of toilets (lavatories)

A9. Construction of berths (safety belts on upper level berths), 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 electrical appliances (hairdryer, iron, etc.)

Source: own

respondents' and experts' estimates of the significance of group A criteria; $\bar{Q}_{A1}, ..., \bar{Q}_{Am}$ denote the mean weight values of j-th criterion of group A (1, …, m) determined by the expert evaluation method [21], [14] $x_{A1},...,x_{Am}$ are the variables of j-th criterion of group A (1, …, m),

whose estimates are used for determining the real criterion value, ranging from 0 to 1.

The multicriteria index K_A [15], describing the criteria associated with the train elements and railway track condition, is calculated by the additive equation 2.

$$K_A = \bar{Z}_A^* \cdot \left(\bar{Q}_{A1} \cdot \left[0.997 + 0.00245 \cdot \frac{\sum_{s=1}^{N_{km}} TQI_{fs}}{N_{km}} - 0.000962 \cdot \left(\frac{\sum_{s=1}^{N_{km}} TQI_{fs}}{N_{km}} \right)^2 + 1.532 \cdot 10^{-5} \cdot \right. \right.$$

$$\left. \left(\frac{\sum_{s=1}^{N_{km}} TQI_{fs}}{N_{km}} \right)^3 - 6.99 \cdot 10^{-8} \cdot \left(\frac{\sum_{s=1}^{N_{km}} TQI_{fs}}{N_{km}} \right)^4 \right] + \bar{Q}_{A2} \cdot \frac{\sum_{l=1}^{n_{stage}} \left(1 - \frac{|\Delta v_f|}{v_{max,l}}\right) \cdot l_l}{\sum_{l=1}^{n_{stage}} l_l} + \bar{Q}_{A3} \cdot \frac{\sum_{c=1}^{n_{car}} \left(\frac{CES_f}{CES_{max}}\right)_c}{n_{car}} +$$

$$\bar{Q}_{A4} \cdot \left(1 - \frac{\sum_{c=1}^{n_{car}} \left(\frac{NL_f}{NL_{max}}\right)_c}{n_{car}}\right) + \bar{Q}_{A5} \cdot \frac{\sum_{c=1}^{n_{car}} \left(\frac{CI_f}{CI_{max}}\right)_c}{n_{car}} + \bar{Q}_{A6} \cdot \frac{\sum_{c=1}^{n_{car}} \left(\frac{VCL_f}{VCL_{max}}\right)_c}{n_{car}} + \bar{Q}_{A7} \cdot \left(1 - \frac{\sum_{c=1}^{n_{car}} \left(\frac{\left|\frac{T_U + T_D}{2} - \bar{T}_f\right|}{T_U - T_D}\right)_c}{n_{car}}\right) +$$

$$\bar{Q}_{A8} \cdot \frac{\sum_{c=1}^{n_{car}} \left(\frac{WC_f}{WC_{max}}\right)_c}{n_{car}} + \bar{Q}_{A9} \cdot \frac{\sum_{c=1}^{n_{car}} \left(\frac{PB_f}{PB_{max}}\right)_c}{n_{car}} + \bar{Q}_{A10} \cdot \frac{\sum_{c=1}^{n_{car}} \left(\frac{S_f}{S_{max}}\right)_c}{n_{car}} + \bar{Q}_{A11} \cdot \frac{TB_f}{TB_{max}} + \bar{Q}_{A12} \cdot \frac{SP_f}{SP_{max}} +$$

$$\bar{Q}_{A13} \cdot \frac{\sum_{c=1}^{n_{car}} \left(\frac{R_f}{R_{max}}\right)_c}{n_{car}} + \bar{Q}_{A14} \cdot \frac{DC_f}{DC_{max}} + \bar{Q}_{A15} \cdot \frac{\sum_{c=1}^{n_{car}} \left(\frac{AC_f}{AC_{max}}\right)_c}{n_{car}} + \bar{Q}_{A16} \cdot \frac{HI_f}{HI_{max}} \right).$$

