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DETERMINATION OF THE INFLUENCE OF INFRASTRUCTURAL AND ECONOMIC FACTORS ON THE VOLUME OF FREIGHT TRANSPORT ON RAILWAY LINES IN POLAND

Summary. This article assesses the effect of factors, such as the number of sidings, the number of station holds, and the occurrence of transit traffic on the volume of freight transport on railway lines in Poland. The volume of freight transport on a railway line was expressed by the operational work done by freight trains running on this line and the transported freight mass by them. Most often the effect of factors affecting on the volume of transport is assessed by a team of experts. In this analysis, calculations of partial correlation coefficients were performed. The calculations showed that there is a clear relationship between the volume of freight transport and the number of sidings on the line and the occurrence of transit traffic. Based on the obtained partial correlation coefficients, weights corresponding to the effects of individual factors on the volume of freight transport were calculated. The use of these weights for further analysis will avoid the subjective expert assessments that have been used in this type of analysis so far.

1. INTRODUCTION

Comprehensive analyses of railway freight transport in Poland are not performed as often as for passenger transport. It is associated, among others, with difficult access to data. Even when the traffic infrastructure model was made by the national infrastructure manager – Polish National Railways Polish Railway Lines, it was necessary to limit the analysis owing to data availability [1]. Many different factors, such as the number of sidings (both station and route), the number of station holds, and the occurrence of transit traffic, affect the volume of freight transport on a railway line. Large plants generating full train shipments are most often connected to a specific railway line by station siding. In the case of local railway lines with a small number of open traffic posts, the connection of the plant with the railway line may be a rail siding. If the plant wishing to send or receive full-load shipments is located at a distance from the railway line, and the number of freight trains needed to operate this plant is small, station holds are used. Then the goods are transported between the railway station and the plant by road transport. During planning the freight transport using railway, it is important to take into account 3 elements of the transport process: substitution of an empty train for loading, passing of a train with a load, and return of an empty train after unloading [2]. Computer programs that perform various types of operational tests are used to solve the problem of network design [3].

This research assesses the effect of selected factors on the volume of freight transport on railway lines located in various voivodeships in Poland. The purpose of this article is to determine the effect and weights of individual factors affecting the volume of freight transport on individual railway lines using partial correlation coefficients. During these calculations, factors affecting the volume of freight transport were used as independent variables, whereas parameters describing the volume of transport were used as dependent variables. The carried-out analyses will allow determining whether individual factors affect the volume of freight transport on this line. Considering the effect of a specific factor on the volume of transport, its weight can be obtained in the range of 0 to 1. The sum of the weights of all factors is 1. Earlier similar analyses were carried out for passenger transport for individual voivodships [4]. In passenger transport, the analysis of the effect of socio-economic factors was also carried out for selected railway lines; however, railway freight transport was not analyzed [5]. The weight values determined in this way can be used in the future for analyzing railway lines in Poland in terms of their use in freight transport. In the case of the anticipated large number of freight trains running on a specific line, it is possible to increase its capacity by reconstruction of the track surface or station railway traffic control devices [6]. In turn, in the case of lines that were excluded from use many years ago, new analyses, carried out after a change in the economic situation of the region in which this line runs, may contribute to its reactivation [7].

2. ANALYZED RAILWAY LINES

In Poland, not all railway lines meet the requirements set by entities commissioning freight transport. The speed limit on almost half of the railway lines does not exceed 60 km/h. Currently, many railway lines are being renovated, which causes traffic restrictions and additional difficulties for clients ordering transport [8]. Railway lines should have optimal construction parameters, which allows reducing energy consumption by trains running on them. This is most important in freight transport, because the energy needed to accelerate a heavy loaded freight train after being released at a point speed limit is much higher than for a much lighter passenger train [9]. The socio-economic situation in various regions of Poland is diversified. In the west of the country, there are areas with a higher population density and many industrial plants. In turn, the east of Poland is characterized by a lower number of inhabitants, and there are also much fewer industrial plants. This diversification affects the volume of rail transport, including freight transport. Therefore, representative 32 railway lines located in various voivodships were selected for analysis. One main line and one local line were selected from each voivodeship. This allows for taking into account specific features occurring in different regions of Poland during the analysis. Both the main railway lines passing through national and regional commercial centers as well as local railway lines located in sparsely populated areas were taken into account. Railway lines in various technical conditions and with different speed limits were selected. Some of these lines are electrified.

