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Analysis and Evaluation of the Impact of Railway Infrastructure Parameters Changes on "Rail Baltica" Project Implementation

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Abstract. "Rail Baltica" project is priority project No 27 "Rail Baltica" axis Warsaw-Kaunas-Riga-Tallinn-Helsinki, approved by Decision No 884/2004/EC of the European Parliament and of the Council of 29 April 2004 amending Decision No 1692/96/EC on Community guidelines for the development of the trans-European transport network (European Union, 2004). An article analyzes the changes in the main parameters of the 1435 mm gauge railway infrastructure during the whole period of the "Rail Baltica" project, determines their impact on the project implementation timeline, purposes and results, highlights basic parameters which need to be met during modernization. On this basis, the main criteria for the evaluation of Rail Baltica rail infrastructure were selected. An expert survey was conducted to evaluate the criteria. The Kendall method was used to calculate the criteria weights. The article ends with a scientific discussion.

Keywords: "Rail Baltica" development, railway infrastructure, Kendall method.

Introduction

Initiation and planning of railway infrastructure modernization projects usually are fallowed by such constraints as insufficient financial resources, time shortage for project preparation and implementation, requirements from the infrastructure manager to avoid traffic brakes as much as possible, changes in technical requirements and parameters, emergence of new projects, which have influence for main project technical solutions (Han et al., 2009). It should be noted, that "Rail Baltica" project is not an exception regarding mentioned constraints as well.

First construction works of "Rail Baltica" 1435 mm railway line from Polish – Lithuanian state border till Kaunas were started on 2010 in Mockava – Šeštokai section. During construction works, which were finished on September 2011, 7.5 km length of 1435/1520 mm gauntleted track were reconstructed accordingly.

Construction works of second section from Mockava till Polish-Lithuanian state border were started on May 2013 and were finished on October 2014. During construction works 13.2 km length of existing 1435 mm gauge railway track, as well as 1435 mm gauge and 1520 mm gauge tracks were reconstructed in Mockava station.

Construction works of 33 km length third section from Šeštokai till Marijampolė were started on June 2013 and were finished on April 2015. During construction works was reconstructed an existing 1520 mm gauge railway track by constructing 1435 mm gauge track and 1520 mm gauge track on single embankment.

It should be noted that the same technical solution – reconstruction of existing 1520 mm gauge track by constructing of 1435 mm gauge track and 1520 mm gauge track on single embankment was used for fourth 33 km length Marijampolė – Kazlų Rūda section as well. Reconstruction works of this section were started on June 2013 and were finished on March 2015.

During reconstruction works of last Kazlų Rūda – Mauručiai, Mauručiai – Jiesia and Jiesia – Kaunas sections, which total length is 36 km, two existing 1520 mm gauge tracks were reconstructed by constructing two 1520 mm gauge tracks and 1435 mm gauge track on single embankment.

All reconstruction works, in 2010–2015, from Polish – Lithuanian state border till Kaunas were followed by reconstruction of Šeštokai, Kalvarija, Marijampolė, Kazlų Rūda, Mauručiai, Jiesia and Kaunas stations. It should be noted that 1435 mm gauge railway line Polish – Lithuanian state border – Kaunas was constructed accordingly in Commission Decision No 2011/275/EU of 26 April 2011 concerning a technical specification for interoperability relating to the "infrastructure" subsystem of the trans-European conventional rail system indicated VII-M category railway line parameters: mixed traffic, 120 km/h passenger train speed, 500 m train length, GA gauge structure and 22.5 t axle load.

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Such relatively low 120 km/h speed parameter was used because of the project constraint – project financing timeline with significant time shortages for territorial planning, land acquisition, design and construction activities. Therefore, the decision to design and construct in the existing railway land plots was taken. Second reason was the lack of commonly agreed technical parameters as well as different development strategies between project partners.