(2)

where K_A is a comprehensive quality index (CQI) of the international train (ranging from 0 to 1); $\bar{Z}_A^*$ is the mean weight, reflecting the respondents' and experts' estimates of the significance of group A criteria; $\bar{Q}_{A1}, ..., \bar{Q}_{Am}$ denote mean weight values of j-th criterion of group A (1, …, m) determined by the expert evaluation method; TQI_f is the real track quality index TQI for the whole railway track determined by the track geometry car; N_{km} is the total length of the railway track, km (s = 1, 2, ..., N_{km}); n_{stage} is the number of railway track sections between stations (l = 1, 2, ..., r); Δv_f is the real and the highest allowable speed

difference of the train at the l-th section of the distance between two stations, km/h; $v_{max,l}$ is the highest allowable speed of a train at the l-th section of a journey, km/h; l_l denotes the lengths of the sections of a journey, km; CES_f is the real condition (cleanness, damages) of the c-th carriage expressed in points (0, 1 or 2 points); CES_{max} is the highest estimate value of the carriage in points (2 points); n_{car} is the number of carriages in the train (c = 1, 2, ..., n_{car}); NL_f is the real noise level in the c-th carriage, dBA; NL_{max}, a is the allowable noise level in the c-th carriage, dBA; CI_f is the real estimate of the c-th carriage interior in points

(0, 1 or 2 points); CI_{max} is the maximum allowable carriage interior estimate value in points (2 points); VCL_f is the estimate (in points) of the operation of the c-th carriage systems (0, 1, 2, 3 or 4 points); VCL_{max} is the highest possible estimate of the systems operating in the carriage (4 points); T_D is the lowest allowable carriage temperature, °C. In winter, when solid fuel is burned and the outdoor temperature is not lower than –40 °C and not higher than +10 °C, $T_D = 18$ °C, while when water is heated by electricity, $T_D = 20$ °C (the temperature of (22 ± 2) °C should be automatically maintained). In summer, when air-conditioning is used, the temperature of (24 ± 2) °C should be automatically maintained, therefore, $T_D = 22$ °C [3]; T_U is the highest allowable temperature inside a passenger carriage (+26 °C). In winter, when the outdoor temperature is not lower than –40 °C and solid fuel is used for heating, $T_U = +22$ °C, while when water is heated by electricity, $T_U = 24$ °C (the temperature of (22 ± 2) °C should be automatically maintained); $\bar{T}_f$ is the average temperature in the c-th carriage, measured n_T times at various places of the carriage during the trip (equation 4); WC_f is the estimate of the real condition of lavatories in the c-th carriage, expressed in points (0, 1, 2, 3 or 4 points); WC_{max} is the highest possible estimate (in points) of the c-th carriage (4 points); PB_f is the estimate in points (0, 1, 2, 3 or 4 points) of the berth structure in the c-th carriage (the availability of safety belts on the upper level berths) and the adaptation of a passenger carriage for the disabled passengers; PB_{max} is the highest possible estimate (4 points) of the berth structure (the availability of safety belts on the upper level berths) and the adaptation of a passenger carriage for the disabled passengers; S_f is the estimate of shower equipment availability and its work hours in the c-th carriage in points (0, 1 or 2 points); S_{max} is the highest possible estimate of shower equipment availability and its work hours (2 points); TB_f means the presence or absence of a special carriage or compartment for carrying bicycles in the train and the evaluation of transportation conditions in points (0, 1, 2 or 4 points); TB_{max} is the highest estimate of the conditions for carrying bicycles in the train (4 points); SP_f is the estimate of smoking places in the train in points (0, 1 or 2 points); SP_{max} is the highest possible estimate of smoking places in the train (2 points); R_f is the estimate in points (0, 1, 2, 3 or 4 points) of operation of the radio broadcasting unit in the c-th carriage and its centralized on/off switching; R_{max} is the highest possible estimate of the radio broadcasting unit operation and centralized on/off switching (4 points); DC_f is the estimate of the dining car availability and the provided services in points (0, 1, 2, 3, 4, 5, 6, 7 or 8 points); DC_{max} is the highest possible estimate of the dining car availability and the provided services (8 points); AC_f is the estimate in points (0, 1 or 2 points) of the possibility to call the conductor to a passenger's compartment of the c-th carriage in the case of emergency; AC_{max} is the highest possible estimate of the possibility to call the conductor to a passenger's compartment in the case of emergency (2 points); HI_f is the estimate of the possibility for passengers to use a hairdryer and an iron in the train expressed in points (0, 1, 2, 3 or 4 points); HI_{max} is the highest estimate of the possibility for passengers to use a hairdryer and an iron in the train (4 points).

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

Using the formulas suggested in the paper, all CQI components (16 criteria) and their significance may be calculated based on the real data taken from standards, technical specifications and other reliable sources. The testing was performed on the train 'Vilnius–Moscow'.

Quality of the railway track. The joint-stock company 'Lithuanian Railways' ("LG") uses a self-propelled geometry car EM-140 made in 2009 by the Plasser&Theurer company (Austria) for measuring geometrical parameters of the railway track. The geometrical railway track parameters measured by the geometry car and stored on a storage device are as follows: gauge, mutual position of the rails with respect to the rail head level, the rails' dents, the position of the rails in the plan view, curves' radii, misalignments, the allowable speed on the curve of a railway, elevation of the slope of the outer rail and the longitudinal slope of the railway track. All geometrical railway track

parameters are obtained by precise measuring of the spatial curve of the track.