The representative 32 railway lines selected for the analysis allow the results to be extended to the entire territory of Poland. The analyzed railway lines are presented on maps. The main railway lines are marked in red, whereas the green color represents local lines. All analyzed railway lines have been numbered; these numbers are shown in Table 1. The numbers of the analyzed railway lines are also marked on the maps. Railway lines located in the north-west of Poland are shown in Fig. 1. In turn, the railway lines located in the north-eastern part of the country are shown in Fig. 2. Then, Fig. 3 shows the railway lines located in the south-west area of Poland. However, Fig. 4 shows railway lines located in the south-eastern part of the country. Table 1 presents the analyzed railway lines divided into voivodships in which they are located. In addition, the length of these lines is given in the table.

The volume of freight transport on the analyzed railway lines was expressed by the operational work done by freight trains running on these lines during the 2018 year and the transported freight mass by them. The values of these two parameters for individual railway lines are presented in Table 2. Owing to the fact that the analyzed railway lines are of different lengths in order to enable their comparison during calculations, the amount of transport work done was not used directly, but its relation to the length of the line. In that way was obtain the number of running freight trains on a railway line during the year. The volume of transported freight mass was used directly because it is not dependent on the length of the line.

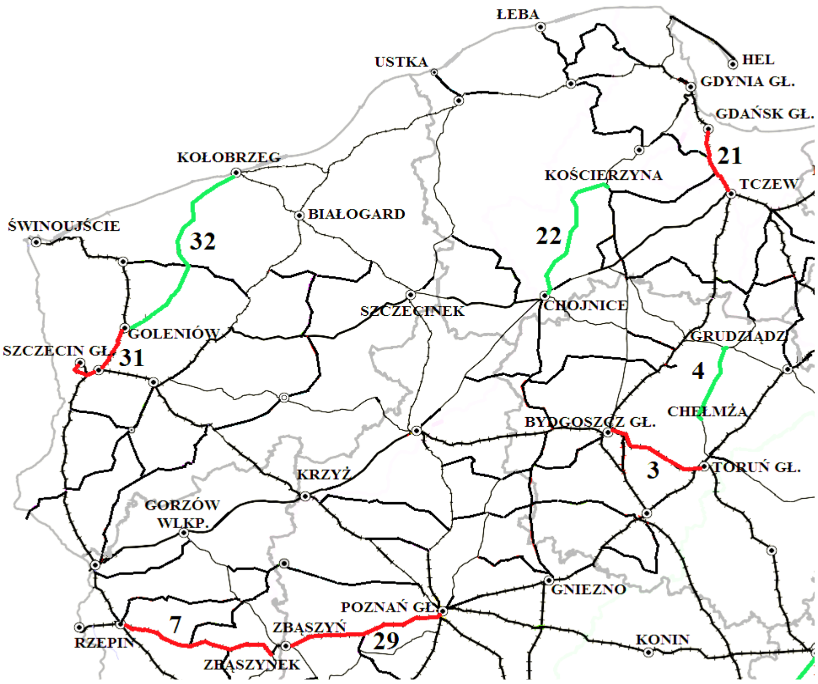

Fig. 1. Railway lines located in the north-west of Poland [20]

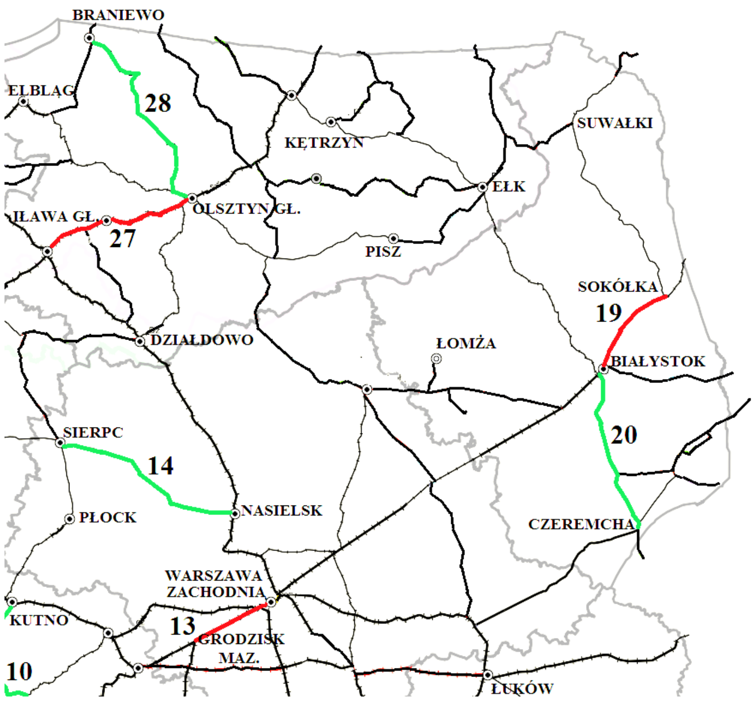

Fig. 2. Railway lines located in the north-east of Poland [20]

