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COMPARISON OF SELECTED RAILWAY LINES IN POLAND USING THE ANALYTICAL HIERARCHY PROCESS METHOD

Summary. The volume of passenger and freight transport on a given railway line depends on many socio-economic factors. Therefore, before starting an investment on a railway line, various analyses are carried out regarding the choice of the line and the scope of works. This article presents the calculation of weights determining the impact of specific socio-economic factors on the volume of rail passenger and freight transport using the Analytical Hierarchy Process (AHP) method. Thereafter, a comparison was made of 12 railway lines located in various regions of Poland in terms of their use in both passenger and freight transport. Half of the analysed railway lines are main lines, while the other part are local lines. The comparison made it possible to arrange the selected lines regardless of their category.

Keywords: railway transport, passenger transport, freight transport, AHP method, logistics

1. INTRODUCTION

Many railway lines in Poland are currently being modernised or revitalised. The rail passenger and freight transport system are very complex. Therefore, before making a decision about the functioning of individual railway lines, which are part of the railway system, many

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multi-criteria analyses are carried out. These analyses allow the consideration of various economic, environmental and social factors.

The purpose of this article is to compare selected railway lines located in Poland, taking into account, factors affecting the volume of transport. Socio-economic factors affect passenger transport. In turn, the volume of freight transport depends mainly on the location of large production plants at the railway line with their own sidings or using station holds. The impact of selected factors on freight transport has not yet been analysed. To enable comparison of railway lines considering various factors, the weights of these factors were first determined using the AHP (Analytical Hierarchy Process) method. For each factor, the weight was obtained in the range of 0 to 1. The values determined in this way were later used to compare railway lines. The AHP method was also used in further calculations, however, the existing comparative scale was used to avoid expert assessment.

The AHP method was developed in 1970 by Thomas L. Saaty. Since then, this method has been constantly modified and is constantly developing [6]. These modifications allow adjusting the AHP method into a specific, analysed problem, considering its specificity [3]. This method is based on the assessment of the impact of the human psyche and on mathematical calculations. The AHP method supports making various complex decisions with a certain number of possible variants. The problem solved by this method is included in many aspects, which is manifested in determining the weights of individual factors included in the assessment criteria of a particular variant. All decision options are assessed using benchmarking [10]. This method has been used in many different fields, including business, industry, logistics during supply chain management [5, 8, 9] and transport. During this research on rail passenger transport, the AHP method was used, among others, to analyse the needs of various groups of passengers [16]. This method is useful for studying complex processes. There are many factors in the transport process, such as: economic, social, technical and environmental, therefore, it is a complex process [12]. The AHP method is particularly useful when there is a hierarchy of evaluation criteria with different impacts on the analysed objective or expected benefits. This method can be used when the assessment criteria are defined not in quantitative but in qualitative terms, however, subjective judgments of the decision-maker are introduced. In this case, the credibility of the information based on which the experts make the assessment should also be considered [2]. In order to avoid subjectivity in this case, attempts were made to introduce the fuzzy set theory into the AHP method, and thus, expand the traditional method [17]. This subjectivity does not occur in the case of full comparability of the analysed variants. With the help of AHP analysis, due to its universality, it is also possible to compare other methods used for calculations in various fields [14]. The application of the AHP method involves building a hierarchical model, followed by an assessment, that is, pairwise comparison of criteria and decision variants, and ultimately allows classification of decision variants [18]. The disadvantage of AHP analysis is the considerable complexity in the case of a large number of criteria or decision variants. This makes it necessary to make a large number of pairwise comparisons. For this purpose, attempts were made to improve this method so that it can be easily used with very large amounts of data for analysis [7]. In these calculations, it can be seen that a greater number of criteria with the same number of decision variants results in more complex comparison matrices.

2. DETERMINATION OF THE INFLUENCE OF SOCIO-ECONOMIC FACTORS ON THE VOLUME OF PASSENGER TRANSPORT

The following hierarchy of problems was adopted:
– first level: assessment of a particular railway line in passenger traffic,
– level two: nine socio-economic factors affecting the volume of passenger transport,
– level three: possible assessment and comparison of any railway lines in Poland.