On the route Vilnius-Moscow, the total length of which is 944 km, the railway double track, running on the territory of Lithuanian Republic from Vilnius to the frontier with Belarus at Kena, makes 36 km. The average $\overline{TQI}_f$, measured by a geometry car in January, 2012 for the railway track running through Vilnius–Kena–State frontier, was calculated by the formula based on TQI_{fs} of all one-kilometre track lengths as follows:

$$\overline{TQI}_f = \frac{\sum\limits_{s=1}^{N_{km}} TQI_{fs}}{N_{km}}, \qquad (3)$$

where TQI_{fs} is quality index of the s-th 1 km track length, with the numerical value equal to the total variance (the sum of σ_g^2) of separate g-th track geometrical parameters, mm2 ($s = 1, 2, ..., N_{km}$; $g = 1, 2, ..., 7$); N_{km} is the total track length, km.

The total TQI of all track lengths making 36 km on the route Vilnus–Kena–State frontier (with Belarus) is $\sum\limits_{s=1}^{36} TQI_{fs} = 903.2$ mm2, $N_{km} = 36$ km, o $\overline{TQI}_f = 25.09$ mm2. The smallest TQI_{fmin} value obtained for 1 km track length was $TQI_{fmin} = 14.95$ mm2, while the largest value was $TQI_{fmax} = 64.04$ mm2.

Based on the standard TQI_{norm} (from 0 to 45 mm2) and modelled TQI_{mod} (from 45 to 90 mm2) values, the correlation (with determination coefficient R2 = 0.9961) between the real TQI_f and the variable x_{A1} of the first group A criterion, showing the effect of variation of geometric track parameters on the track and trip (by train) quality, has been obtained:

$$x_{A1} = 0.997 + 0.00245 \times \overline{TQI}_f - 0.000962 \times \overline{TQI}_f^2 + 1.532 \times 10^{-5} \times \overline{TQI}_f^3 - 6.99 \times 10^{-8} \times \overline{TQI}_f^4. \qquad (4)$$

Given the average $\overline{TQI}_f = 25.09$ mm2 of the track measured by a geometry car, the value $x_{A1} = 0.667$, which was obtained from the regression equation (4), complies with good quality of travel by train, depending on track parameters, determining its quality.

Speed of the train (trip duration). The railway track on the route Vilnius–Kena–state border (with Belarus) consists of 4 sections of a journey (representing the lengths between the stations) (Fig. 3). The total length of the railway track is $L = 36$ km. The lengths between intermediate stations are $l_1 = 9$ km, $l_2 = 8$ km, $l_3 = 12$ km and $l_4 = 7$ km ($L = l_1 + l_2 + ... + l_i$). The highest allowable train speed on the route (railway track) Vilnius–state border is $v_{max,l} = 120$ km/h [2]. The engine driver had a written instruction that, on May 17, 2012, the train speed on the route Kena–state border had to be limited to 40 km/h. The real train speed on the sections of the considered railway track was $v_{f1} = 43$ km/h, $v_{f2} = 77$ km/h, $v_{f3} = 57$ km/h and $v_{f4} = 51$ km/h (the average speed was recorded based on the data provided by the control panel screen of the railway carriage). The CQI component was calculated by equation (2) and $x_{A2} = 0.473$ was obtained. In the ideal case, the train could move at the highest allowable speed ($x_{A2} = 1$) on all railway track sections. In the worst case, it could either exceed the highest allowable speed, which is risky (taking into account traffic safety), or move very slowly. Therefore, it is assumed that $x_{A2} = 0$.

The condition of passenger carriage exterior (cleanness, deformations, damages, etc.). There are seven railway carriages in the train. All railway carriages are washed before the train departs from the station of its formation, therefore, they are clean. There are no damages on carriages' bodies either. The CQI component was calculated by equation (2) and the maximum $x_{A3} = 1$ was obtained.

