Keywords: railway infrastructure capacity; planning of measures for increasing the railway infrastructure capacity; ARTIW; Kendall's rank correlation method

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CREATING A PLAN FOR IMPLEMENTING MEASURES FOR INCREASING RAILWAY INFRASTRUCTURE CAPACITY BY APPLYING MULTI-CRITERIA DECISION-MAKING METHODS

Summary. This study addresses the challenge of increasing railway infrastructure capacity. It investigates the key factors that lead to a reduction in this capacity. The study focuses on the Lithuanian railway line, assessing train traffic schedules to determine actual capacity. An evaluation of potential measures to enhance this capacity has been conducted, and a comprehensive expert survey questionnaire was developed based on these measures. A strategic plan to improve railway capacity for Lithuanian railways was formulated using Kendall's rank correlation and ARTIW average rank for weight transformation methods. The study proposes a novel approach to creating these improvement plans and ends by presenting recommendations and conclusions.

1. INTRODUCTION

Researching railway infrastructure capacity is a complex task. It covers several complex railway structures, including infrastructure, rolling stock, and train traffic organization. The following four types of railway infrastructure capacity are distinguished: theoretical, practical, operational, and existing [12].

Academically, railway infrastructure capacity is described as the largest number of operating railway services that can be provided by infrastructure – the entire railway network, a separate corridor, or one station [5]. Generally, railway infrastructure capacity is measured by the maximum absolute number of trains over a certain period or the corresponding minimum infrastructure occupancy time for a certain number of trains within a set time interval [4].

The problem of increasing railway infrastructure capacity was already investigated by the authors, and recommendations were provided at a scientific conference [1]. This article is a continuation of the research started by the authors. An analysis of statistical data and the literature shows that the problem of increasing railway infrastructure capacity is closely related to the increasing volume of freight transportation by trains. To reduce road traffic and ensure environmental sustainability more and more countries around the world are switching to freight transportation by railway transport using intermodal transportation [3]. Even though freight transportation by railway has been investigated by many scientists, the body of research on increasing railway infrastructure capacity is relatively few [2]. However, in increasing the volume of freight transportation by railway it is necessary to assess the infrastructure capacity of the existing railway lines. This affects not only the railway network but also the entire logistics network. Increasing the capacity of railway infrastructure is possible only through effective train traffic organization, avoiding railway network disruptions, ensuring the required level of security, and the timely implementation of measures for increasing the railway infrastructure capacity.

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The research aims to evaluate the factors that reduce railway infrastructure capacity, the strategies employed to increase this capacity, including their effectiveness and suitability. Additionally, it seeks to propose a new model for the formulation and execution of measures aimed at increasing railway infrastructure capacity.

2. RESEARCH ON MEASURES FOR REDUCING RAILWAY INFRASTRUCTURE CAPACITY

The authors assume that infrastructure capacity is the number of pairs of trains per day that can pass through a certain railway line. One commonly used method for calculating the capacity of railway lines is the UIC Code 406 compression method [20]. This method analyses a train traffic schedule by calculating the occupancy rate, which is derived from the blocking time of train journeys within a specified timeframe. It focuses on how well the train schedule uses available capacity by looking at the time trains occupy the tracks [21]. In the course of the research performance, the train traffic schedules and infrastructure technical parameters were assessed, and the layout of single and double-track sections and the method of train traffic management were applied.

In Lithuanian railways, semi-automatic relays or automatic track blocks are installed in order to control the train traffic at intermediate sections. Automatic track blocks are train traffic management equipment based on the traffic lights of intermediate sections. Relay semi-automatic track blocks are equipment for interval train traffic management in non-intensive traffic sections [6]. An intermediate section with an automatic track block system is divided into sections that are 1-2.6 kilometers long, and each blocked stretch is separated by traffic lights [8]. This system controls the location of trains at the section, and therefore, the traffic of several trains going in the same direction in separate blocked sections of the same section is allowed. The system of semi-automatic track blocks does not control the location of trains at intermediate sections; therefore, in this case, only one train can be on the same section at any given time [7].

The infrastructure capacity of a single-track railway line with an installed semi-automatic block, the number of pairs of trains per day, is determined by Formula (1) [16]:

$$n_{SAB1} = \frac{T}{T_g}; \tag{1}$$

where: T – the number of minutes in one day (min.); T_g – train traffic schedule period (min).

The period of the train traffic schedule is given by Formula (2) [16]:

$$T_g = t_1 + t_2 + t_p; \tag{2}$$

where: t_1 and t_2 – running time of odd and even trains (min.); t_p – extra time for station intervals (route preparation), acceleration, or deceleration on station tracks (min).

The extra time depends on the station's rail automation equipment. When electric switches and signal interlockings are used to prepare the route, the additional time can be from 20 to 40 sec. When route preparation is based on route and control equipment, the additional time is approximately 8 min.

Installing a second main track on the railway line with a semi-automatic block doubles the infrastructure capacity, which can be determined by Formula (3):

$$n_{SAB2} = 2 \cdot n_{SAB1}; \tag{3}$$

where: n_{SAB1} – infrastructure capacity of a single-track railway line with an installed semi-automatic block (the number of pairs of trains per day).