3. FACTORS AFFECTING THE VOLUME OF FREIGHT TRANSPORT

The railway network can be divided into railway lines, stations, station holds, and sidings. These elements are connected, thus interacting and influencing each other [10]. The volume of freight transport on a specific railway line depends on the location in the area through which the railway line runs plants, which can send or receive full train shipments. These plants can be connected with a railway line via station siding, track siding, or may not have a direct rail connection. Then the load between the plant and the nearest station hold is transported by trucks. Less often, smaller plants use rail transport, where only a few wagons arrive. Then these wagons are combined into longer train sets at marshalling yards. Various IT systems are used to improve this process [11]. Rail transport most often is used when plants generating demand for the transport have goods of significant weight, over a considerable distance and with one designated destination. Hard coal, metal ores, petroleum and related products, aggregates, sand, gravel, and clay are transported most often in Poland using rail transport [12]. The volume of goods to be transported and their mass is a key factor in determining the price for its transport by a railway carrier [13]. Therefore, in the case of more dispersed loads, road transport is most often used.

Therefore, in 2015, 224.3 million tons of goods were transported on railway lines in Poland, whereas in the same year as much as 1505.7 million tons of goods were transported by road transport [14]. Attempts have been made to use railway transport toward movement of dispersed goods over short distances within an agglomeration using suburban railways, but such a solution has not been applied in practice [15]. Container terminals, which generate more and more train traffic, are also connected with railway lines by sidings [16]. In addition, there may be carried out freight train traffic on a railway line not serving plants located in its vicinity, but overcoming it in transit when the railway line is part of a longer transport route. During the analysis, factors such as the number of sidings (station and route), the number of stations holds, and the occurrence of transit traffic were taken into account. These data are presented in Table 3. To enable comparison of the analyzed railway lines, which have different lengths, the calculations did not directly use the values of factors such as the number of sidings and the number of stations holds, but their ratio to the length of the line. Only the occurrence of transit traffic on a railway line is not dependent on its length. In the case of this factor, information is provided whether or not there is transit traffic on the route.

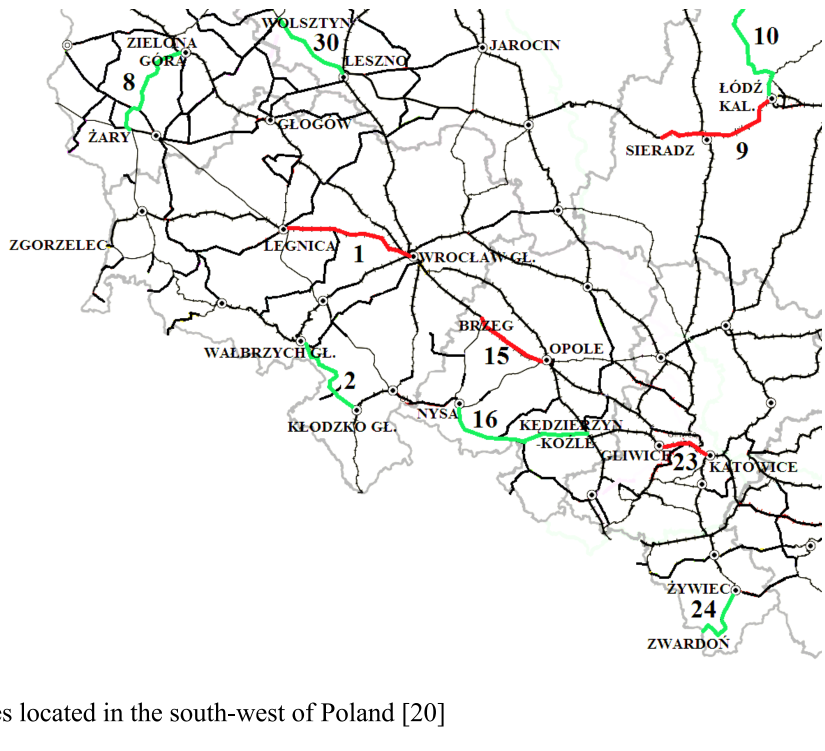

Fig. 3. Railway lines located in the south-west of Poland [20]