Noise reduction measures (noise insulation). On November 24, 2005, the department of passenger servicing of the Directorate for Passenger Transportation by the JSC "Lithuanian Railways" – "LG" specified the equivalent noise exposure level in the train Vilnius–Moscow (for the conditions, when two conductors work in one passenger carriage) to be equal to 72 dB (A), fixing it in the card for determining occupational risk. In the dining car of this train, the equivalent noise level at the workplace of the conductor-waiter (a bar) was specified to be 62 dB (A) [19]. According to time characteristic, noise produced in the train is variable (≥ 5 dB). The train has seven railway carriages. The CQI component was calculated
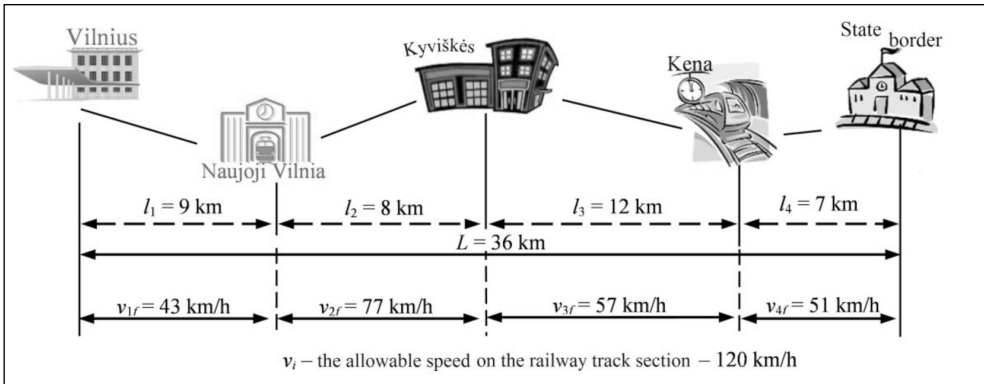
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by equation (2) and $x_{A4} = 0.188$ was obtained. In the ideal case, the noise level is equal to 0 dB (A) ($x_{A4} = 1$), while, in the worst case, when the noise level exceeds the limiting noise exposure value, a negative value is obtained. It is considered that $x_{A4} = 0$.

The interior of a passenger carriage. The renewal of the company's rolling stock (particularly, passenger carriages) is performed in two ways: a) the service life of the employed passenger carriages is prolonged (by their modernization); b) new passenger carriages are purchased. To validate the suggested model for evaluating passenger carriage interior and to show its applicability, it was tested in the international train Vilnius–Moscow on November 20, 2010. The train is made up of 7 railway carriages, including 4 new and 3 modernized carriages. The CQI component was calculated by equation (2) and $x_{A5} = 0.786$ was obtained.

Operation of ventilation, air conditioning, cooling and lighting systems in terms of their timely on/off switching. There are seven railway carriages in the train. Air conditioning systems are installed in all railway carriages, running on international routes. In six carriages, all systems, including air conditioning, ventilation, heating and lighting systems, are operating, while, in one carriage, all systems, except for air conditioning system, which has

not been installed yet, are operating. The CQI component was calculated by equation (2) and $x_{A6} = 0.964$ was obtained.

Temperature required inside a passenger carriage. The train has seven railway carriages. On March 22 and 24, 2012, the indoor temperature was measured in a four-berth compartment of a sleeping carriage from 4:00 p.m. to 7:00 a.m. Sixty one measurements were made with the interval of 15 minutes in compartments 1 and 9. The indoor temperature in the carriage was measured by a digital thermometer (TA20) for measuring indoor and outdoor temperature. The ambient air temperature was recorded based on the data displayed on the screen of the control panel of the carriage. The change of the outdoor and indoor temperature is shown in Figs 4 (a, b).

At the time of measuring (Figs 5 and 6), the average outdoor temperature was 7.23 °C and 3.35 °C, i.e. higher than –40 °C. It is assumed that the dates of measurement belong to the winter period.

$\bar{T}_f$ is the average temperature in the c-th carriage, measured n_T times at various places of the carriage during the trip:
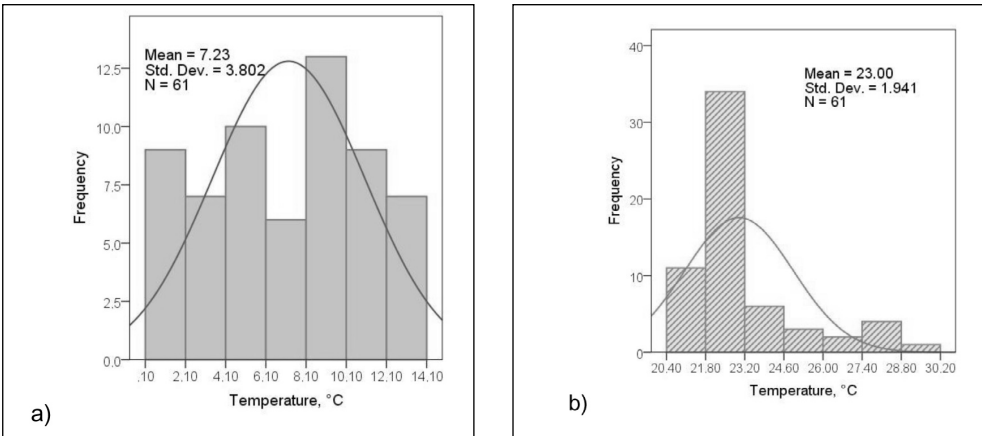
$$\bar{T}_f = \frac{\sum_{t=1}^{n_T} T_{ft}}{n_T}, \qquad (5)$$