The infrastructure capacity of a single-track railway line with an installed automatic block, the number of pairs of trains per day, is determined by Formula (4) [16]:

$$n_{AB1} = \frac{0.4 \cdot T}{I}; \tag{4}$$

where: I – a minimal interval of running trains (min.).

The infrastructure capacity of a double-track railway line with an automatic block, the number of pairs of trains per day, is determined by Formula (5) [16]:

$$n_{AB2} = \frac{0.85 \cdot T}{I}. \tag{5}$$

When a section is equipped with a three-signal system, the interval between running trains (without speed reduction) consists of three interlocking sections. It can be determined by Formula (6) [16]:

$$I = 0.06 \cdot \frac{(3L_b + L_t)}{v_{avr}}. \quad (6)$$

where: L_b – average length of the blocked section (m); L_t – average train length (m); v_{avr} – average speed on a railway section (km/h); 0.06 − transfer coefficient.

For the practical determination of the infrastructure capacity, the Kena-Klaipeda Lithuanian railway line was chosen. This railway line is very important for freight train traffic. It connects the Vilnius Intermodal Terminal with the Klaipeda seaport. The railway line also runs through the whole territory of Lithuania.

Freight train traffic schedules were assessed to determine the infrastructure capacity of the Kena-Klaipeda railway line. Train schedules provide the following data: length of sections (km), average freight train speed on sections (km/h), actual running times of freight trains on sections (min.), type of rail tracks (single track or double track) on the sections, and type of signaling system installed on the sections (semi-automatic block or automatic block).

For the calculations, it is also assumed that:

1. Freight train length = 1316 m.
2. Average length of blocked sections = 2600 m.

The results of the calculations of infrastructure capacity are shown in Fig. 1.

To facilitate the calculation, the authors split the Kena–Klaipeda railway line into sections and named them A-B-C. In the course of the research, it was found that the capacity of infrastructure of the railway lines A-B-C is 34 pairs of trains per day. However, the capacity potential of this line is over 50 pairs of trains per day. Two intermediate sections limiting the capacity were determined: 1-2 and 3-4. Fig. 2 shows the railway line A-B-C and the location of intermediate sections 1-2 and 3-4 reducing the railway capacity.

Figure 2 shows an intermediate section 1-2 and 3-4 of the Lithuanian railway network lines A-B-C, which reduce infrastructure capacity.

According to the data of the manager of the Lithuanian public infrastructure, the capacity of the railway line A-B-C is reduced by single tracks of limiting intermediate sections 1-2 and 3-4.

3. ANALYSIS OF MEASURES FOR INCREASING RAILWAY INFRASTRUCTURE CAPACITY

The infrastructure capacity of the railway could be increased by taking organizational and technical measures and reconstructing parts of the infrastructure [3]. Organizational and technical measures require lower costs and are faster to implement and reconstruct. However, such an increase in the capacity of railway lines is limited. Moreover, organizational and technical measures cannot always be implemented without reconstructing the railway network or separating railway lines.

The main organizational and technical measures include the following:

1. Optimizing train traffic schedules.
2. Using doubled trains.
3. Using helper locomotives (pushers) or double locomotives.
4. Reducing train traffic intervals.
5. Organizing train stops of doubled trains only at intermediate sections.
6. Eliminating tracks for trains traveling in both directions on railway lines and at stations.
7. Increasing the mass of freight trains.
8. Applying temporary measures (organizing train traffic in one direction in single- and double-track railway lines and train traffic in caravans when two trains pass one after another).

The most important organizational and technical measures are optimizing the train traffic schedules and the usage of double freight trains.