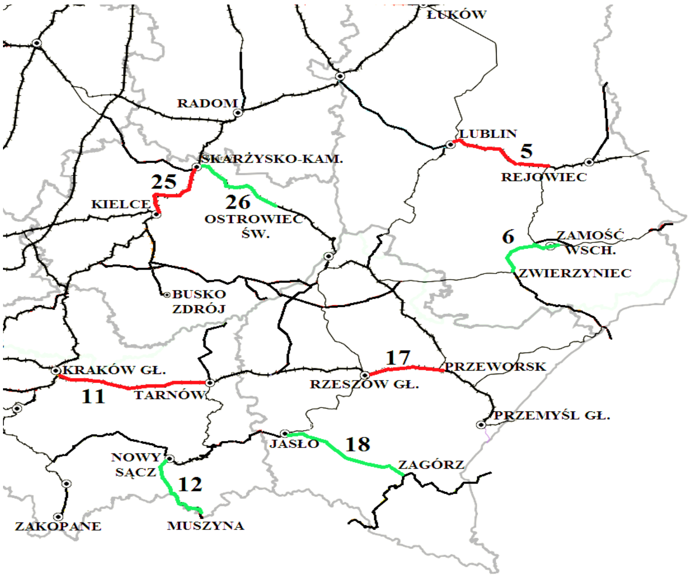

Fig. 4. Railway lines located in the south- east of Poland [20]

Table 1

Main and local analyzed railway lines

Voivodship:	Main line:	Line length [km]:	No. on the map:	Local line:	Line length [km]:	No. on the map:
Lower Silesian	Wrocław Gł. – Legnica	65	1	Kłodzko Gł. – Wałbrzych Gł.	51	2
Kuyavian-Pomeranian	Bydgoszcz Gł. – Toruń Gł.	51	3	Grudziądz – Chełmża	38	4
Lubelskie	Lublin – Rejowiec	55	5	Zamość Wsch. – Zwierzyniec	32	6
Lubuskie	Zbąszynek – Rzepin	75	7	Żary – Zielona Góra	53	8
Łódzkie	Łódź Kal. – Sieradz	59	9	Łódź Kal. – Kutno	68	10
Lesser Poland	Kraków Gł.– Tarnów	77	11	N. Sącz – Muszyna	51	12
Mazovian	Warszawa Zach. – Grodzisk Maz.	27	13	Nasielsk – Sierpc	88	14
Opolskie	Opole Gł. – Brzeg	40	15	Nysa – Kędz. Koźle	75	16
Podkarpackie	Rzeszów –Przeworsk	36	17	Jasło – Zagórz	69	18
Podlaskie	Białystok – Sokółka	42	19	Białystok – Czeremcha	77	20
Pomeranian	Gdańsk Gł. – Tczew	32	21	Chojnice – Kościerzyna	69	22
Silesian	Katowice – Gliwice	27	23	Żywiec – Zwardoń	37	24
Świętokrzyskie	Kielce – Skarżysko-Kam.	45	25	Skarżysko-Kam. – Ostrowiec Św.	46	26
Warmia-Masurian	Olsztyn Gł. – Iława Gł.	69	27	Olsztyn Gł. – Braniewo	96	28
Greater Poland	Poznań Gł.– Zbąszyń	74	29	Leszno – Wolsztyn	46	30
West Pomeranian	Szczecin Gł. – Goleniów	38	31	Kołobrzeg – Goleniów	100	32

4. DETERMINATION OF THE INFLUENCE OF INDIVIDUAL FACTORS ON THE VOLUME OF FREIGHT TRANSPORT

The most popular and simplest correlation coefficient is the Pearson correlation coefficient. This coefficient determines the effect between 2 analyzed variables. Unfortunately, the obtained value of Pearson's correlation coefficient may be disturbed owing to the relationship of a pair of variables with other analyzed variables [17]. Therefore, the analysis of the effect of individual factors on the volume of railway freight transport was carried out using partial correlation coefficient. This coefficient allows to determine the relationship between two variables excluding the influence of other analyzed variables [18]. For calculation, the partial correlation coefficient correlation matrix is used. This matrix contains all the relationships between analyzed variables. The individual element of the correlation matrix is the value of the Pearson correlation coefficient for the variables i and j. The partial correlation coefficient is calculated using the formula (1).