Fig. 4: The change of the outdoor and indoor temperature: a – in the passenger carriage compartment 1 (on March 22, 2012); b – in the passenger carriage compartment 9 (on March 24, 2012)

a)

b)
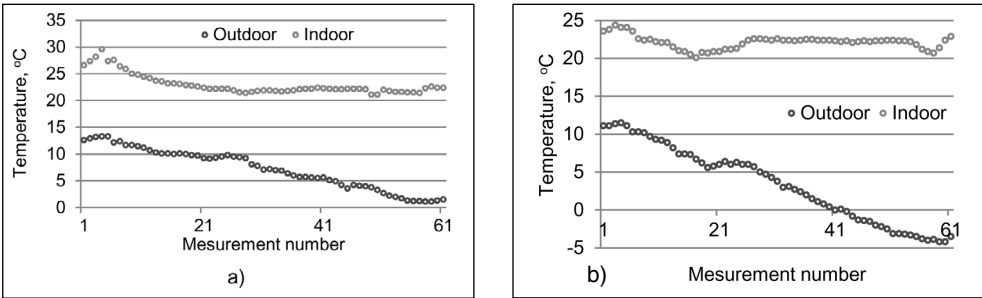
Source: own

Fig. 5: The histogram and statistical data of the outdoor (a) and indoor (b) temperature (in the passenger carriage compartment 1), measured on March 22, 2012

a)

b)

Source: own

where T_{ft} is the temperature obtained in the t-th measurement, °C; n_T is the number of temperature measurements ($t = 1, 2, ..., n_T$).

The average indoor temperature in the carriage measured on March 22 was 23 °C

(equation 4) $\left(\overline{T}_f = \dfrac{1402.7}{61} = 23 \right)$ (Fig. 4 (b)),

while, on March 24, it was 22 °C

$\left(\overline{T}_f = \dfrac{1350.3}{61} = 22.14 \right)$ (Fig. 6 (b)). By

interpolating the data from the graph (Fig. 5), the quality level was obtained to be $x_{A7} = 0.750$,

while, on the following day (Fig. 6), it was $x_{A7} = 0.965$. The case with real data from equation (2) for winter season was calculated (when water in all passenger carriages was heated by electricity obtained from the high-voltage (3000 V) overhead contact system). Based on the measurement of the indoor temperature in the compartment 1 (the first day), it was determined that $x_{A7} = 0.75$ ($T_U = 24$, $T_D = 20$, $\overline{T}_f = 23$), while for the compartment 9 (the second day) $x_{A7} = 1$ ($T_U = 24$, $T_D = 20$, $\overline{T}_f = 22$) was obtained. This is an ideal case.

The limiting case, with $x_{A7} = 0.5$, when $T_U = 24$, $T_D = 20$ and $\overline{T}_f = 20$, and a critical (not allowable) case, with $x_{A7} = 0$ when $T_U = 24$, $T_D = 20$ and $\overline{T}_f = 18$, are calculated for winter period (when water in all passenger carriages was heated by electricity obtained from the high-voltage (3000 V) overhead contact system).

The worst case ($x_{A7} = 0$) is obtained, when $\overline{T}_f$ is by 2 °C lower than the lower allowable limit T_D, or when $\overline{T}_f$ is by 2 °C higher than the upper allowable limit T_U. If $\overline{T}_f$ is lower than T_D by more than 2 °C or higher than T_U by 2 °C, the value of x_{A7} will be negative. Therefore, it is assumed that $x_{A7} = 0$.