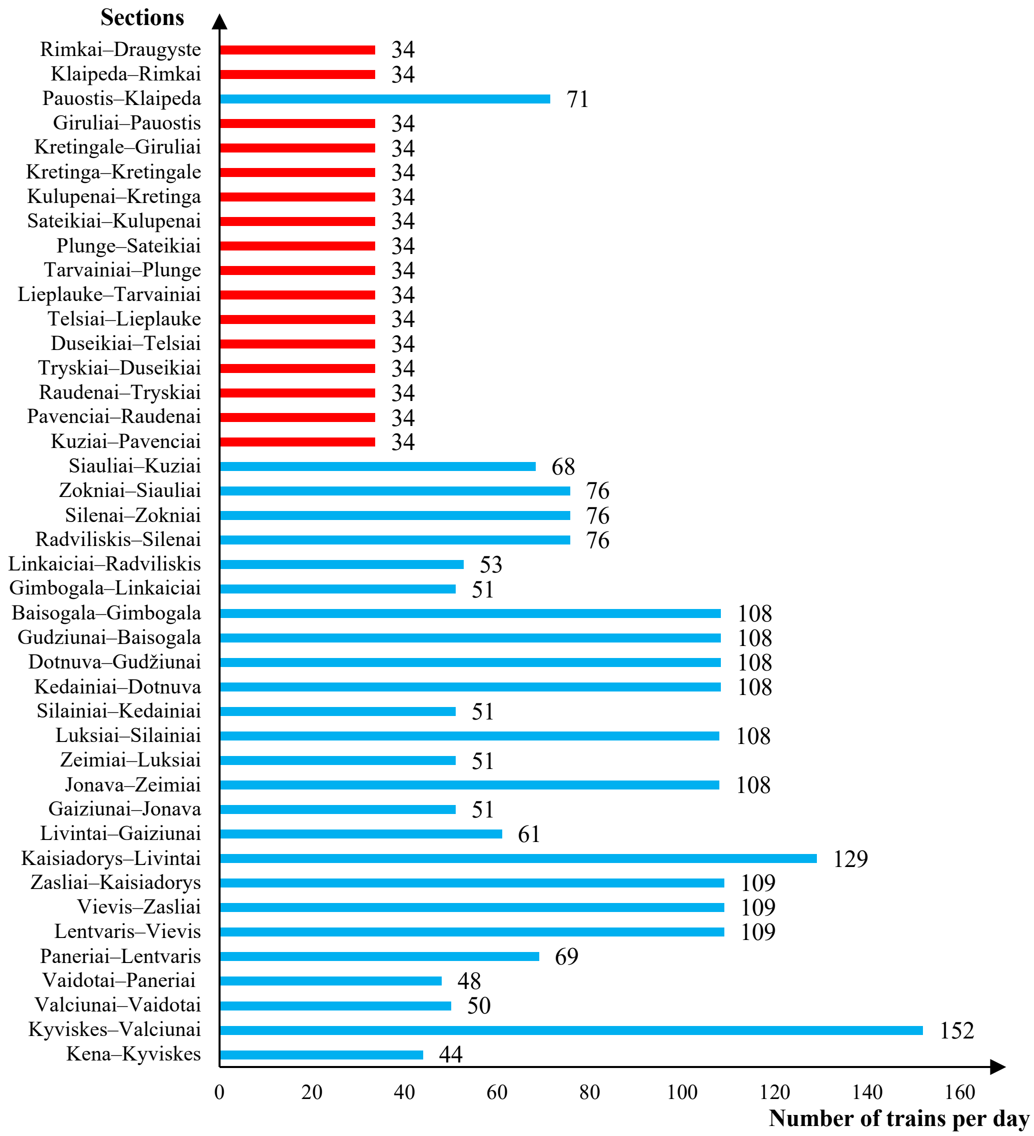

Fig. 1. Infrastructure capacity of the Kena–Klaipeda railway line

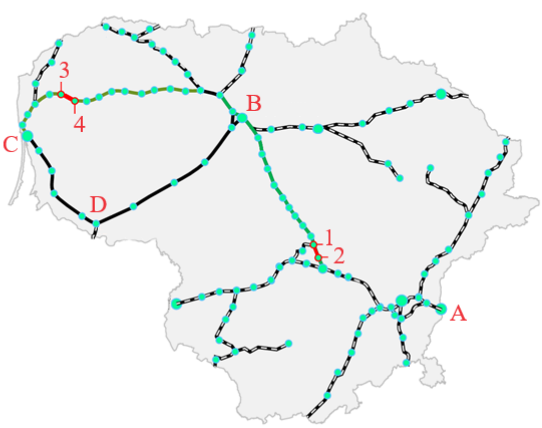

Fig. 2. Scheme of split Lithuanian railways into sections

The main reconstruction actions are:

1. Building the second and the third tracks at intermediate sections.
2. Aligning the track profile of the railway line.
3. Extending the train arrival and departure tracks at railway stations.
4. Electrifying railway lines.
5. Changing the method of train traffic management.
6. Efficiently placing train traffic lights at intermediate sections.
7. Installing centralized train electrical switches and train signals.
8. Modernizing and renewing rolling stock.

The most important reconstruction measures are building the second and third tracks and extending the train arrival and departure tracks at railway stations.

4. CREATING AND MODELING A PLAN OF MEASURES FOR INCREASING RAILWAY INFRASTRUCTURE CAPACITY

It is necessary to plan the measures for increasing the infrastructure capacity of the railway. Such a plan should present its implementation procedure, which would ensure the timely and effective implementation of measures for increasing the infrastructure capacity of the railway.

The importance of the proposed expert assessment methods regarding the plan for increasing railway infrastructure capacity is that they enable the carrying out of the analysis, taking into account the expert insights through applying the quantitative assessment of the obtained opinions and their results. A generalized opinion of the expert group in railway transport was considered suitable for solving the problem.

To make a decision based on the expert group assessment results, it is necessary to evaluate the degree of compatibility of the experts' opinions by applying a multi-criteria assessment [14]. Multi-criteria decision-making methods are divided into two groups: multi-objective and multi-aimed methods. Methods for making multi-criteria solutions that use vector optimization based on a decision-making model are called multi-criteria organization methods or multi-objective decision-making methods. These methods are used for solving a problem, which covers multi-objective functions, that are optimized simultaneously [14].

