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Gediminas VAIČIŪNAS
Vilnius Gediminas Technical University
Department of Railway Transport
J. Basanavičius str. 28, LT-03224 Vilnius, Lithuania
Corresponding author. E-mail: gediminas.vaiciunas@vgtu.lt

ASSESSMENT OF RAILWAY LINES: AN EFFICIENCY RATING ANALYSIS FOR BALTIC COUNTRIES

Summary. The article investigates a possibility of using the traditional multi-criteria assessment methods to evaluate how significance of a railway line is distributed for the countries it crosses. The article analyses two examples of railway lines: the railway line Rail Baltica (Poland, Lithuania, Latvia and Estonia) and the container train Viking route (Lithuania, Belarus and Ukraine). When investigating for which countries the Rail Baltica project will have bigger significance, and for which smaller, indicators of the countries are analysed by the length of Rail Baltica in the country, length falling per million residents in the country, length falling per thousand km of the existing railway, length per area of the county and length falling per country's gross domestic product (GDP). To generalize them, multi-criteria optimization methods, such the geometric mean method, were used. To answer the question whether the methodology used is adequate, it was tested using the example of the already operating container train Viking. The results of calculations for the previously mentioned criteria are combined with the actual distribution of the freight turnover. A positive conclusion is made about the adequacy of the methodology to assessment of the importance of the railway line for the country.

1. INTRODUCTION

The association of countries into political, economic or military unions gives rise to the need for new transport links. For example, with the change of the European Union structure (accession by one country, and secession by others), new trade routes are forming, and with the change of the NATO structure, new needs for the transportation of military freight emerge. New transport links should be efficient (passable), safe and environmentally friendly (for nature and human being). In light of the above, priority is given to the railway transport on land. Therefore, new railway lines are being constructed, and new train routes are being formed within the existing railway line networks. For some countries, these railway sections are more important, and for others, of less significance, and therefore are a permanent subject of doubts and debate. Therefore, a natural need arises to have a reasonable methodology for answering these questions. This need is especially relevant when investigating the significance of Eastern European railway lines [1,2]. This significance has several aspects. This is the significance of a new line in terms of the existing railway infrastructure, the environment (nature and geography), the country's economy and social aspect. Prior to making generalizations, it is worthwhile to find out what studies have been carried out on the aforementioned issues.

2. A SURVEY OF THE STUDY OF THE IMPORTANCE OF RAIL LINES

In different countries, geographic conditions, with varying need for tunnels, bridges, trenches, track formations and peculiarities for the operation of the given structures, are diverse. The given structures are ordered by different customers and designed by different designers, and therefore their operation parameters are different. For example, the structure of the roadbed may differ, which requires different means for ensuring safe train speed. A good example is described through Chinese high-speed railway. Prior to the Olympic Games in Beijing in 2008, a high-speed railway was completed, and further studies after several years of analysis thereof disclosed that a possible train speed varies in different stretches due to seismic patterns [3]. If such a situation recurs in the railway section that crosses different countries, claims could arise between the countries that one or another of them has failed to ensure the train speed determined in the original design. Besides, not only issues of geology but also of geodesy and topography are important. It is obvious that the whole railway line should be perceived as a uniform topographic system, although in different countries, different systems and databases for processing topographic information are valid [4]. Climate changes in the countries also make an impact. In warmer countries, the railway is covered by sand, and in northern regions, by snow. To solve these problems, respective studies are carried out, and their results are appropriate decisions, such as planting of greenery or installation of respective structures. Methodologies for selecting a more rational method have been developed [5]. One of the key parameters that should be assessed is the longevity of railway bridges and other structures. In the whole railway line, the service time of structures should be systemised. To this effect, methodologies for assessing the service time of railway structures may be used [6]. Based on design parameters of structures and traffic intensity parameters, it is possible to determine the service time of railway structures, and then to systemise it. Some authors emphasize the significance of railway structures for the environment. For example, with the ageing of structures, they pollute the environment, and this process must be controlled [7]. The authors provide methodologies on how to forecast pollution. However, the very same issue of information systemizing for the entire railway line remains. If climate is different in various countries (this is relevant for the lines constructed in the South-North direction), it is necessary to analyse the diversity of probability of track formations, bridges and other structures being washed away by rain water. Wash-away processes of the given structures have been investigated, and based on statistical data, methodologies have been created to forecast their indicators [8]. One only has to apply these methodologies for a respective line. Not to speak about railway structures, rails themselves wear out. Since rails are different and are operated differently, their depreciation in various routes will be different, and different countries will have to allocate different capacities to this effect [8]. Depreciation of the rails is forecastable, yet different forecasting and monitoring methods and systems are encountered. For example, in Turkish railways, a new mathematical apparatus for modelling the railway geometry was created that was more economic than the existing ones (in terms of facilities and maintenance), yet difficulties arose regarding its integration into the already existing systems [9]. This is in one country (Turkey), and if we speak about a line that crosses several countries, this problem becomes even more acute.