Table 2

Parameters describing the volume of freight transport on the analyzed lines

Section:	Operational wok done [train km]:	Transported freight mass [tones]:
Wrocław Gł. – Legnica	1007240	21887528
Kłodzko Gł. – Wałbrz ,bgnych Gł.	39312	3777280
Bydgoszcz Gł. – Toruń Gł.	169936	4911920
Grudziądz – Chełmża	0	0
Lublin – Rejowiec	219960	14143480
Zamość Wsch. – Zwierzyniec	128128	6558812
Zbąszynek – Rzepin	1228500	19692296
Żary – Zielona Góra	9464	423748
Łódź Kaliska - Sieradz	518492	11996192
Łódź Kaliska - Kutno	159120	2886156
Kraków Gł. – Tarnów	560560	10102248
Nowy Sącz – Muszyna	143208	3898024
Warszawa Zach. – Grodzisk Maz.	181116	11321908
Nasielsk – Sierpc	50336	961272
Opole Gł. – Brzeg	505440	19030076
Nysa – Kędzierzyn Koźle	284700	5893576
Rzeszów Gł. – Przeworsk	123552	5311956
Jasło – Zagórz	48360	390780
Białystok – Sokółka	259896	11129300
Białystok – Czeremcha	244244	5527340
Gdańsk Gł. – Tczew	990080	50434852
Chojnice – Kościerzyna	3536	317824
Katowice – Gliwice	179712	7623928
Żywiec – Zwardoń	1924	23712
Kielce – Skarżysko-Kamienna	444600	14357304
Skarżysko-Kamienna – Ostrowiec Św.	243984	8025264
Olsztyn Gł. – Iława Gł.	304980	5058300
Olsztyn Gł. – Braniewo	39936	221936
Poznań Gł. – Zbąszyń	1377584	23800348
Leszno – Wolsztyn	4680	329940
Szczecin Gł. – Goleniów	237120	10029500
Kołobrzeg – Goleniów	15808	119080

$$r_{ij.1..(i-1)(i+1)..(j-1)(j+1)..k} = -\frac{C_{ij}}{\sqrt{C_{ii} \cdot C_{jj}}} \quad (1)$$

where: C_{ij}, C_{ii}, C_{jj} – algebraic complements of the elements r_{ij}, r_{ii}, r_{jj} of matrix.

Table 3

Factors affecting the volume of freight transport

Section:	No of sidings:	No of station holds:	Transit traffic:
Wrocław Gł. – Legnica	5	2	occurs
Kłodzko Gł. – Wałbrzych Gł.	2	1	lack
Bydgoszcz Gł. – Toruń Gł.	2	1	occurs
Grudziądz – Chełmża	1	0	lack
Lublin – Rejowiec	4	1	occurs
Zamość Wsch. – Zwierzyniec	4	1	occurs
Zbąszynek – Rzepin	4	1	occurs
Żary – Zielona Góra	4	2	lack
Łódź Kaliska – Sieradz	3	2	occurs
Łódź Kaliska – Kutno	3	0	occurs
Kraków Gł. – Tarnów	5	2	occurs
Nowy Sącz – Muszyna	1	0	occurs
Warszawa Zach. – Grodzisk Maz.	2	1	occurs
Nasielsk – Sierpc	1	2	lack
Opole Gł. – Brzeg	4	0	occurs
Nysa – Kędzierzyn Koźle	1	1	occurs
Rzeszów Gł. – Przeworsk	2	1	occurs
Jasło – Zagórz	3	2	lack
Białystok – Sokółka	7	0	occurs
Białystok – Czeremcha	5	1	occurs
Gdańsk Gł. – Tczew	16	1	occurs
Chojnice – Kościerzyna	2	0	lack
Katowice – Gliwice	5	0	occurs
Żywiec – Zwardoń	1	1	lack
Kielce – Skarżysko-Kamienna	2	0	occurs
Skarżysko-Kam. – Ostrowiec Św.	2	1	occurs
Olsztyn Gł. – Iława Gł.	1	0	occurs
Olsztyn Gł. – Braniewo	3	1	lack
Poznań Gł. – Zbąszyń	5	0	occurs
Leszno – Wolsztyn	1	2	lack
Szczecin Gł. – Goleniów	3	1	occurs
Kołobrzeg – Goleniów	2	2	lack

The partial correlation coefficient allows to determine only the linear relationship between the analyzed variables. Therefore, after its calculation, especially in the case of obtaining no relationship between variables, it is necessary to analyze scatter plots to check whether there is no non-linear relationship between the analyzed variables. Another problem occurring during calculations is the considerable complexity of calculations performed using partial correlation coefficient. Owing to the fact that these calculations are very complex, STATISTICA software was used to calculate partial correlation coefficients. During calculations, individual factors affecting the volume of freight transport, presented in Table 3, were used as independent variables. In turn, the parameters determining the volume of freight transport contained in Table 2 were used as dependent variables. Owing to the total lack of freight transport, the railway line between Grudziądz and Chełmża, located in the Kuyavian-Pomeranian Voivodeship, was excluded from the calculations. Freight trains on this line ran in the years 2009-2010, when aggregates necessary for the construction of the A1 motorway was transported. At present, no plants generate freight traffic on this section, and transit freight traffic is also not carried out. Therefore, calculations of partial correlation coefficients were made for 31 different railway lines. The results of calculations of partial correlation coefficients are presented in Table 4. In this table, values of the correlation coefficient with a significance level of 0.05 bilaterally are shown in bold, whereas the correlation coefficient values with a significance of 0.01 bilaterally are shown in bold and italics.