It should be important to state that on 31 January 2017 Intergovernmental Agreement (hereinafter – Intergovernmental Agreement) was signed between the Government of the Republic of Latvia, the Government of the Republic of Estonia and the Government of the Republic of Lithuania On the Development of the Rail Baltic/Rail Baltica Railway Connection. It was agreed to ensure the completion and functionality of an effective fast conventional European gauge railway, built as a project of common interest according to the common technical parameters, for passengers and freight transport on a route as part of the TEN-T Network North Sea – Baltic Core Network Corridor.

It was agreed as well to construct new fast conventional double track electrified railway line with the maximum design speed of 240 km/h and European standard gauge (1435 mm) on the route be complete in accordance with uniform technical parameters based on the Commission Regulation (EU) No 1299/2014 of 18 November 2014 on the technical specifications for interoperability relating to the "infrastructure" subsystem of the rail system in the European Union (hereinafter – INF TSI).

Accordingly with INF TSI, it was agreed to construct P2/F1 category railway line: mixed traffic, 25 AC kV electrified double track, 240 km/h design speed for passenger trains, 120 km/h design speed for freight trains, 740–1050 m freight train length, 200–400 passenger train length, GC gauge structure, 4.2 m distance between track centres and 22.5 t axle load.

INF TSI parameters agreed to use for "Rail Baltica" project developments were updated on April 2018, when unified "Rail Baltica" Design Guidelines (hereinafter – RBDG) were approved. It was agreed to design and construct "Rail Baltica" railway lines accordingly to newly updated parameters: mixed traffic, 25 kV AC electrified double track, 249 km/h design speed for passenger trains, 120 km/h design speed for freight trains, 1050 m freight train length, 400 passenger train length, GC gauge structure, 4.5 m distance between track centres and 25 t axle load. It is important to note as well that structure gauge parameter GC was updated to structure gauge parameter SeC on 2020.

However, such significant changes in "Rail Baltica" project technical parameters induced the need to modernize existing or even to construct completely new "Rail Baltica" Polish/Lithuanian state border – Kaunas railway line. Therefore, to find optimal railway modernization alternative, several technical studies were prepared.

Thus, this article will try to solve main question: what basic parameters are needed to be met during modernization of the projects when insufficient financial resources and time shortage for project preparation and implementation exist?

1. Rail Baltica development in Lithuania

Accordingly, with Intergovernmental Agreement, Parties have agreed to ensure completion and functionality of the railway by 2025 in order to commence its operation by 2026. Therefore, it is planned to modernize according with the newest parameters an existing 1435 mm gauge Polish/Lithuanian border – Kaunas railway line (86.0 km length), as well as to develop and complete Kaunas railway node with Jiesia-Kaunas (8 km length), Kaunas-Palemonas (10 km length), Jiesia-Rokai (5 km length) and Rokai-Palemonas (8 km length) sections (Figure 1).