In social respect, a new railway line will have an effect on the cities adjacent to it and their transport infrastructure. Research shows that this is a reciprocal problem of both travelling people and those living in cities. Such issues as in what languages information should be announced in that railway line become acute. Sometimes it turns out that not only the railway harms the environment, but also the environment harms ergonomics of travellers, for example, bad architecture creates a bad view across the train window. This diminishes the competitiveness of trips [10]. One social issue is traffic safety. First of all, it should be agreed by what indicators it is assessed. In some countries, relative indicators falling per length of the railway network are determined, when train mileage is assessed, and in other countries, train operation in ton kilometres. Therefore, often, the same situation in one or another country may be assessed ambivalently. One of the examples is the railway safety study in Pakistan, where the authors emphasize and illustrate these facts [11]. Some authors note that, when examining railway efficiency, it is helpful to frame the discussion around two distinct railway functions: infrastructure and operations. For each of these functions, costs and revenues can be separated [12]. Studies by authors from different countries show that the aforementioned issues are not so relevant when considering the relevance of the railroad network in the internal country. In one country, the significance of future railways can be estimated from the projections of cargo flows [13, 14]. But the railway crosses several countries, and this question becomes more complicated.

When deciding what issues should be evaluated while investigating the distribution of significance of a railway line for respective countries, the conclusion increasingly rises up that it is hardly expedient to conduct in-depth research. Lithuanian research studies decided that a study should be started from the indicators that are noncomplicated, yet cover a broader range of issues. The indicator representing the social aspect could be the number of residents in a country, the indicator representing the economic aspect would be the country's gross domestic product, the geographic one would be area of the country and the indicator of the impact on the infrastructure could be the aggregate length of existing railway lines in the country. Researchers analysed the distribution of significance of the railway line Rail Baltica (constructed across Poland, Lithuania, Latvia and Estonia) and of the container train Viking route (going across Lithuania, Belarus and Ukraine) by countries.

3. RESEARCH METHODOLOGY AND RESULTS

When investigating for which countries the Rail Baltica project will have higher significance, and for which, smaller, indicators of the countries are analysed (pertaining to the significance of Rail Baltica for a country), such as length of Rail Baltica in the country, length falling per million residents in the country, length falling per thousand km of the existing railway, length per area of the county and length falling per country's gross domestic product (GDP). Each of these indicators only partially evaluates the significance of project under study for one or another country; therefore, to generalize them, multi-criteria optimization methods should be used. To solve this problem, one does not need too complicated methods. The choice of method is not the main purpose of this article (this is a separate topic), but a short review of the methods that could be performed is worthwhile. The most common are relatively simple methods, such as sum of ratings method, the geometric mean method and SAW (Simple Additive weighting) method [15]. These methods apply when the criteria are presented in a discrete form (in the form of numbers and not in function form). Usually they are technical or other actual data, and not the opinion of the respondents. Based on these elements of the method, more advanced methods are created. For example, PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluation) and ELECTRE (ELimination Et Choix Traduisant la REalité) methods provide the opportunity to present the criteria as functions [16]. AHP (Analytic hierarchy process) method provides the opportunity for the possibility of checking the consistency of respondent answers, thus checking whether the respondent answers responsibly [17]. For choosing a method for study, one can follow the principle of consistency from simple to more complex – first try the simplest methods, or if necessary, go to more complex ones. Because objective and homogeneous data are evaluated (in this study), there is no need to evaluate the hierarchy of criteria, which allows the method AHP. But rating by the sum-of-ratings method is insufficiently accurate, and with the help of it, one can build a priority sequence, but it is impossible to obtain a quantitative assessment of the alternatives. In other words, this method does not take into account the magnitude of the difference between alternatives. One of the simplest and fairly accurate is the geometric mean method. The generalized rating R_i is calculated for each country according to the following formula:

$$R_i = \sqrt[4]{\prod_{j=1}^{4} R_{ij}}\,; \tag{1}$$

where: R_i is the value of the generalized rating for i-country and R_{ij} is the value of j- indicator of i-country.