To choose a rational alternative from a particular list, multi-attribute decision-making methods are used. These methods investigate problems, the solution set of which is discreet—that is, it consists of a set of possible alternatives $A = (A_1, A_2, \dots, A_i, \dots, A_m)$. Alternatives are possible different and purposeful solutions described by certain indicators $(X_1, X_2, \dots, X_j, \dots, X_n)$. Indicators reflect certain aspects of alternatives, and each describes one feature of an alternative [14].

The classification of multi-objective methods is presented in Table 1.

Table 1

Classification of multi-objective methods [14]

Class of methods	Information on indicators	Methods
Multi-attribute utility theory	Quantitative measurements	SAW; TOPSIS; TOPSIS-G; COPRAS; COPRAS-G; ARAS; MOORA; VIKOR; MultiMOORA
Analytic hierarchy and fuzzy set methods	Qualitative measurements are given a quantitative form	AHP; Fuzzy TOPSIS; Fuzzy AHP
Decision methods for verbal analysis	Qualitative measurements without moving to quantitative variables	ZAPROS; PARK; ORKLASS; CLARA; DIFLASS; CIKL
Comparative preference methods	Quantitative and qualitative measurements	ELECTRE; PROMETHEE; MELCHIOR; UTA; MAUT; TACTIC

There are many generally accepted multi-criteria decision-making methods for solving different problems. However, the methods used are not perfect, and it is currently not possible to identify the best one, as the field of multicriteria analysis is not fully developed.

The authors propose determining the compatibility of opinions of the expert group concerned with increasing railway infrastructure capacity by using Kendall's rank correlation method. The ranks assigned are further transformed into linear weights by using the methods of the average rank transformation into weight (i.e. ARTIW).

The algorithm for applying the ARTIW method is shown in Fig. 3.

The expert group consists of n experts who quantitatively assessed m objects (quality indicators). Assessment $R_{ij}(i = 1, 2, \dots, n;\ j = 1, 2, \dots, m)$ forms a matrix of n rows and m columns. Experts could assess an expected value R_{ij} in a different way. Only a ranking of expert indicators could be used for calculating the concordance coefficient [15].