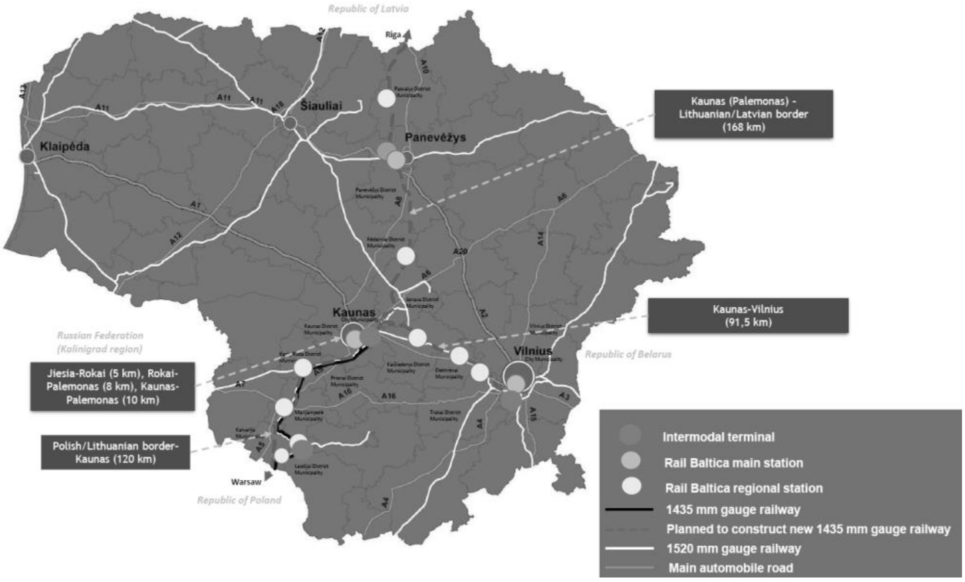

Figure 1. Rail Baltica development in Lithuania

For the connection with Latvia it is foreseen to construct new railway line from Kaunas to Lithuanian/Latvian border (168 km length) and for Vilnius connection – to construct new railway line from Kaunas to Vilnius (91.5 km length). It is agreed to construct three international passenger stations in Kaunas, Vilnius and Panevėžys. For freight transportation new 1435 mm gauge freight yards with at least 8 tracks 1050 m useful length will be constructed in Kaunas and Vilnius, which will serve for Kaunas and Vilnius intermodal terminals. To ensure higher usage and effectiveness of the "Rail Baltica" infrastructure it is agreed to construct new regional stations, stops or halts along the new railway lines. For proper infrastructure maintenance new infrastructure maintenance facilities will be designed and constructed in Kaunas and Panevėžys areas, as well as infrastructure maintenance points will be created in Vilnius and Marijampolė.

An existing 1435 mm gauge railway line Polish/Lithuanian border – Kaunas, which is foreseen to be modernized, will be used as a regional line and will have the connections with the exiting station. The railway stations and their connections to the main line, such as Mockava, Šeštokai, Marijampolė and Kazlų Rūda, which are under operation already, will be used for regional purposes (Figure 2).

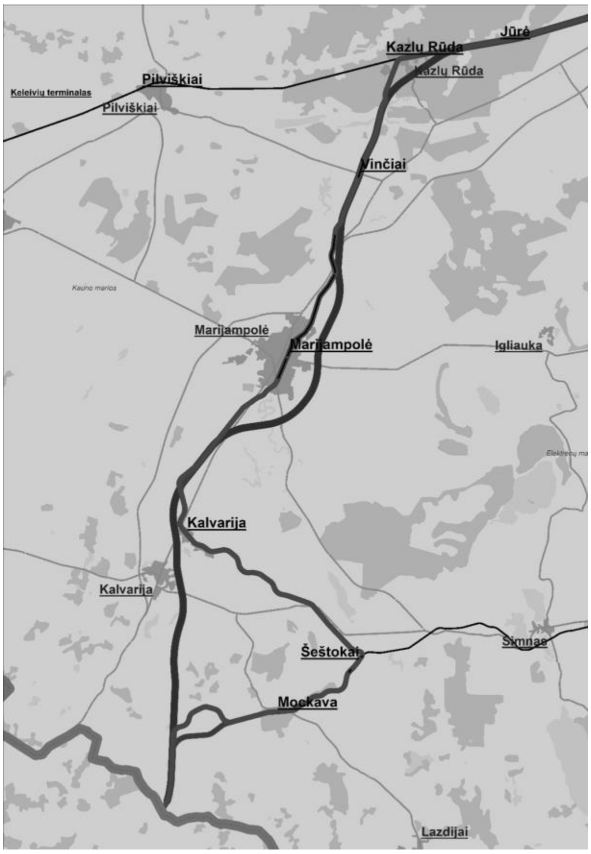

Figure 2. Polish/Lithuanian border – Kaunas railway line modernization alternative

It should be noted that during modernization works of existing 1435 mm gauge railway line in Lithuania, one of the main condition will be to do not close an existing traffic, the same condition will be applied in E75 Bialystok-Elk-Suwalki railway line (Poland), which is foreseen to be modernized accordingly with the Rail Baltica main parameters as well.

2. Rail Baltica design guidelines

To avoid differences in design of railway infrastructure technical solutions between countries, which usually have different national legislation and practice, RBDG were created. It was agreed that "Rail Baltica" line shall accommodate passengers' trains classified as P2 traffic code and freight trains classified as F1 traffic code and gauge structure GC (agreed to update to SeC on 2020) will be applied (Figure 3).