The number 4 is used because in this case four criteria are analysed. The essence of formula 1 is that for each country, the geometric mean of the value of the evaluation criterion is calculated. The value of each criterion is calculated as the proportion of its value from the sum of the value of that criterion by country:

$$R_{ij} = \frac{\frac{L_{ri}}{X_{ij}}}{\sum_{i=1}^{n} \frac{L_{ri}}{X_{ij}}}; \quad (2)$$

where: L_{ri} is the length of Rail Baltica in *i*-country, in km, and X_{ij} is the value of *j*-indicator in *i*-country (number of residents in the country, length of the existing railway, area of the county, and gross domestic product).

The data and results of calculations (ratings) are provided in Table 1.

Table 1

Results of percentage rating of Rail Baltica countries according to weightiness of indicator values

	Length falling per million residents	Rating according to length falling per million residents (R_{1j})	Length falling per thousand km of the existing railway, km	Rating according to length falling per thousand km of the existing railway, km (R_{2j})	Length falling per area of the country	Rating according to length falling per area of the country	Length falling per country's GDP	Rating according to length falling per country's GDP (R_{4j})	Mean of ratings, R_i
Estonia	176.2	**0.44**	109.0	**0.26**	5.07	**0.34**	8.8	**0.39**	***0.35***
Latvia	102.1	**0.25**	111.4	**0.26**	3.8	**0.25**	7.0	**0.31**	***0.27***
Lithuania	116.3	**0.29**	197.1	**0.46**	5.13	**0.34**	6.2	**0.27**	***0.34***
Poland	8.8	**0.02**	9.2	**0.02**	1.1	**0.07**	0.7	**0.03**	***0.04***

The study results showed that the biggest significance by this railway corridor will be for Estonia and Lithuania, and the smallest for Poland. The following significance coefficients were received: for Estonia, 0.35; for Lithuania, 0.34; for Latvia, 0.27; and for Poland, only 0.04. It should be noted that although this coefficient is very small for Poland, this does not indicate anything bad about the country. When comparing the scale of the railway corridor with the scale of the country, significance of the railway corridor for this country was assessed by this coefficient. Irrespective of that, when presenting such findings of the study in Poland, researchers of this country found them doubtful. Polish researchers provided an observation that Rail Baltica railway should not only be assessed in the section from Tallinn to Warsaw but also through a possibility of communication of the Baltic Sea region countries with Berlin and Hamburg. In this case, a bigger part of Rail Baltica would go across the territory of Poland, and this way would have a relatively greater significance for Poland. Polish researchers also noted that the research methodology should be primarily applied for the existing railway routes where freight turnovers are known. In this way, it would be possible to check whether the obtained distributions of significance of railway lines correlate with the actual distributions of freight flows. The authors of this study (Lithuanian researchers) found these remarks fairly reasonable; therefore, they took them into consideration in their next studies. The railway section from Tallinn to Hamburg was investigated. The ratio of Rail Baltica indicators with economic indicators of the countries was rated by the geometric mean method.

For analyzing the railway section from Tallinn to Hamburg, the geometric mean method was used [15], and the results of this calculation are provided in Table 2. In the numerator of formula 2, there is the length of Rail Baltica in *i*-country falling per unit of *j*-indicator (e.g. millions of residents, unit area of the country, etc.), and in the denominator, the ratio of the aggregate length of Rail Baltica with the sum of *j*-indicators (4 countries in the region). The results of calculations are provided in Table 2.