Matrices containing compared pairs of socio-economic factors affecting the volume of transport for both passenger and freight transport were developed by persons involved in rail transport, representatives of railway infrastructure manager, passenger long-distance carrier and a freight carrier.

2.1. Determining the weight of socio-economic factors using the AHP analysis

The volume of passenger transport on a particular railway line depends on the distribution of the population and the transport needs of the area through which the railway line passes. During the analysis, socio-economic factors were taken into account, such as the size of cities located along the railway line, the number of registered vehicles per 1000 inhabitants, the number of economic entities broken down by the size of enterprises (expressed by the number of employees), the accessibility of residents to the railway line, the number of beds in facilities, beds in communes at the railway line, number of commuters and average number of bus and tram connections from the city centre to the railway station. The matrix containing comparisons of socio-economic factors affecting the volume of passenger transport is presented in Tab. 1. The elements on the diagonal of this matrix have a value of 1, as a comparison of two factors with each other. Above the diagonal, is the result of comparing two criteria with each other. However, the inverse of these comparisons is recorded below the diagonal [15].

The weights of individual socio-economic factors affecting the volume of rail passenger transport were determined based on a pair-of-pair comparison matrix. These weights are presented in Tab. 2. The sum of received weights for all factors is 1.

2.2. Checking the correctness of the obtained results

After determining the weights using the AHP analysis, the correctness of the results is obtained by checking the principle of constancy of preferences. In this method, it is necessary to obtain adequate conformity of assessments, expressed by the value of the compatibility ratio of the CI comparison matrix and the CR compliance ratio. For their calculation, it is necessary to determine in advance the inconsistency coefficient λ_{max} [4]. Most often, the pair-wise comparison matrix is not perfectly consistent. In some cases, it is not possible to achieve the required consistency. Therefore, research was carried out in this regard using optimisation models aimed at increasing the consistency of the matrix [11]. When calculating the inconsistency coefficient λ_{max}, the product of the sum of grades and the weight obtained should be calculated for each socio-economic factor. Then, after adding up the obtained values, a λ_{max} is obtained. Thereafter, the compliance index was calculated in accordance with formula (1) using the obtained value of the inconsistency coefficient.

$$CI = \frac{\lambda_{max} - n}{r \cdot (n-1)} \tag{1}$$

where:

λ_{max} – inconsistency coefficient,

n – matrix size,

r – the indicator depends on the size of the matrix (for n = 9 this value is r = 1.45).

Tab. 1

Matrix of comparisons by pairs of socio-economic factors affecting the volume of passenger rail transport

Factor	Popul. [pe.]	No. of veh. / 1000 pe.	Bus. ent. up to 9 pe.	Bus. ent. 10 - 49 pe	Bus. ent. over 50 pe.	Av. of inh. to the line. [pe./km]	No. of beds [pe.]	No. of comm. [pe.]	Av. no. of con. in a day [con.]	Sum
Popul. [pe.]	1.00	7.00	3.00	3.00	3.00	0.33	3.00	0.33	5.00	25.67
No. of veh. / 1000 pe.	0.14	1.00	0.14	0.20	0.20	0.11	0.33	0.11	0.33	2.57
Bus. ent. up to 9 pe.	0.33	7.00	1.00	3.00	3.00	1.00	5.00	1.00	5.00	26.33
Bus. ent. 10 - 49 pe.	0.33	5.00	0.33	1.00	1.00	0.33	3.00	0.33	3.00	14.33
Bus. ent. over 50 pe.	0.33	5.00	0.33	1.00	1.00	0.33	3.00	0.33	3.00	14.33
Av. of inh. to the line. [pe./km]	3.00	9.00	1.00	3.00	3.00	1.00	7.00	1.00	7.00	35.00
No. of beds [pe.]	0.33	3.00	0.20	0.33	0.33	0.14	1.00	0.14	1.00	6.49
No. of comm. [pe.]	3.00	9.00	1.00	3.00	3.00	1.00	7.00	1.00	7.00	35.00
Av. no. of con. in a day [con.]	0.20	3.00	0.20	0.33	0.33	0.14	1.00	0.14	1.00	6.35
Sum	8.68	49.00	7.21	14.87	14.87	4.40	30.33	4.40	32.33	166.08

Subsequently, the compliance ratio was calculated according to formula (2).

$$CR = \frac{CI}{r} \tag{2}$$

where:
CI – compliance index,
r – the indicator depends on the size of the matrix.