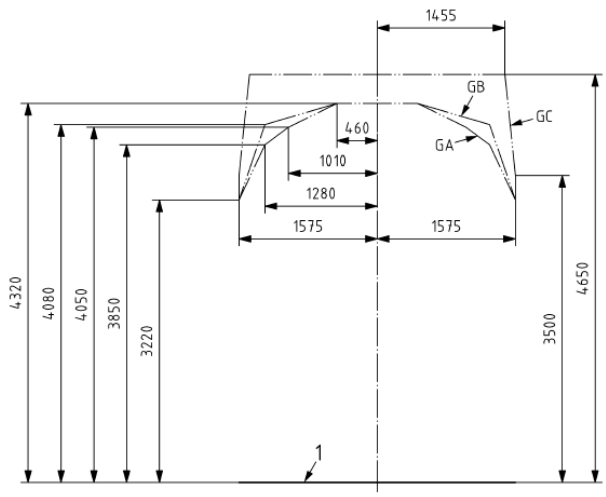

Figure 3. Reference profiles for static gauges GA, GB and GC

Main parameters and requirements were agreed to use for railway alignment, superstructure-track and substructure (embankments and earthworks, hydraulic, drainage and culverts, bridges, overpasses, tunnels and similar structures), railway energy (traction power system, catenary, non-traction power supply, electromagnetic compatibility), railway control-command signaling system, telecommunications system, SCADA, infrastructure facilities, stations and passenger platforms, environment, mechanical electrical plumbing in tunnel, adaption to climate change, BIM, architectural and landscaping, visual design requirements and security. Main line general cross-sections were prepared for designing (Figure 4).

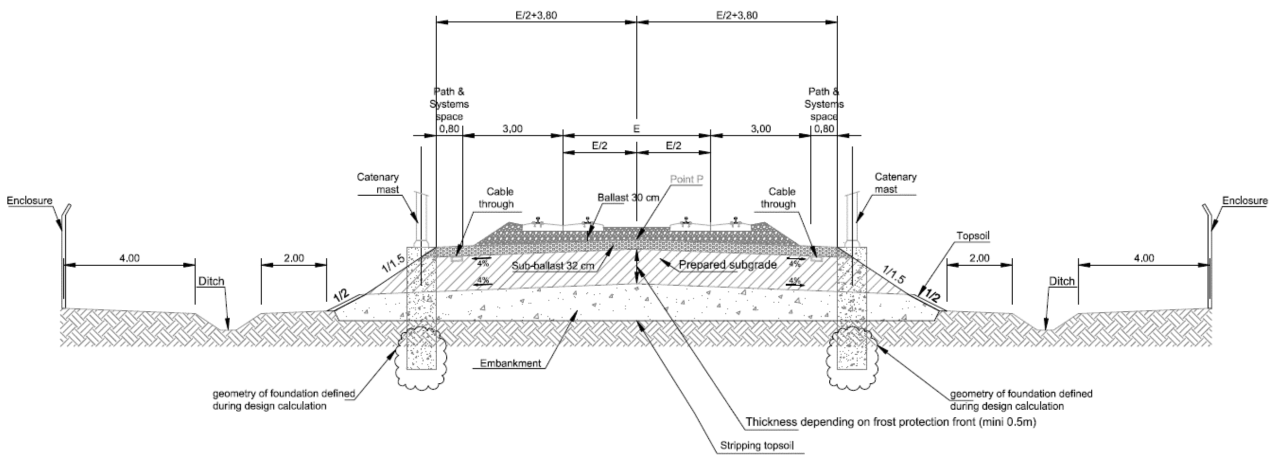

Figure 4. Cross-sectional profile. Main line embankment – Double track

3. Expert survey methodology

Expert survey methodology was applied for 1435 mm gauge railway infrastructure which is not in line with "Rail Baltica" main technical requirements and needs to be modernized accordingly. The aim of the survey was to rate main railway infrastructure technical parameters which should be used for railway modernization projects, when significant constraints exists. The survey evaluated in practice non-existent 1435 mm gauge railway line constructed by technical parameters: single track 1435 mm gauge railway line with passing loops, non-electrified, no ERTMS installed, passenger train design speed – 160 km/h, freight train design speed – 80 km/h, 22.5 t axle load, freight train length – 750 m, passenger train length – 200 m.