Table 2

Rating of the countries by the geometric mean method

	Length of Rail Baltica per million residents	Rating according to length falling per million residents	Length of Rail Baltica falling per thousand km of the existing railway	Rating according to length, falling per thousand km of the existing railway km	Length of Rail Baltica per area of the country	Rating according to length falling per area of the country	Length of Rail Baltica per GDP of the country	Rating according to length falling per GDP of the country	Rating average, R_i
Estonia	176.15	0.43	109.05	0.25	5.07	0.31	8.81	0.39	**0.34**
Latvia	102.08	0.25	111.36	0.26	3.79	0.23	7	0.31	**0.26**
Lithuania	116.32	0.29	197.06	0.45	5.13	0.32	6.2	0.27	**0.32**
Poland	8.83	0.02	9.24	0.02	1.09	0.07	0.71	0.03	**0.03**
Germany	4.74	0.01	9.4	0.02	1.08	0.07	0.13	0.01	**0.02**

The right column of Table 1 shows the final solution result obtained by assessing the indicators using the geometric mean method. The solution shows that the project is the most important for Estonia; the second by significance is Lithuania; the third, Latvia; the fourth, Poland; and the fifth, Germany. Since four countries of the Rail Baltica region were analysed (the line from Tallinn to Warsaw was analysed), a conclusion was made that the railway line had the smallest significance for Poland. By extending the analysed railway line up to Hamburg and adding the fifth state (Germany), it also became the country for which Rail Baltica railway will have the smallest significance of all the five countries of this region. This absolutely does not indicate anything bad about either Germany or Poland. This means that when comparing the scale of the Rail Baltica line with economic and social scales of these countries, the given railway line is more significant for other countries in the region, such as Estonia or Lithuania. For the Tallinn – Hamburg line, data for calculations are taken from Table 2 (right column), and for the Tallinn – Warsaw line, from-Table 1. A summary of the calculation results is provided in Fig. 1.

The comparison of dimensionless rating values (see Figure 1) shows that a new country appearing in the results of a new study did not change significance ratios of the Rail Baltic railway line among other countries, but only proportionately reduced the values of dimensionless ratings (as if took away a part from them for itself proportionately). Such survey results raised the question even more acutely whether the methodology used is adequate, and to be more precise, whether the results of use of such methodology would correlate with the actual distribution of freight flows.

4. VERIFICATION OF THE ADEQUACY OF THE METHODOLOGY

The previously mentioned question may be answered by an assessment of the usefulness of the container train Viking for the countries. The container train Viking is an on-going project; therefore, there are all possibilities to compare the results of methodology application with the distribution of freight flows. For investigating the route significance, the very same method was used as the one used for analysing the Rail Baltica route. When analysing the train load, statistical data on the number of transported containers in 2015 and 2016 were collected first of all. The measurement unit of container turnover is a relative 20-foot container – TEU. These data are provided in Table 3.

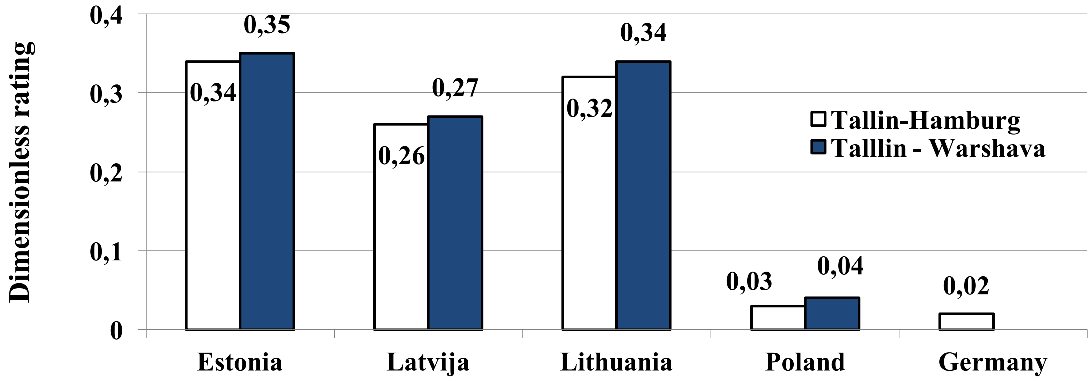

Fig. 1. Comparison of the distribution of rating values

Table 3

Transport volumes of by the container train Viking, in TEU containers a year

Direction	Transport volumes, TEU containers a year		Mean transport volumes, in TEU containers a year
	2015 year	2016 year	
Lithuania – Belarus	19562	16008	17785
Lithuania – Ukraine	1615	3691	2653
Belarus – Lithuania	19847	16218	18032
Ukraine – Lithuania	224	981	602

When analysing the means of transport volumes in TEU containers a year, it is clear that the biggest volumes are from Lithuania to Ukraine and from Lithuania to Belarus, i.e., 17-18 thousand TEU containers a year on average. These results show that the train Viking has the greatest significance for Lithuania. This significance may be clarified by assessing how many TEU containers were imported into the country, and how many were exported. On the other hand, when assessing the number of imported or exported TEU containers, consideration should be made to the volume of the country's economy, and they are defined by the gross domestic product GDP [19]. Therefore, an assessment criterion may be the ratio of imported or exported TEU containers with the country's GDP. Data on the countries' GDP and the number of imported and exported TEU containers are provided in Table 4.