Table 4

Calculated values of partial correlation coefficients

Factor:	Operational work done / line length [trains]:	Transported freight mass [tones]:
Number of sidings / line length	**0.691**	**0.768**
Number of station holds / line length	-0.017	0.045
Transit traffic	***0.474***	***0.496***

The calculations showed that there is a clear relationship between the volume of freight transport and the number of sidings on a railway line and the occurrence of transit traffic. This relationship occurs for the volume of freight transport expressed both by the number of launched freight trains on the line during the year and by the transported freight mass. The obtained results of partial correlation coefficients show the complete lack of relationship between the volume of freight transport on a railway line and the number of stations holds on this line. Fig. 5 presents a scatter chart of transported freight weight depending on the number of stations holds on this line. From this chart, it can be noticed not only the lack of a linear relationship, which was indicated by the test using a partial correlation coefficient, but also the lack of any relationship between these quantities. This is owing to the fact that the majority of factories that generate heavy freight trains are connected to railway lines using sidings. Station holds are currently only used sporadically, mainly by smaller plants; loading on them usually takes place in primitive conditions; it lasts a long time; and the number of freight trains generated in this way is small. As a result, freight trains ending or starting a run at a specific station and loaded at that station's hold do not affect the overall volume of transport on the railway line, on which this station is located. After switching off the factor of the number of stations holds, the partial correlation coefficients were again calculated for the remaining factors. The results of these calculations are presented in Table 5.

Table 5

Calculated values of partial correlation coefficients after eliminating the number of stations holds

Factor:	Transport work done / line length [trains]:	Transported freight mass [tones]:
Number of sidings / line length	**0.696**	**0.776**
Transit traffic	***0.496***	***0.505***

The values of partial correlation coefficients after eliminating the number of station holds for both the number of sidings and for the occurrence of transit traffic increased slightly. The largest relationship exists between the transported freight mass and the number of sidings. This relationship is shown in Fig. 6.

This graph shows that the amount of transported freight mass is closely related to the number of sidings located on a railway line. The smallest correlation occurs between the number of freight trains running on a line during the year and the occurrence of transit traffic on this line. In the case of transit traffic, which may be or not, in calculations a value 1 was assumed if there is transit traffic on an analyzed line, whereas if there is no transit traffic on a line, the value 0 was adopted. The scatter chart of the dependence of operational work done on the occurrence of transit traffic is presented in Fig. 7.

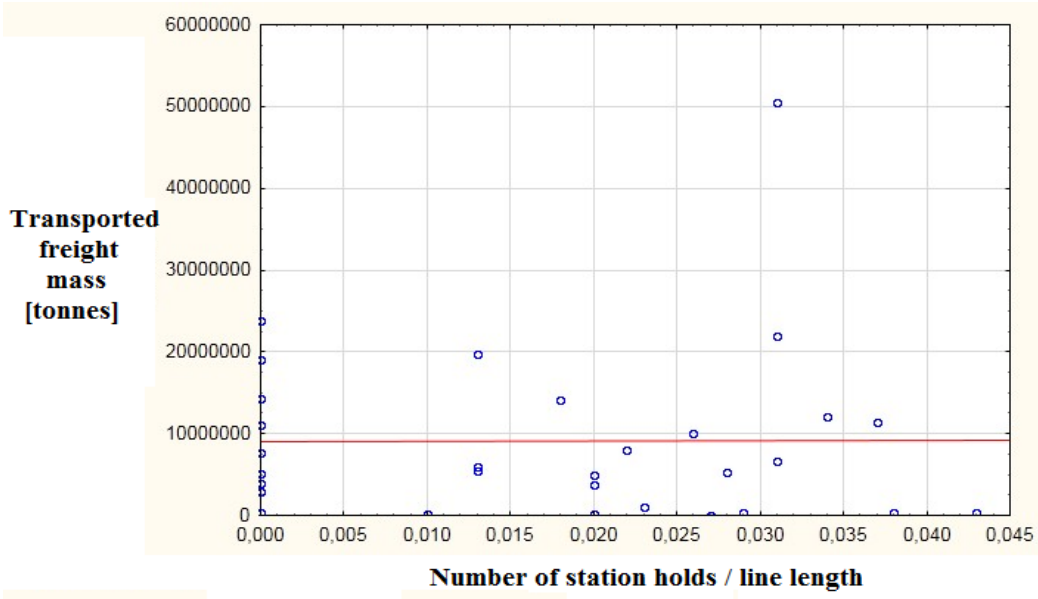

Fig. 5. A scatter chart of transported freight mass and the number of station holds on the line