Experts participated in the survey were asked to rank infrastructure technical parameters by indicating what parameters should be met if significant project constraints such as insufficient financial resources, time shortage for project preparation and implementation would exists. It was agreed to do note rate the parameters accordingly construction technologies sequences.

4. Determination of the weight criteria by Kendall method

A criteria list was created prior to carrying out an expert survey. An existing scientific literature review was carried out to compile the list of criteria. It was indicated that the main targets of the infrastructure modernization are optimal infrastructure capacity (Gašparík et al., 2018), traffic safety level (Meijer et al., 2009), passenger and freight train speed (Lebid et al., 2019; Brezina & Knoflacher, 2014; Ižvolt & Hodas, 2012). It was noted as well that all main infrastructure parameters should be applied in a comprehensive system model to provide the optimum infrastructure design and capacity (Connor, 2014).

One of the main infrastructure parameters of the infrastructure is the geometry of the track (Lazarević et al., 2018a, 2018b; Stenstrom et al., 2012), on which not only the speed of the trains but also the energy consumption depends (Sarsembayev et al., 2015). When the railway traffic is increasing and with higher speed of trains there is an acute need for modernization of railway signalling technology. Even with the advent of microprocessor-based technology, the traffic capacity and safety targets could not be reached (Patalay, 2014).

The list below is made by way of expertise, i.e. a group, consisting of 11 persons formed by the authors hereof, have selected 20 key criteria (Table 1), which later should be subject to attribution of certain weights. 20 criteria for expert evaluation (Yazdani et al., 2016).

Table 1. Criteria list and description

Item No.	Railway infrastructure technical parameter	Description
Q1	Structure gauge	The structure gauge is the area where no track-side equipment shall be located (signals, catenary masts, etc.). It determines minimum height of structures tunnels and bridges. It is considered for "Rail Baltica" project to use GC structure gauge (agreed to update to SeC on 2020)
Q2	Distance between track centres	It is agreed that main lines in project "Rail Baltica" will be designed and constructed as double track. Therefore, it is important to use proper horizontal distance between track centers. According with INF TSI, when the design speed is from 200 km/h up to 250 km/h minimum nominal horizontal distance between track centres is 4.0 m, considering the margins for aerodynamic effects. However, according with RBDG, for mixed traffic section with 249 km/h maximum design speed it is agreed to use 4.5 m minimum distance between track centres
Q3	Maximum gradients	According with INF TSI, the gradient of tracks through passenger platforms and of rolling stock parking tracks shall not be more than 2.5 mm/m. The slope of the P1 main lines shall be 25 mm/m. An exception for slope of 35 mm/m could be used for the distances which do not exceed 6 km However, according with RBDG, the maximum gradient of 12.5 mm/m shall be used for mixed lines. It is considered nominal gradient of 8.0 mm/m for design of main lines purposes. For passenger lines maximum gradient of 25 mm/m can be used. For station tracks the nominal gradient limit is 0 mm/m. The maximum gradient limit is 1.5 m/mm and the exceptional gradient limit is 2.5 mm/m
Q4	Minimum radius of horizontal curve	According with RBDG, minimum radius of horizontal curve is considered as 3600 m. Recommended value is considered as 4000 m, when the design speed is 249 km/h and cant value is 90 mm
Q5	Minimum radius of vertical curve	According with RBDG, recommended radius of vertical curve is considered as 37201 m, exceptional value is 21700 m and minimum value is 15500 m, when design speed is 249 km/h
Q6	Number of tracks	It is agreed to use double track for main lines in "Rail Baltica"
Q7	Cant	According to INF TSI, the design cant for ballasted track of freight and mixed traffic lines shall be limited to 160 mm, for ballasted track of passenger traffic lines only shall be limited to 180 mm However, according to RBDG, the design cant shall be limited to 90 mm and the exceptional value is 110 mm
Q8	Design geometry of switches and crossings	INF TSI does not foresee exact requirements for design geometry of switches and crossings. However, it is indicated that the infrastructure manager needs to decide geometrical design values appropriate to its maintenance plan For "Rail Baltica" project it is recommended that mainline separation turnouts and crossovers carrying fare paying passengers have a minimum operating speed in the diverging track 140 km/h