Fig. 6:	**The histogram and statistical data of the outdoor (a) and indoor (b) temperature (in the passenger carriage compartment 9), measured on March 24, 2012**

a)

Source: own

b)
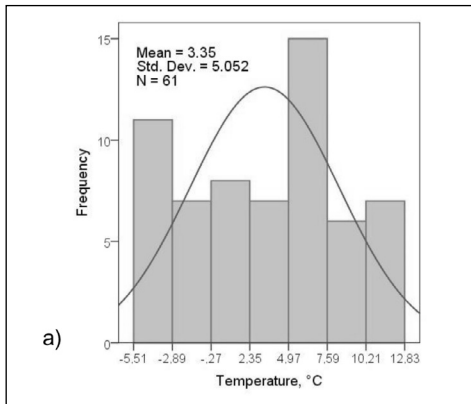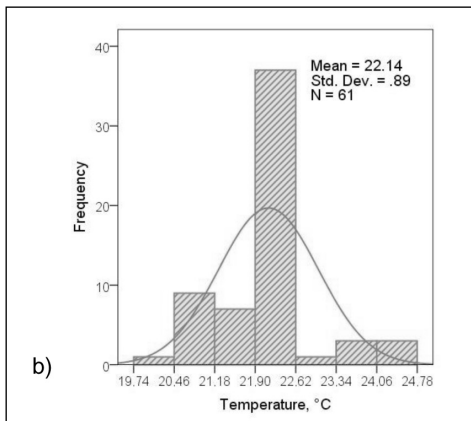
Source: own

Type (ordinary or vacuum) and condition of toilets (lavatories). Now, 70% of the employed passenger carriages of the "LG" company have vacuum toilets. It is planned that in 2–4 years ecological toilet equipment will be installed in all passenger carriages. The train has seven railway carriages. In six carriages, there are vacuum toilets, which are properly maintained (the head of the train controls their condition), while the toilets in the first car are ordinary, but clean. The CQI component was calculated by equation (2) and $x_{A8} = 0.893$ was obtained.

The availability of safety belts on the upper births and special facilities for the disabled. In some passenger carriages of the JSC "Lithuanian Railways" ("LG"), the upper berths have special holders, while, in ordinary sleeping carriages, safety belts are available for passengers. Some passenger, diesel and electric trains are adapted for special needs of disabled passengers. The trains have special places for their wheelchairs, as well as toilets adapted for disabled persons and enlarged doorways. The number of such passenger carriages is constantly growing because, when new carriages are purchased or the old ones are modernized, special needs of disabled passengers are taken into account. The wheelchairs with disabled persons are raised to the level of the carriage entrance by mobile hoists, available at large railway stations. The train has six carriages (not including the dining car). In five passenger carriages the upper layer berths are provided with safety belts, though these carriages are not adapted for the disabled. The first carriage has only lower berths, therefore, safety belts are not needed there. This carriage is not adapted for disabled passengers either. The CQI component was calculated by equation (2) and $x_{A9} = 0.333$ was obtained.

Availability of regularly operating shower. Currently, no shower facilities are available in the passenger carriages of the JSC "Lithuanian Railways" ("LG"), though they are urgently needed for both passengers and service staff of international long-distance trains. The CQI component was calculated by equation (2) and the critically low $x_{A10} = 0$ was obtained.

Special compartments for transporting bicycles. The international trains of the JSC "Lithuanian Railways" ("LG") do not have any

carriages adapted for carrying bicycles. However, the regulations allow for carrying one engineless knocked-down and packed bicycle if there is room for it in a special compartment for hand luggage. In this case, the service is provided to passengers free of charge. The CQI component was calculated by equation (2) and $x_{A11} = 0.50$ was obtained.

Smoking places. The Lithuanian law of tobacco control prohibits smoking of cigarettes (or other tobacco products) in public transport (except for long-distance trains, which should have carriages for smokers and non-smokers). In passenger carriages of international trains of the JSC "Lithuanian Railways" ("LG"), smoking is allowed only in special vestibules. Some passengers object to it because smoke often penetrates through poorly sealed or open doors and gets into the corridor and compartments of the carriage. The experiment was made in the train Vilnius–Moscow to determine the influence of smoking, according to the above-mentioned regulations, on travel quality. The CQI component was calculated by equation (2) and $x_{A12} = 0.50$ was obtained.

Radio broadcasting unit and its centralized operation (on/off switching). Volume controls of the train radio are provided in the compartments and corridors of carriages. At present, passengers can also use headphones in the compartments of new carriages made at the plant of railway carriages in Tver (Russia). If headphones are not available in a carriage (because the conductor did not hand them out to passengers), they may listen to the radio if they wish. In these passenger carriages, the radio is switched on and off by the button located in the conductor's compartment, though it cannot be used for volume control. When the train departs from the main station, passengers often ask the conductor to switch off the radio because it is too loud and, therefore, do not hear any information on the route of the train provided by the head of the train. The train has six carriages (not including the dining car). The CQI component was calculated by equation (2) and $x_{A13} = 0.50$ was obtained.