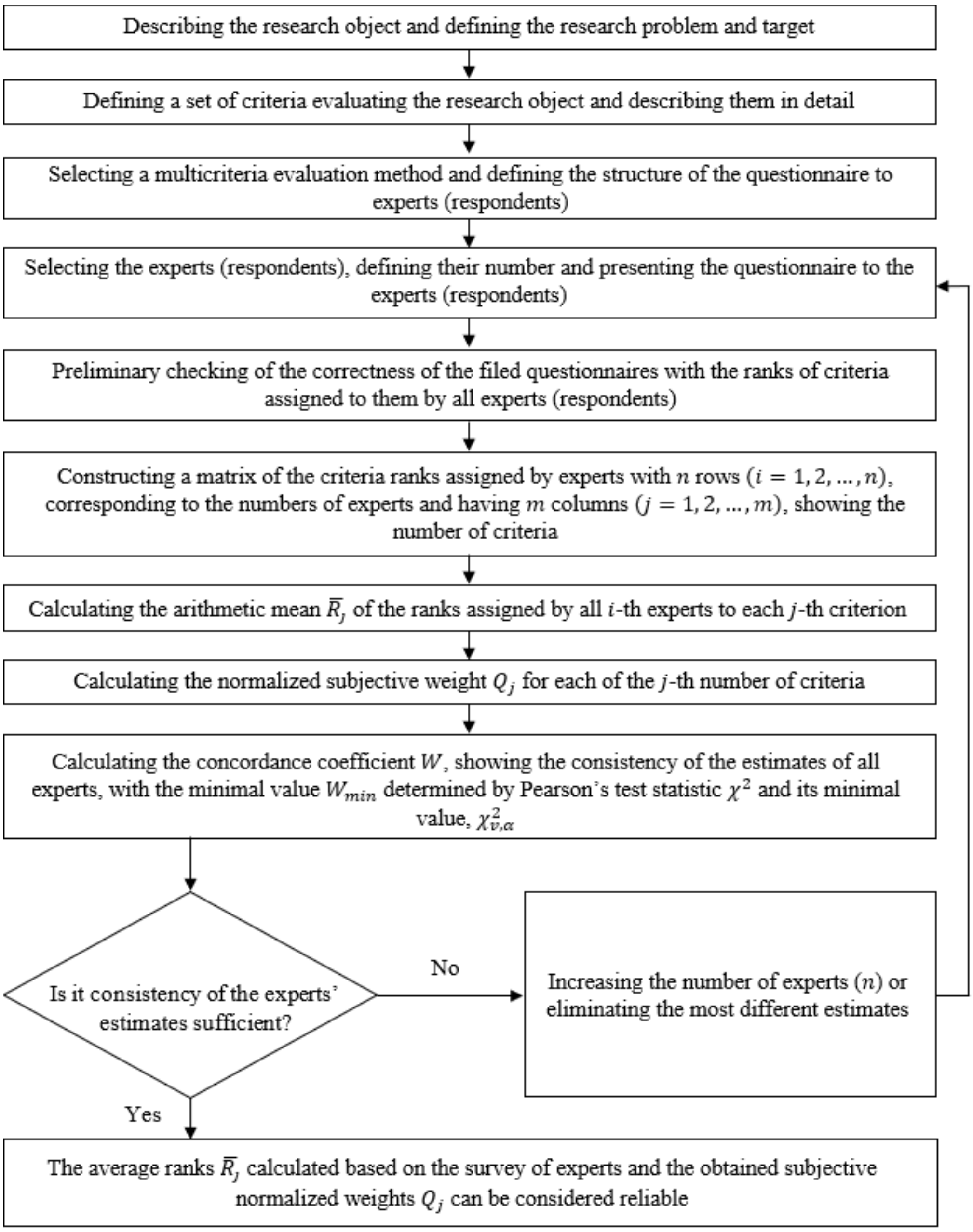

Fig. 3. The algorithm for applying the ARTIW method [13]

Once all the experts have given ranks to the criteria, the consistency of their opinions is determined by calculating Kendall's rank concordance coefficient. The idea of Kendall's concordance coefficient relates to the sum of the ranks R_j of each of the j-th criteria across all experts. The sum of the ranks R_j can be determined by Formula (7):

$$R_j = \sum_{i=1}^{n} R_{ij} \;\; (j = 1, 2, \dots, m). \tag{7}$$

More precisely, it is related to the deviation of the values R_j from the overall mean $\bar{R}$ sum of squares S. It can be determined by Formula (8) [18]:

$$S = \sum_{j=1}^{m} (R_j - \bar{R})^2 \, ; \tag{8}$$

where: R_j – a sum of ranks awarded for criterion j-th; $\bar{R}$ – average rank for each criterion; n – number of experts in the group ($i = 1, 2, \dots, n$); m – number of criteria ($j = 1, 2, \dots, m$).

Overall average $\bar{R}$ is calculated according to Formula (9) [18]:

$$\bar{R} = \frac{\sum_{j=1}^{m} R_j}{m} = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n} R_{ij}}{m} = \frac{n(m+1)}{2} \, ; \tag{9}$$

where: R_{ij} – the rank given to the j-th criterion by the i-th expert.

If S is the real sum of the squares calculated according to Formula (8), then the concordance coefficient W in the absence of associated ranks is defined by the ratio of the resulting S to the corresponding maximum S_{max}. It can be determined by Formula (10) [17]:

$$W = \frac{12 \cdot S}{n^2 \cdot m(m^2-1)} = \frac{12 \cdot S}{n^2 \cdot (m^3 - m)} \, ; \tag{10}$$

where: S – the sum of squares of an average rank.

The sum of the squares of the deviations of the ranks R_{ij} of each criterion from the mean rank, S, can conveniently be calculated using Formula (11) [18]:

$$S = \sum_{j=1}^{m} \left[\sum_{i=1}^{n} R_{ij} - \frac{1}{2} \cdot n\,(m+1) \right]^2 . \tag{11}$$

The concordance coefficient can be applied in practice if a threshold is set at which expert judgments can be considered to agree. Kendall proved that if the number of criteria is higher than 7, the significance of the concordance coefficient can be determined using the Pearson criterion χ^2. It can be determined by Formula (12) [17]:

$$\chi^2 = n \cdot (m-1) \cdot W = \frac{12 \cdot S}{n \cdot m \cdot (m+1)} . \tag{12}$$

Random variables are distributed according to the χ^2 distribution with $v = m - 1$ degrees of freedom. According to the chosen significance level α (in practice α is taken to be 0.05 or 0.01), the critical value $\chi^2_{cr} = \chi^2_{v,\alpha}$ is derived from the χ^2 distribution for a degree of freedom of $v = m - 1$ [18]. If the value of χ^2 calculated by Formula (12) is greater than χ^2_{cr}, the experts are in the agreement. The minimum value of the concordance coefficient W_{min}, at which it cannot yet be assumed that the opinions of all n experts on the quality of the test object composed of m criteria to be compared are in agreement, given the significance level α and the degree of freedom $v = m - 1$, can be calculated using Formula (13) [18]:

$$W_{min} = \frac{\chi^2_{v,\alpha}}{n(m-1)} . \tag{13}$$

where: $\chi^2_{v,\alpha}$ – critical Pearson statistics.

If expert opinions are compatible, the value of the concordance coefficient W is close to 1; if an assessment varies widely, W is close to 0 [13].

The object quality is assessed by an additive mathematical model, which helps to calculate a complex indicator and enables one to determine its quality as a single number, as well as to compare it to other analogous objects. However, to achieve this goal, it is better not to use the average ranks of criteria $\bar{R_j}$ that do not indicate the extent to which one rank is more important than the other; instead, it is better to emphasize their importance Q_j.

The importance of a normalized solution of quality criteria of the expert group can be found by calculating the importance indicator of each criterion Q_j using Formula (14) [18]:

$$Q_j = \frac{(m+1)-\overline{R_J}}{\sum_{j=1}^{m} \overline{R_J}}; \quad (14)$$

where: m – the number of criteria determining the object quality; $\overline{R_J}$ – the average rank of criterion.