If the values of both coefficients are less than 0.1 it means that the assessments made are consistent, which was achieved in the analysed case.

Tab. 2

Obtained weights of individual socio-economic factors affecting the volume of passenger rail transport

Factor	Popul. [pe.]	No. of veh. / 1000 pe.	Bus. ent. up to 9 pe.	Bus. ent. 10 - 49 pe.	Bus. ent. over 50 pe.	Av. of inh. to the line. [pe./km]	No. of beds [pe.]	No. of comm. [pe.]	Av. no. of con. in a day [con.]	Sum
Weig.	0.155	0.016	0.159	0.086	0.086	0.211	0.039	0.211	0.038	1.000

3. DETERMINATION OF THE INFLUENCE OF FACTORS ON THE VOLUME OF FREIGHT TRANSPORT

The following hierarchy of problems was adopted:
– first level: Assessment of a particular railway line in freight traffic,
– level two: four factors affecting the volume of freight transport,
– level three: possible assessment and comparison of any railway lines in Poland.

3.1. Determining the weight of factors using the AHP analysis

The volume of freight transport on a particular railway line depends on the location of plants along this line that can generate full-length shipments and the possibility of using the line in transit traffic. During the analysis, the following factors were taken into account: the number of sidings (both station sidings and less frequent route sidings were considered), the number of stations holds and the occurrence of transit traffic. The matrix containing comparisons of socio-economic factors affecting the volume of freight is presented in Tab. 3.
The weights of individual factors affecting the volume of rail freight transport were determined based on a pair-of-pair comparison matrix. These weights, which sum is 1, are presented in Tab. 4.

Tab. 3

Matrix of comparisons by pairs of factors affecting the volume of rail freight transport

Factor	Number of sidings	Number of stations holds	Transit traffic	Sum
Number of sidings	1.00	1.00	3.00	5.00
Number of stations holds	1.00	1.00	3.00	5.00
Transit traffic	0.33	0.33	1.00	1.67
Sum	2.33	2.33	7.00	11.67

Tab. 4

Obtained weights of individual factors affecting the volume of rail freight transport

Factor	Number of sidings	Number of stations holds	Transit traffic	Sum
Weig.	0.429	0.429	0.143	1.000

3.2. Checking the correctness of the obtained results

After determining the weights of factors affecting the volume of freight using the AHP analysis, as in the case of determining the weights of factors affecting passenger transport, the correctness of the results obtained was checked.

The compliance index value was then calculated in accordance with formula (1). For the analysed number of factors ($n = 3$), the value of the index depending on the size of the matrix is $r = 0.58$. For freight, the values of both factors are less than 0.1, so the assessments made are consistent. Due to the small number of factors affecting the volume of rail freight that was considered, and the high consistency of the assessments, the values obtained for both the compliance index and the compliance ratio are 0.

4. COMPARISON OF SELECTED RAILWAY LINES

The comparison was made of 12 railway lines located in different regions of Poland. The analysis was carried out for 6 voivodships, choosing from one of the 2 railway lines in accordance with the principle that, however, one from the analysed railway lines is the main line, while the other is a local line. The analyzed railway lines are presented in Fig. 1. On the map, the analysed main railway lines are marked in bold solid line, whereas the local railway lines are marked in bold dashed line.

During comparing the individual socio-economic factors on selected railway lines, the existing comparative scale was used. Evaluation of pairwise comparison of specific railway lines for each factor is expressed by the ratio V_A/V_B, while the inverse value in the matrix expresses the ratio V_B/V_A. For this purpose, data on socio-economic factors affecting the volume of passenger transport was used. The source of data are reports published by the Central Statistical Office (CSO). One of the factors, the residents' availability to the railway line, was calculated using the CSO data. These data are presented in Tab. 5.