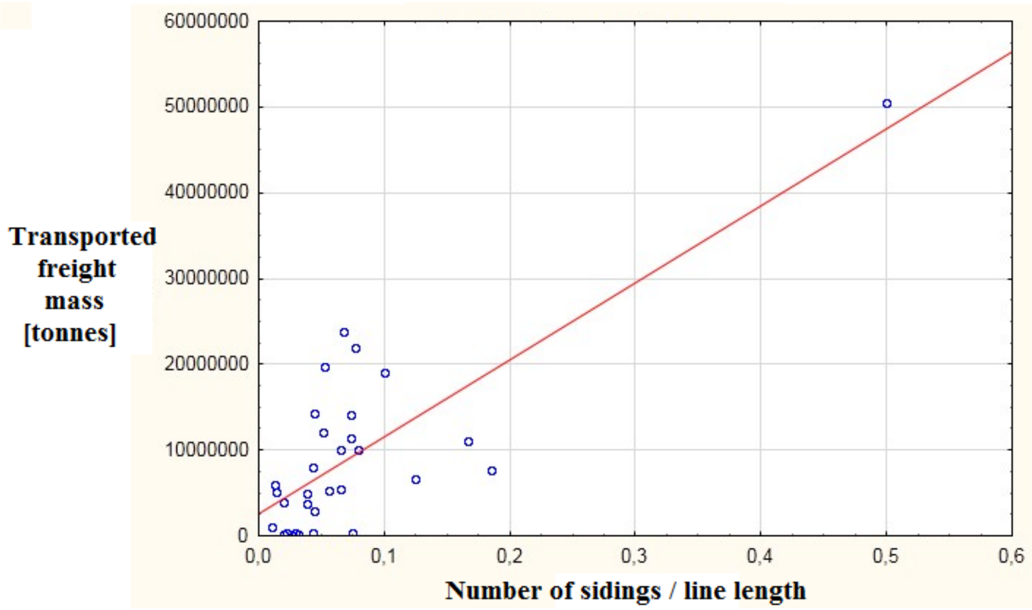

Fig. 6. A scatter chart of transported freight mass and the number of sidings on the line

From this chart, it can be seen that on lines where there is no transit traffic, the number of trains running in freight transport is small. In turn, there is also transit traffic on all lines with a large number of freight trains running on it. It can therefore be concluded that the relationship exists here.

5. CALCULATION OF WEIGHTS OF INDIVIDUAL FACTORS

During determining the weights of individual factors affecting the volume of railway freight transport for both factors, the absolute value of the partial correlation coefficients calculated for the number of trains launched during the year and for the transported freight mass was added. The use of absolute value is related to the fact that the direction of their impact is not important, but only its strength [19]. Then the total value was divided by two, because two parameters describing the volume of freight were used. This action is illustrated by formula (2). In this formula I_F means impact of a particular factor on the volume of freight transport, while C_{Ci} it is calculated correlation coefficient between factors and parameters describing the volume of transport.

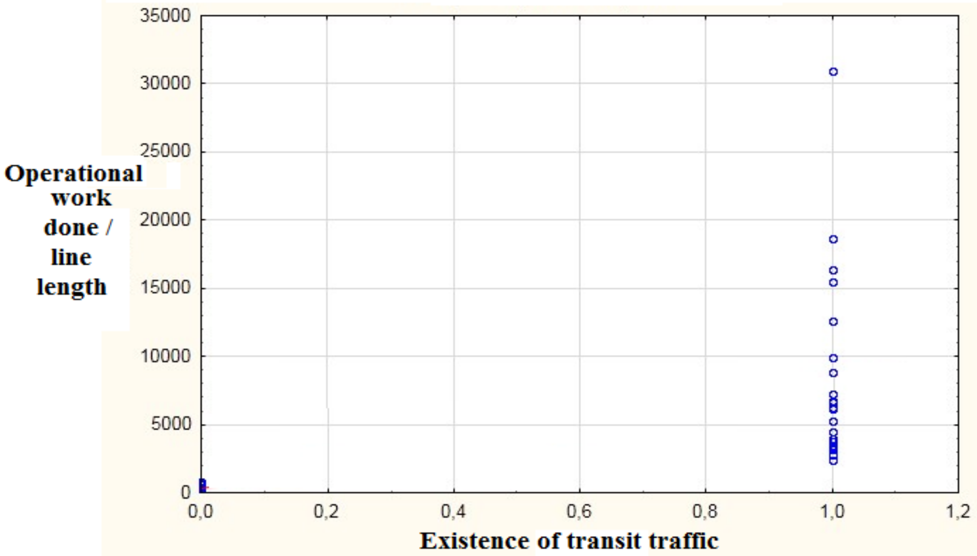

Fig. 7. A scatter chart of the number of running trains during the year and the occurrence of transit traffic.