The importance indicators determined in this way Q_j show that the most important criterion has the highest indicators. Hence, the important indicator Q_j enables one to determine whether one criterion is more important than another (this is evident from average ranks $\overline{R_J}$), as well as by how many times one criterion is more important than another [18].

After assessing the proposals of the manager of the Lithuanian railway public infrastructure of the railway line A–B–C for measures increasing infrastructure capacity, the authors developed a questionnaire to assess these measures. The questionnaire covers 11 measures for increasing the infrastructure capacity of the railway. These measures are presented in Table 2.

Table 2

Measures for increasing infrastructure capacity in the railway line A–B–C

Seq. No.	Criterion	Measures for increasing infrastructure capacity in the railway line A–B–C
1.	A	Constructing secondary tracks at intermediate sections 1–2 and 3–4
2.	B	Changing the mode of train traffic regulation
3.	C	Installing blocking posts at intermediate sections
4.	D	Implementing the European Rail Traffic Management System
5.	E	Electrifying the railway line A–B–C
6.	F	Extending the station’s arrival and departure tracks of the railway line A–B–C
7.	G	Shortening the tracks of the railway line A–B–C at intermediate sections
8.	H	Modernizing or eliminating railway and pedestrian crossings
9.	I	Modernizing the railway line C–D–B to organize a circular train traffic
10.	J	Modernizing and renewing the rolling stock
11.	K	Optimizing the train traffic schedules

The research survey involved 11 railway transport experts. Their rankings of the criteria and the results of related calculations are displayed in Table 3.

Table 3

The ranks assigned to the criteria of the expert group and the results of the calculations

Expert number, $\boldsymbol{i = (1, 2, \ldots, n)}$	Measures for increasing infrastructure capacity in the railway line A–B–C, $\boldsymbol{j = (1, 2, \ldots, m)}$										
	A	B	C	D	E	F	G	H	I	J	K	Total
$\boldsymbol{E_1}$	1	5	8	7	2	4	10	9	3	11	6	66
$\boldsymbol{E_2}$	1	7	6	10	9	3	5	2	4	11	8	66
$\boldsymbol{E_3}$	2	3	4	10	9	8	6	11	5	7	1	66
$\boldsymbol{E_4}$	3	7	10	5	1	2	8	6	9	4	11	66
$\boldsymbol{E_5}$	1	6	3	9	2	8	7	5	4	11	10	66
$\boldsymbol{E_6}$	3	9	6	10	1	5	7	8	4	2	11	66
$\boldsymbol{E_7}$	3	2	4	10	8	9	5	11	6	7	1	66
$\boldsymbol{E_8}$	2	3	10	11	4	9	7	8	1	5	6	66
$\boldsymbol{E_9}$	1	2	4	7	11	6	5	3	8	10	9	66
$\boldsymbol{E_{10}}$	7	11	8	4	1	5	9	10	3	2	6	66
$\boldsymbol{E_{11}}$	1	4	9	5	8	2	6	11	3	7	10	66
$R_j = \sum_{i=1}^{n} R_{ij}$	25	59	72	88	56	61	75	84	50	77	79	726
$\overline{R_j} = \overline{\sum_{i=1}^{n} \frac{R_{ij}}{n}}$	2.3	5.4	6.5	8.0	5.1	5.5	6.8	7.6	4.5	7.0	7.2	66
$\sum_{i=1}^{n} R_{ij} - \frac{n(m+1)}{2}$	−41	−7	6	22	−10	−5	9	18	−16	11	13	0
$\left[\sum_{i=1}^{n} R_{ij} - \frac{n(m+1)}{2}\right]^2$	1681	49	36	484	100	25	81	324	256	121	169	3326

Based on the results of the questionnaire, a concordance coefficient was calculated as shown below. The result indicates the consistency of the experts' opinions. The formula (10) is used for the calculations:

$$W = \frac{12 \cdot 3\,326}{11^2 \cdot (11^3 - 11)} = 0.2499.$$

Since $v = 11 - 1 = 10$ degrees of freedom and the significance level is $\alpha = 0.05$, the critical value is $\chi^2_{cr,\alpha} = 18.307$.

The empirical value $\chi^2 = 27.49$ is higher than the critical value $\chi^2_{cr,\alpha} = 18.307$. This means that the experts' opinions on measures for increasing infrastructure capacity in railway lines A-B-C are consistent.

Formula (13) is used to calculate the minimum value of the concordance coefficient:

$$W_{min} = \frac{18.307}{11 \cdot (11 - 1)} = 0.1664.$$

The empirical concordance coefficient $W = 0.2499$ is higher than its minimum value $W_{min} = 0.1664$. Therefore, it could be stated that the experts' opinions are in agreement.

The graph of the average rank ratings $\overline{R_j}$ of the experts' opinions on measures for increasing infrastructure capacity in railway lines A–B–C is presented in Fig. 4.