Table 4

Data on the countries' GDP and the number of imported and exported TEU containers

State	GDP	Imported TEU containers	Exported TEU containers
Lithuania	38,345	18634	20438
Belarus	44,773	17785	18032
Ukraine	140,484	2653	602

Based on data provided in Table 4, further, the ratio of imported or exported TEU containers with the country's GDP will be calculated. The generalized significance of the container train Viking by countries (crossed by the train) may be assessed by the geometric mean method, using the formulas 1 and 2. Each indicator is calculated through a rating by each country. The rating shows what share the indicator value by country constitutes with respect to the sum of values of that indicator. Calculation results are provided in Table 5.

Table 5

Ratings of the significance of container turnover of the train Viking by countries

State	Imported/ GDP, TEU containers/ billion USD	Rating according to "imported/ GDP"	Exported/ GDP, TEU containers/ billion USD	Rating according to "exported/ GDP"	Generalised rating of the significance of container turnover
Lithuania	486.0	0.54	533.0	0.57	**0.55**
Belarus	397.2	0.44	402.7	0.43	**0.43**
Ukraine	18.9	0.02	4.3	0.00	**0.01**

Table 5 clearly shows that the container train Viking, in terms of container turnover, has the greatest significance for Lithuania. By rating the ratio of the number of imported and exported TEU containers with the GDP by the geometric mean method, the rating value for Lithuania is 0.55, for Belarus it is smaller by one forth at 0.43, and for Ukraine is smaller by 55 times than that for Lithuania at 0.01. Having in mind the fact that the train Viking is a project of Lithuania, such a distribution of indicators is justified. Yet, by assessing the scale of countries crossed by the aforementioned train, a question arises whether such ratio of the indicators is normal, since Belarus and Ukraine are the countries with a bigger economic potential than Lithuania, therefore the container turnover should be bigger there. This question may be partially answered after assessing the significance of this route for the countries. By assessing the significance of the route of the container train Viking for the countries (crossed by the route), ratings of each country were calculated with respect to specific criteria. The criteria are the ratio of the length of the train Viking route in that country with the length of railways, number of residents, gross domestic product, and area of that country. For each country, the rating is calculated using the formula 1 by each of these criteria. This rating shows what share the given indicator analysed in terms of one of the country constitutes in the sum of these indicators (in terms of all countries). Using the formula 2, the geometric mean of ratings is calculated – a generalized rating of the route significance. Significance ratings of the container train Viking route for the countries are shown in Table 6.

Comparison of generalized rating of route significance and generalised rating of the significance of container turnover is provided in Fig. 2.

Interestingly, the distribution of the generalized rating values of container turnover significance (Fig. 2), although not very precisely, yet essentially reiterate the distribution of analogous rating results of the ratio of container turnover with the countries. From this fact, we can make a positive conclusion about the adequacy of the methodology to assessment of the importance of the railway line for the country.