$$I_F = \frac{\sum_{i=1}^{2} |C_{Ci}|}{2} \tag{2}$$

Using formula (1), the values of individual factors are obtained, which correspond to their average strength of impact on the parameters describing the volume of freight transport. By dividing the obtained values for each of the two factors by their sum, it is possible to determine the weight of a particular factor (W_F) [19]. This operation is illustrated by formula (3).

$$W_F = \frac{I_F}{\sum_{i=1}^{7} I_{Fi}} \tag{3}$$

The weights calculated according to the formula (3) are presented in Table 6.

Table 6

Weights of factors affecting the volume of freight transport

Factor:	Impact of a particular factor:	Weight of a particular factor:
Number of sidings / line length	0.736	**0.595**
Transit traffic	0.501	**0.405**
SUM	1.237	1.000

6. CONCLUSIONS

The analyses of factors affecting the volume of freight transport on individual railway lines in Poland have eliminated one factor, the number of stations holds on the line, which has no real effect on the volume of transport. The calculated values of partial correlation coefficients between the number of stations holds on the railway line and the number of freight trains launched on this line during the year and the transported freight mass by those trains indicated no linear relationship between these quantities. The subsequent analysis of the scatter chart confirmed the complete lack of relationship between these quantities. This is influenced by the fact that station holds are currently used only sporadically. The vast majority of former cargo holds at railway stations are unused. In turn, those that are used usually have very poor infrastructure. They lack lighting, which means that loading and unloading of goods is carried out only during the daytime. These holds usually do not have any working devices accelerating the unloading (such as gantries or cranes), and the reloading of goods from freight cars to trucks is carried out by means of excavators; therefore, loading on them takes a long time. The station holds are mainly used by small plants, which do not generate large volumes of freight transport and the number of freight trains generated from station holds is small. Therefore, the number of trains starting or ending in a station's hold is much smaller than the number of other freight trains. As a result, the number of stations holds on a railway line has no significant effect on the volume of freight transport on this line.

In turn, calculations of partial correlation coefficients showed a clear linear relationship between the number of sidings (both station and route) and the occurrence of transit traffic, and the number of freight trains running on the line during the year and the volume of freight transported by these trains. Further calculations allowed determining the weights of these two factors affecting volume of freight transport. After analysis, it was found that the number of sidings on the line has a greater effect (0.595) on transport than the occurrence of transit traffic (0.405). This is owing to the fact that usually large plants that generate a significant amount of freight trains are connected to railway lines by sidings. Such a plant is usually connected to one railway line, so all freight trains reaching this plant must pass the railway line from which the siding branches off. Therefore, the number of railway sidings located on a railway line has the greatest effect on the volume of freight transport on this line. In turn, for the plant that generates or accepts large quantities of freight trains every day, it is important to maintain the passability of the railway line to which a siding is connected. Temporary loss of line passability, caused, for example, by washing the embankment, causes the inability to enter to the plant. Next, trains servicing plants move along the railway network using lines located on their communication routes, generating freight transit traffic on these lines. The possibility of using the railway line in transit freight transport, in addition to carrying only trains to plants located near this line, increases the volume of transport on this line. However, when routing a freight train, there are often many options for traveling on the rail network. The most suitable route is selected for a particular train, e.g. the shortest, the fastest, and meeting the required parameters. Even a railway line located on the most appropriate route of a transit train is not necessary to carry out this transport. In case of loss of passability of this line or deterioration of its parameters, a different route can be chosen. Therefore, the possibility of using the railway line in transit traffic has an impact on the volume of transport on this line, but it is smaller than the number of sidings located at the railway line. The weight values obtained during this analysis, presented in Table 6, may be used in the future for multi-criteria analyzes of railway lines in Poland in terms of their use in freight transport. This will avoid subjective expert assessments when determining weights in methods such as the zero unitarization method or the TOPSIS method. The analysis of the effect of individual factors on the volume of rail freight transport, and thus the determination of the weights values, may be carried out in the future for other countries. For this purpose, it will be necessary to select representative railway lines from a specific region. Further calculations should be carried out in the same way, as in this analysis.

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