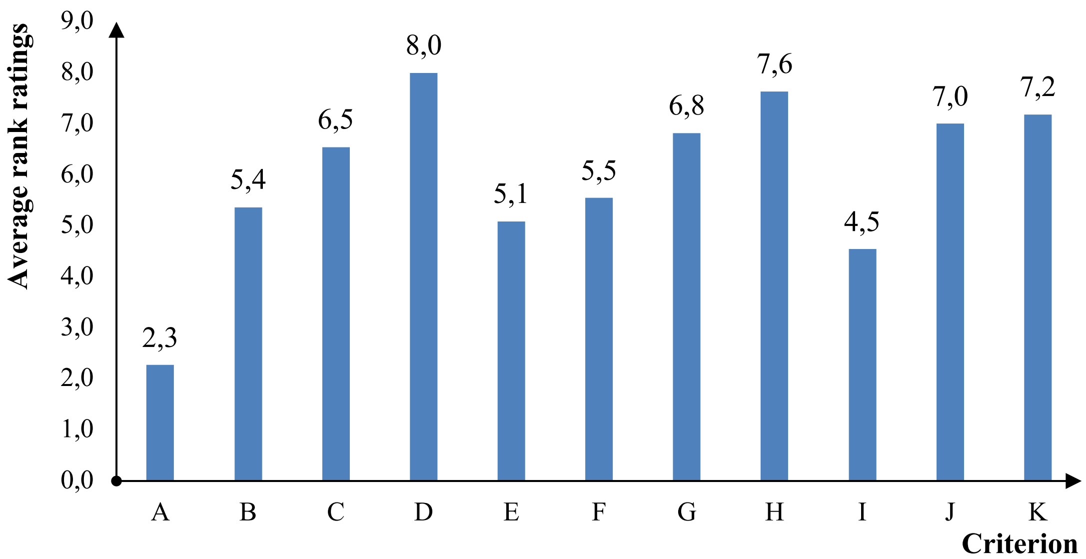

Fig. 4. Assessment of the average rank ratings $\overline{R_j}$ of the experts' opinions on measures for increasing infrastructure capacity in the railway lines A–B–C

It should be noted that the most important criterion has the lowest rank. Therefore, the importance of measures for increasing the infrastructure capacity of railway lines A–B–C (i.e., the weights of all criteria) was determined by Formula (14). Indicators of the importance of criteria are presented in Table 4.

Table 4

Indicators of measures for increasing infrastructure capacity in the railway line A–B–C

Indicator	**Measures for increasing infrastructure capacity in the railway line A–B–C, $j = (1, 2, \ldots, m)$**											
	A	B	C	D	E	F	G	H	I	J	K	**Total**
Importance indicator, Q_j	0.15	0.10	0.08	0.06	0.10	0.10	0.08	0.07	0.11	0.08	0.07	**1.00**

The graph of normalized importance indicators Q_j of measures for increasing infrastructure capacity in railway lines A–B–C is presented in Fig. 5.

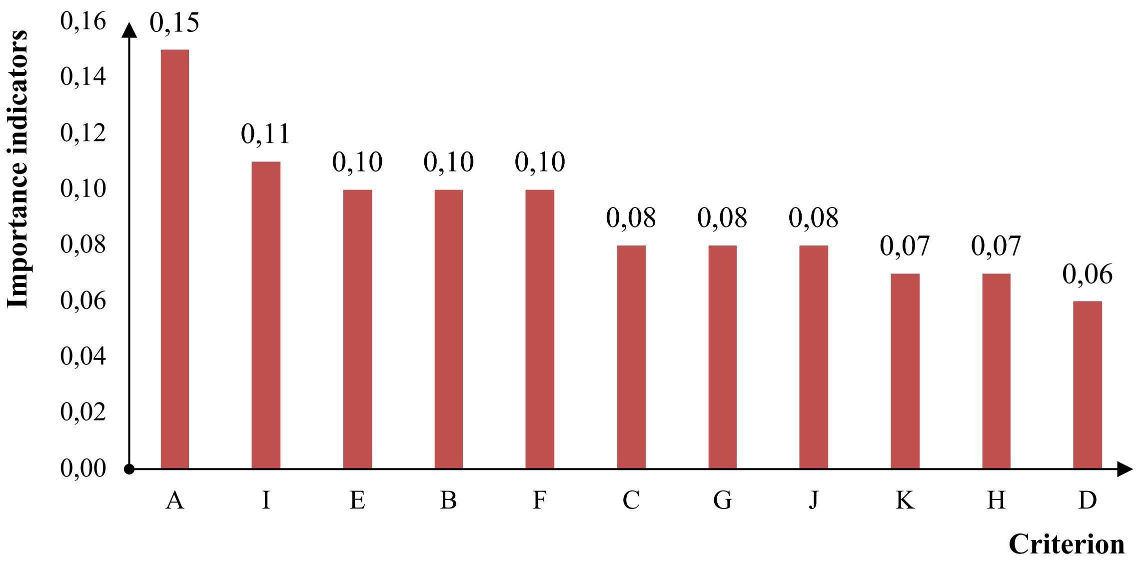

Fig. 5. Normalized indicators Q_j of the importance of increasing measures for infrastructure capacity in railway lines A-B-C

The measures for increasing infrastructure capacity in railway lines A–B–C were implemented in the following order: $A > I > E > B > F > C > G > J > K > H > D$.