End of Table 1

Item No.	Railway infrastructure technical parameter	Description
Q9	Track resistance to vertical loads	Track resistance to vertical loads considers the track, including switches and crossings affecting forces: the axle load, maximum vertical wheel forces and vertical quasi-static wheel forces
Q10	Longitudinal track resistance	Longitudinal track resistance considers longitudinal forces equivalent to the force arising from braking of 2.5 m/s^2
Q11	Lateral track resistance	Lateral track resistance considers lateral forces and quasi-static guiding forces
Q12	Resistance of bridges to traffic loads	Resistance of bridges to traffic loads consists of vertical loads, allowance for dynamic effects of vertical loads, centrifugal forces, nosing forces, actions due to traction and braking (longitudinal loads) and design track twist due to rail traffic actions. RBDG indicates to refer for requirements needed in INF TSI
Q13	Resistance of new structures over or adjacent to tracks	Resistance of new structures over or adjacent to tracks is described as aerodynamic actions from passing trains. RBDG indicates to refer for requirements needed in INF TSI
Q14	Resistance of new structures over or adjacent to tracks	Resistance of new structures over or adjacent to tracks considers bridges and earthworks resistance interoperability according to the TSI category of line. RBDG indicates to refer for requirements needed in INF TSI
Q15	Usable length of freight station tracks	According to INF TSI, the usable length of freight station track varies from 740 up to 1050 m. However, according to RBDG, usable length of freight station track is 1050 m which shall allow to retain 1050 m long freight trains
Q16	Usable length of passenger station tracks	According to INF TSI, the usable length of passenger station track varies from 200 up to 400 m. However, according to RBDG, usable length of passenger station track is 405 m
Q17	Usable length of platforms	According to INF TSI, the length of passenger station platform varies from 200 up to 400 m. However, according to RBDG, the length of passenger station platform is 400 m
Q18	Platform height	According to INF TSI two values are allowed for platform height: 550 and 760 mm. However, for Rail Baltica project 550 mm shall be used. A 12-meter-wide is usually planned on island platform and 6 to 9 meters on lateral platforms
Q19	Voltage and frequency	25kV 50Hz AC system is planned to be designed
Q20	Railway traffic management system	ERTMS level 2 for Rail Baltica project foreseen to be implemented and used

Individual surveys to these experts, hereinafter referred to as E1-E11, gave the results about the importance of criteria that can be observed in the Table 2.

Table 2. Criteria ranks awarded by each expert

	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**	**Q13**	**Q14**	**Q15**	**Q16**	**Q17**	**Q18**	**Q19**	**Q20**
E1	1	2	18	8	12	3	10	7	15	17	14	11	20	16	19	9	13	6	5	4
E2	1	5	6	15	10	14	16	17	4	9	18	2	11	3	20	19	13	12	7	8
E3	1	2	4	8	10	19	3	9	7	5	6	11	20	12	16	15	17	18	14	13
E4	12	9	8	7	6	5	4	3	20	19	18	17	16	15	14	1	13	2	11	10
E5	3	4	5	6	7	2	8	1	16	18	19	9	10	11	12	13	14	15	20	17
E6	3	4	14	15	16	12	13	5	9	10	11	7	8	1	20	19	18	17	6	2
E7	4	16	12	10	11	15	17	9	5	6	7	3	2	1	13	20	18	14	19	8
E8	5	6	14	15	18	4	19	13	10	11	12	2	9	3	7	8	16	17	20	1
E9	1	11	9	2	12	6	13	7	3	8	14	4	15	5	20	19	18	17	16	10
E10	1	2	12	11	13	19	14	9	6	7	8	3	4	5	17	18	20	15	16	10
E11	19	20	3	2	1	17	18	16	13	14	15	4	5	6	7	8	9	10	11	12