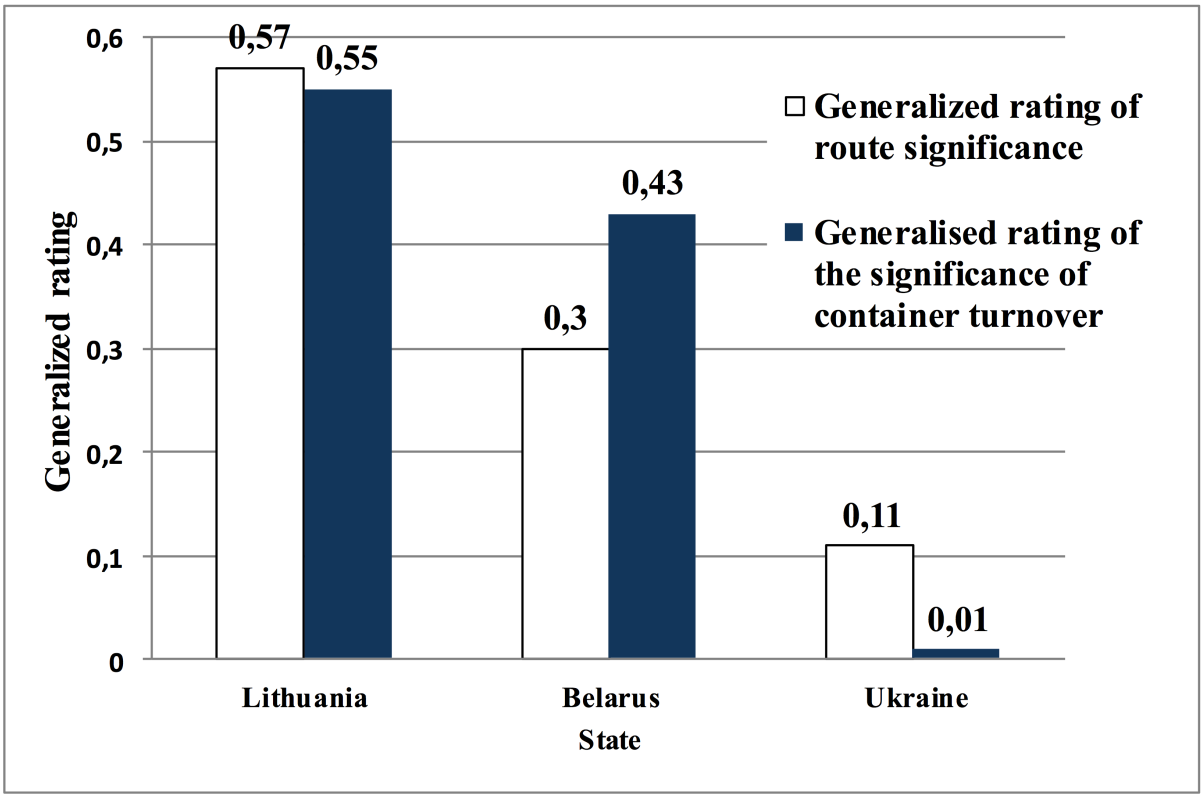

Fig. 2. Comparison of Generalized rating of route significance and Generalised rating of the significance of container turnover

5. CONCLUSIONS

1. The investigation found that it is possible to assess the significance of the railway line for the countries it crosses, relying on length falling per million residents in the country, length falling per thousand km of the existing railway, length per area of the county, and length falling per country's gross domestic product (GDP). To generalize them, multicriteria optimization methods, such as the geometric mean method, were used.
2. The investigation found that, the biggest significance by railway corridor Rail Baltica, from Tallin before Warshaw, will be for Estonia and Lithuania, and the smallest, for Poland.
3. In addition, studies have found that a new country additionally included in the route did not change significance ratios of the Rail Baltic railway line among other countries, but only proportionately reduced the values of dimensionless ratings (as if took away a part from them for itself proportionately).
4. To assess the adequacy of the methodology, it was tested on the data of the operating railway line (the container train Viking). Comparing the distribution of significance indicators with the distribution of the turnover of the grapes, an obvious correlation was observed. Based on that fact, the author concludes that the methodology is adequate.

Table 6

Significance ratings of the container train Viking for the countries

State (code)	LT	BY	UA
Length of the Viking route, km	434	554	756
Length of the country's railway network, km	1878	5491	21640
Ratio of the length of the Viking route with the length of the country's railway, km/thousand km	0.23	0.10	0.03
Rating according to the ratio of the length of Viking route with the length of the country's railway	**0.62**	**0.27**	**0.09**
Number of residents, in million	2.88	9.48	45.5
Length of Viking route falling per million of residents, km/million residents	150.7	58.4	16.6
Rating according to the length of Viking route falling per million residents	**0.67**	**0.26**	**0.07**
GDP, billion USD	38.34	44.77	140.5
Length of Viking route falling per GDP in billion USD, km/billion USD	11.32	12.37	5.38
Rating according to the length of Viking route falling per billion USD of GDP	**0.39**	**0.43**	**0.19**
Area in thousand km^2	65.3	207.6	603.6
Length of Viking route falling per km^2 of the area	6.65	2.67	1.25
Rating according to length of Viking route falling per km^2 of area, km/km^2	0.6	0.3	0.1
Generalized rating of route significance	**0.57**	**0.30**	**0.11**

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