Dining-car (buffet-car). All international trains of the JSC "Lithuanian Railways" ("LG") have dining cars. Strong drinks are served there. For economic reasons, a waiter can be rarely found in the dining car. Usually, self-service is used or the conductor of a dining car provides the waiter's services. The conductors of passenger carriages offer tea, coffee, soft drinks and pastries to passengers. If a passenger wishes, the conductor should bring him/her the required dish or drink from the dining car. The CQI component was calculated by equation (2) and $x_{A14} = 0.875$ was obtained.

Possibility of calling a conductor to a passengers' compartment in emergency cases. At present, the buttons for calling a conductor to the compartment in the case of emergency cannot be found in all carriages of the train. In all new passenger carriages made at the plant in Tver (Russia), there is a possibility to call a conductor to the compartment. However, push buttons, providing the connection with the conductor, function only if a magnetic card is inserted in the magnetic card reader. Now, these cards are still not available, therefore, passengers cannot call a conductor to the compartment. The train has six carriages (not including the dining car). The CQI component was calculated by equation (2) and $x_{A15} = 0.417$ was obtained.

Possibility of using electrical appliances (hairdryer, iron, etc.). The trains made up in Lithuania do not have any compartments, where passengers could use a hairdryer or an iron. The CQI component was calculated by equation (2) and $x_{A16} = 0.25$ was obtained.

The quality level of the criteria of group A, and the respective x_{Aj} value based on the real data are presented in Table 2. The quality level represented by the estimate of the variable x_{Aj} is equal to 1, when it is based on the highest values of the real data, it is equal to 0.5, when based on the average values, and to 0, when based on the lowest values of the data.

Using the equation (2), the index K_A of the criteria describing the train elements and the technical state of rails (railway track) is calculated as follows:

$$K_A = 0.228 \times (0.0411 \times 0.667 + 0.1035 \times$$
$$\times 0.473 + 0.0307 \times 1 + 0.0716 \times 0.188 +$$
$$+ 0.0560 \times 0.786 + 0.0997 \times 0.964 + 0.1042 \times$$
$$\times 0.75 + 0.0813 \times 0.893 + 0.0624 \times 0.333 +$$
$$+ 0.0709 \times 0 + 0.0345 \times 0.50 + 0.0360 \times$$
$$\times 0.050 + 0.0450 \times 0.50 + 0.0822 \times 0.875 +$$
$$+ 0.0359 \times 0.417 + 0.0452 \times 0.25) =$$
$$= 0.228 \times 0.58807 = 0.1341.$$

The index referring to the criteria, describing the elements of the train and the condition of the railway track, was obtained to be $K_A = 0.134$. The influence of the criteria of group B on CQI K was evaluated by an additive model and $K_B = 0.099$ was obtained [22]. The influence of the criteria of the groups C and D on CQI K can be evaluated by other additive models, which will be described in further publications.

Fig. 7: Mean weight values $\bar{Q}_{Aj}$ of j-th criterion of group A, determined by AHP method
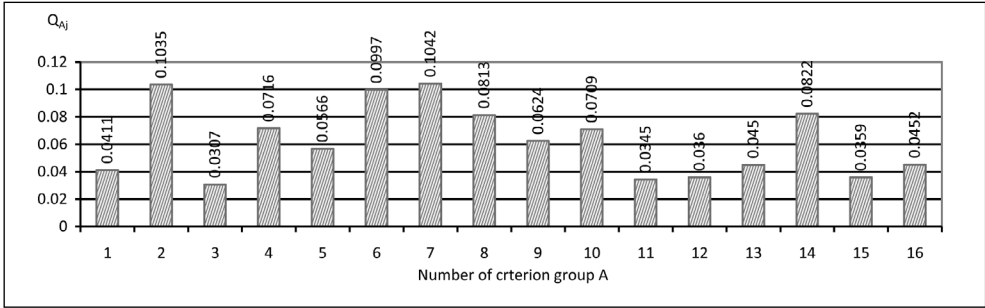
Source: own

Tab. 2: Quality level of the criteria of group A and the respective value of the variable x_{Aj} based on real data