One of the simplest methods applicable – Kendall method (Kendall, 1970). Ranking is done pursuant to the criteria list, i.e. when the highest rank is given by an expert to the most important criterion, i.e. place or score equal to one. The second most important criterion is given a rank equal to two, the third one – three and etc. The last rank receives the lowest value of ranking. This method is logical and easily applicable in practical calculations (Jakimavičius et al., 2016).

Kendall concordance coefficient (Kendall, 1970) is linked with the sum of rank of each factor R_j and with regard to respondents or experts:

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

The mean rank of each factor $\overline{R}$ is obtained dividing the sum of ranks assigned thereto by number of factors:

$$\overline{R} = \frac{\sum_{j=1}^{m} R_j}{m}, \tag{2}$$

where: R_{ij} – rank given by expert *i* to factor *j*; *n* – number of experts ($i = 1, 2, ..., n$); *m* – number of factors ($j = 1, 2, ..., m$).

The difference between sum $\sum_{i=1}^{n} R_{ij}$ of ranks R_{ij} and constant quantity $\frac{1}{2}n(m+1)$ is calculated for each criterion:

$$\sum_{i=1}^{n} R_{ij} - \frac{n(m+1)}{2}. \tag{3}$$

The square of the difference between ranks‘ sum $\sum_{i=1}^{n} R_{ij}$ and constant quantity $\frac{n(m+1)}{2}$ is calculated:

$$\left[\sum_{i=1}^{n} R_{ij} - \frac{1}{2}n(m+1)\right]^2. \tag{4}$$

Upon calculation as per formulas (1)–(4), the next step is to calculate the concordance coefficient W:

$$W = \frac{12S}{n^2(m^3 - m)}. \tag{5}$$

Significance of concordance coefficient and compatibility of expert evaluation of factor groups is determined by χ^2:

$$\chi^2 = \frac{12S}{nm(m+1)}. \tag{6}$$

Min value of the concordance coefficient $W_{\min}$ is calculated from formula (7):

$$W_{\min} = \frac{\chi^2_{\nu,\alpha}}{n(m-1)}, \tag{7}$$

where: $\chi^2_{\nu,\alpha}$ – Pearson critical statistics, which value is found in the table (Montgomery, 2009), taking the degree of freedom $v = m - 1$ and significance level α.

The outcome from 11 expert surveys was that the structure gauge should be firstly adjusted (0.0779), second place – resistance of bridges to traffic loads (0.0684), third place – resistance of earthworks to traffic loads (0.0662), fourth place – distance between track centres (0.064), fifth place – railway traffic management system (0.0589), other criteria weights of modernization of 1435 mm gauge railway infrastructure are provided in Figure 5.

According to the results achieved, the priority parameters, were identified for railway modernization projects, when significant constraints exists such as insufficient financial resources. It should be noted that:

First priority parameters are structure gauge, resistance of bridges to loads and resistance of new structures over or adjacent to tracks. This parameters group could be explained as basic parameters which should be met prior to any railway traffic operation. For an instance, the structure gauge will play the most important role in the route consideration between different infrastructure managers. As well as resistance of bridges to loads and resistance of new structures over or adjacent to tracks will have crucial importance in route consideration and traffic safety.

Second priority parameters are distance between track centres, railway traffic management system, design geometry of switches and crossings. This parameters group could be assigned to the parameters which have biggest influence on the railway infrastructure performance – traffic speed, safety and management.