The most important measures for increasing infrastructure capacity in the railway line A-B-C are as follows:

1. A criterion – constructing secondary tracks at intermediate sections 1-2 and 3-4. Secondary tracks allow for more trains to run simultaneously, reducing bottlenecks and increasing the overall number of trains that can be accommodated on the network, and provide more routing options, thus making it easier to manage traffic during peak times or in case of disruptions.
2. I criterion – modernizing the railway line C-D-B and organizing circular train traffic. Circular routes can help distribute train traffic more evenly across the network, reducing congestion along heavily used lines. It can help manage traffic flow more effectively, as trains can be rerouted in cases of disruptions, thus minimizing delays and maintaining service continuity.
3. E criterion – electrifying the railway line A-B-C. Electrification can support heavier and longer trains, increasing the overall capacity of the railway network and achieving higher speeds, thereby reducing travel times and allowing for more trips within the same timeframe.
4. B criterion – changing how train traffic is regulated. Introducing automated or semi-automated train operations can improve precision in train movements, reduce human error, and increase the overall capacity of the network.
5. F criterion – extending the station's arrival and departure tracks of the railway line A-B-C. Extended tracks can accommodate more trains simultaneously, reducing waiting times for trains to enter or leave the station and providing more flexibility in train scheduling and routing.

Other measures for increasing infrastructure capacity in railway lines (shortening the tracks of the railway line A-B-C at intermediate sections, modernizing or eliminating railway and pedestrian crossings, modernizing the railway line C-D-B to organize a circular train traffic, modernizing and renewing the rolling stock, and optimizing train traffic schedules) are of minor importance. However, other measures, such as modernizing and renewing the rolling stock or optimizing train timetables should not be underestimated. New trains are generally more reliable and require less maintenance than old trains, reducing the likelihood of breakdowns and service disruptions. Optimized timetables can help spread train traffic more evenly throughout the day, thus reducing peak-time congestion and improving overall flow. It could be stated that these measures will be effective only when the most important measures for increasing railway infrastructure capacity of railway line A-B-C are implemented.

5. CONCLUSIONS

The results show that multi-criteria decision-making methods can be applied to make and implement a plan to increase measures for the railway infrastructure capacity.

The capacity of infrastructure in the railway line A-B-C is 34 pairs of trains per day. To increase this, considerable attention should be focused on the following reconstructive measures for increasing the railway infrastructure capacity.

1. Secondary tracks should be constructed at intermediate sections 1-2 and 3-4, whereas the existing tracks should be modernized. It is necessary to reconstruct bridges, culverts, signaling and communication systems, and engineering networks; install fences for protecting animals, soundproof walls, and rainwater and drainage systems. These measures would increase the infrastructure capacity by up to 18 trains per day.
2. To reduce train traffic in railway lines A-B-C and organize circular traffic, it is proposed to modernize railway lines C-D-B where the train traffic is limited due to the insufficiently strong construction of the upper railway track. Accordingly, it is necessary to strengthen the upper railway track construction and build new additional tracks.
3. Implementing the project of electrification of the railway line A-B-C will make it possible to increase the running speed of freight and passenger trains.
4. Replacing semi-automatic blocks with automatic ones will increase train traffic volume, and the use of railway possibilities will be more efficient and safer. Moreover, implementing an automatic block will increase the total single-track capacity by up to 25%.
5. Extending arrival and departure tracks at railway stations would solve the problem of receiving freight trains at railway stations when the length of arrival and departure tracks is shorter than the freight train set. The extension of tracks allows passengers and other priority trains to pass safely.
6. The implementation of the above measures will improve the capacity of rail infrastructure the most, but this does not mean that measures such as shortening the tracks of the railway line A-B-C at intermediate sections, the modernization or elimination of railway and pedestrian crossings, the modernization of the railway line C-D-B to organize circular train traffic, the modernization and renewal of the rolling-stock, or the optimization of the train traffic schedules are irrelevant.
7. The proposed measures for increasing railway infrastructure capacity emphasize the need for a comprehensive approach that integrates organizational and technical strategies. The overall efficiency and safety of train operations can be significantly enhanced by prioritizing reconstructive efforts – such as constructing secondary tracks and modernizing existing systems—alongside implementing automatic signaling. This multifaceted strategy tackles current capacity limitations and positions the railway network to meet future demands, such as high-speed rail development, thereby ensuring sustainable growth in rail transport.

The findings underscore the potential for applying similar methodologies in other countries to optimize railway infrastructure. By adapting multi-criteria decision-making methods and leveraging modern technologies, other countries can effectively assess and enhance their railway capacity. Furthermore, integrating advanced scheduling techniques and infrastructure improvements can lead to better resource utilization and increased service reliability, ultimately contributing to a more robust and efficient railway system worldwide.

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