Variables x_{Aj} of the criteria	The value of the component	The calculated value x_{Aj}
x_{A1}	$\sum_{s=1}^{36} TQI_{fs} = 903.2\,\text{mm}^2$; $N_{km}=36$; $\overline{TQI}_f = 25.09\,\text{mm}^2$ $TQI_{f\,max} = 64.04\,\text{mm}^2$; $TQI_{f\,min} = 14.95\,\text{mm}^2$	0.667
x_{A2}	$l_1 = 9\,\text{km}$, $l_2 = 8\,\text{km}$, $l_3 = 12\,\text{km}$, $l_4 = 7\,\text{km}$ ($L = 36$) km; $v_{max,l} = 120\,\text{km/h}$; $v_{f1} = 43\,\text{km/h}$ $v_{f2} = 77\,\text{km/h}$, $v_{f3} = 57\,\text{km/h}$, $v_{f4} = 51\,\text{km/h}$	0.473
x_{A3}	$CES_f = 2\,(1,2,...,7^*)$; $CES_{max} = 2$; $n_{car} = 7$	1
x_{A4}	$NL_f = 72\,\text{dB}\,(1,2,...,6^*)$ $NL_f = 62\,\text{dB}\,(7^*)$; $NL_l = 87\,\text{dB}$; $n_{car} = 7$	0.188
x_{A5}	$Cl_f = 2\,(1,2,3,4^*)$; $Cl_f = 1\,(5,6,7^*)$ $Cl_{max} = 2$; $n_{car} = 7$	0.786
x_{A6}	$VCL_f = 4\,(1,2,...,6^*)$; $VCL_f = 3\,(7^*)$ $VCL_{max} = 4$; $n_{car} = 7$	0.964
x_{A7}	$T_U = 24$; $T_D = 20$; $\overline{T}_f = 23$; $n_{car} = 7$	0.75
x_{A8}	$WC_f = 4\,(1,2,...,6^*)$; $WC_f = 1\,(7^*)$; $WC_{max} = 4$; $n_{car} = 7$	0.893
x_{A9}	$PB_f = 3\,(6^*)$; $PB_f = 1\,(1,2,...,5^*)$ $PB_{max} = 4$; $n_{car} = 6$	0.333
x_{A10}	$S_f = 0\,(1,2,...,7^*)$; $S_{max} = 2$; $n_{car} = 7$	0
x_{A11}	$TB_f = 2$; $TB_{max} = 4$	0.50
x_{A12}	$SP_f = 1$; $SP_{max} = 2$	0.50
x_{A13}	$R_f = 3\,(1,2,3^*)$; $R_f = 1\,(4,5,6^*)$; $R_{max} = 4$; $n_{car} = 6$	0.50
x_{A14}	$DC_f = 7$; $DC_{max} = 8$	0.875
x_{A15}	$Pl_f = 2\,(1^*)$; $Pl_f = 1\,(2,3,4^*)$; $Pl_f = 0\,(5,6^*)$ $Pl_{max} = 2$; $n_{car} = 6$	0.417
x_{A16}	$HI_f = 1$; $HI_{max} = 4$	0.25

Note: (for c-th passenger carriage*)

Source: own

Conclusions

The suggested multicriteria model allows for evaluating the quality of travel by train objectively, expressing it by a single value. The value of K_A, calculated based on the values of the real parameters, allows the authors to state that the considered mathematical model is valid and can be used in practice. The significance of the criteria, describing the train elements and the technical state of rails (railway track) for the comprehensive quality index K_A, may be evaluated by determining only the variables x_{Aj} and using them in the suggested mathematical model.

The highest quality level determined by using the real data was obtained for the criteria A3 (the state of the carriage exterior) ($x_{A3} = 1$). The lowest quality level determined by using the real data was obtained for the criteria A10 (availability of regularly operating shower) ($x_{A10} = 0$). The average quality level was determined for A11 (special compartments for transporting bicycles) ($x_{A11} = 0.50$), A12 (smoking places) ($x_{A12} = 0.50$) and A13 (radio broadcasting unit and its centralized operation) ($x_{A13} = 0.50$) based on the real data. First, the real values of the criteria, whose variables $x_{Aj} = 0$ or are about zero, should be improved. The developed model may be applied to determining the quality or effectiveness of other objects or processes, which can be described by sets of criteria.

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Abstract

THE NUMERICAL EXAMPLE FOR EVALUATING THE CRITERIA DESCRIBING THE QUALITY OF THE TRIP BY INTERNATIONAL TRAIN

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The paper aims to determine the quality of the trip by train, which depends on the number of factors described by four groups of criteria. Each group includes individual criteria. The weight of the criteria of each group describing the quality of the trip by train is different. It is determined by using Kendall's rank correlation method. The normalized weights of sixteen criteria of the group A, describing the elements of the train and the state of the railway track, are found based on the analytic hierarchy process (AHP) method. They are used in the original additive mathematical model, allowing the quality of the trip by train to be expressed by a single value – the multiple criteria index. The weight of each criterion is multiplied by its dimensionless variable calculated by comparing the real criterion value to its best, worst or allowable (standard) value. The validity of the developed mathematical model is checked by using the data on the technical state of the elements of the international train 'Vilnius-Moscow' and the railway track obtained on the territory of Lithuania.