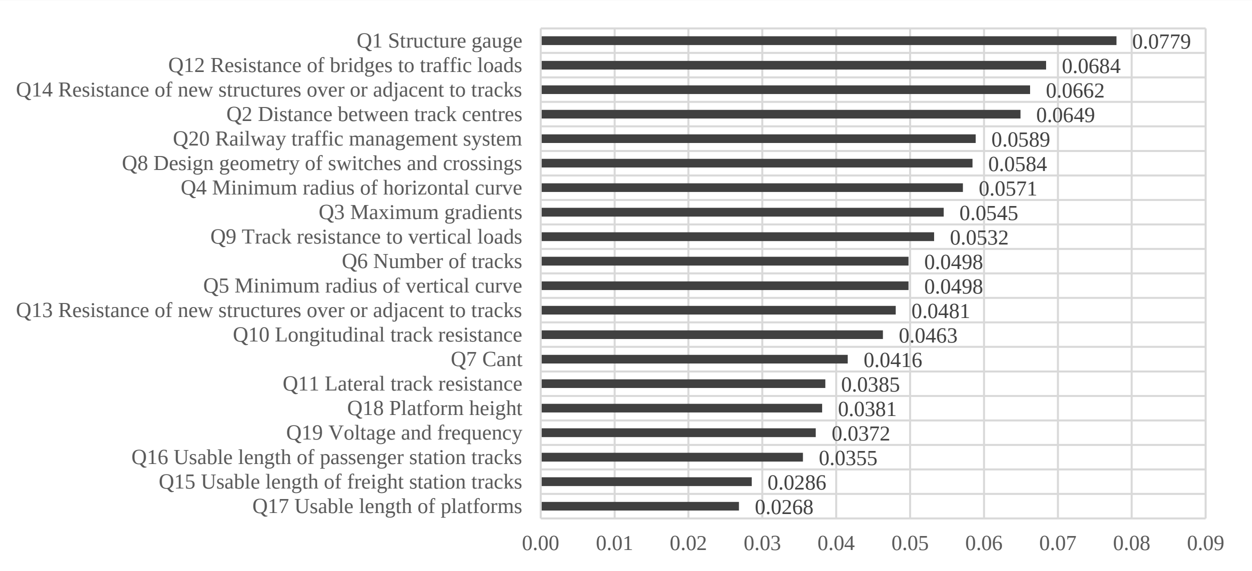

Figure 5. Determined criteria weights

Third priority parameters are minimum radius of horizontal curve, maximum gradients and track resistance to vertical loads, which corresponds mostly railway infrastructure operational parameters – traffic speed, safety, energy consumption and maximum loads of freight trains.

Fourth priority parameters are all other subsequent parameters, which are similar in purpose to parameters mentioned upon, but according to the survey results have lower importance. Additionally, should be discussed usable length of freight station tracks, passenger station tracks and passenger platforms. It should be stated that these parameters have crucial importance for railway infrastructure performance, effectiveness.

Conclusions

It should be noted at first that expert survey was conducted for a project which does not exist in the practice. Construction technologies and their sequence were not considered. Some expert surveys circumstances and conditions were taken from similar long-term international importance projects such as "Rail Baltica" project practice achieved during 2008–2015 years period, when insufficient project implementation time constraint existing as well as lack of commonly agreed technical parameters for project development between project partners.

After the expert surveying and evaluation of weights of railway infrastructure parameters it has been determined the basic parameters which need to be met during modernization of the projects when insufficient financial resources and time shortage for project preparation and implementation exist. Such parameters are prioritized as fallows: first place – structure gauge (0.0779), second place – resistance of bridges to traffic loads (0.0684), third place – resistance of earthworks to traffic loads (0.0662), fourth place – distance between track centres (0.064) and fifth place – railway traffic management system (0.0589).

It should be noted that similar expert survey should be conducted within the normal conditions when any constraints does not exist. It is obvious that according such conditions modernization parameters theoretically would be prioritized as follows: structure gauge, track alignment (horizontal and vertical radiuses, cant, distance between track centers, maximum gradients), number of tracks, design geometry of switches and crossings, track and bridge resistance to traffic loads, usable length of station tracks and platforms.

Therefore, for every railway infrastructure modernization project should be identified clear targets which shall be reached, constraints which exist and only afterwards – main infrastructure parameters that should be modernized. Using such framework, a comprehensive system model should be created and further research should be done.

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