Fig. 1. Location of analysed railway lines in Poland [13]

In turn, for freight transport, factors affecting its volume related to the existing infrastructure (sidings and station holds) and transit traffic were determined. These data are shown in Tab. 6.

Using the V_A/V_B ratio, the lines were compared for all factors relating to passenger transport and for the factor determining the number of sidings responsible for freight traffic. Due to the use of the existing, specific comparative scale, for these factors, it was not necessary to calculate the compliance index and the compliance ratio, which are then zero. In the case of the factor which is the number of stations holds, a comparative scale should have been introduced due to the lack of holds on some railway lines and the need to avoid zero value in the denominator. Additionally, a comparative scale should have been introduced for transit traffic in freight transport given only descriptively.

Tab. 5

Factors affecting the volume of passenger transport

Section	Popul. [pe.]	No. of veh. / 1000 pe.	Bus. ent. up to 9 pe.	Bus. ent. 10 - 49 pe.	Bus. ent. over 50 pe.	Av. of inh. to the line. [pe./km]	No. of beds [pe.]	No. of comm. [pe.]	Av. no. of con. in a day [con.]
Wroc. Gł. - Legnica	758013	637.22	135152	3641	985	3591.72	13296	73076	285.62
Kłodz. Gł. - Wał. Gł.	184290	557.68	20654	577	141	1185.58	2601	12719	8.33
Bydg. Gł. - Tor. Gł.	572163	559.15	68354	2330	698	3516.38	8115	43327	210.00
Grudziądz - Chełmża	111431	523.75	9684	369	115	1954.70	1425	3813	31.33
Lublin - Rejowiec	388645	579.17	48982	1514	418	2735.39	4526	41053	34.86
Zam. W. - Zwierzyn.	76677	519.60	8541	279	90	1919.04	2544	7084	23.89
Zbąszynek - Rzepin	40853	634.42	6528	227	54	356.75	2566	6295	2.64
Żary - Ziel. Góra	185775	627.69	26129	897	208	1514.98	1534	21145	28.10
Łódź Kal. - Sieradz	863521	728.76	107563	4303	925	10267.10	9521	57623	74.15
Łódź Kal. - Kutno	828287	718.48	102150	3985	903	10864.94	8965	53155	86.56
Krak. Gł. - Tarnów	948204	587.11	163658	6068	1421	5268.79	35440	123357	80.00
N. Sącz - Muszyna	104896	447.03	13308	527	143	987.71	4755	11364	69.13

4.1. Socio-economic factors affecting the volume of passenger transport

During comparing railway lines in terms of their use in passenger transport, a matrix of comparisons was created for each socio-economic factor and pairwise comparison of all railway lines was made. A total of 9 comparison matrices were performed during the analysis. Then, after analysis in pairs of railway lines in terms of all socio-economic criteria, values were added for each line. For this purpose, the weights obtained in Tab. 2 were used and the sum of the product of the values obtained for each of the factors and the weights obtained was calculated.

4.2. Factors affecting the volume of freight

When comparing lines in terms of utilisation in freight transport, a pair comparison matrix was created for the criterion of the number of sidings using the V_A/V_B ratio. For the factor, which is the number of stations holds, a comparative scale was introduced due to the

lack of holds on some railway lines and the need to avoid zero value in the denominator. To compare the line in terms of this criterion, it was assumed when a line without any hold was combined with a line with one hold, value 5, while with a line with two holds, value 9, and when comparing a line with one station hold with a line with two holds, value 5 was assumed. The introduction of this comparative scale was associated with the need to check the correctness of the results obtained and to calculate the compliance index and compliance ratio. Both values obtained are less than 0.1. In addition, a comparative scale should have been introduced for transit traffic in freight transport given only descriptively. Here, it was assumed when comparing the line on which freight transit traffic does not occur with the railway line on which such traffic runs a value of 5. In this case, the compliance indicator and compliance factor were also checked for the results obtained. After analysis in pairs of railway lines in terms of criteria affecting freight transport, values were added for each line. The sum of the product of the obtained values was calculated for each of the factors and weights obtained in Tab. 4.

Tab. 6

Factors affecting the volume of freight transport

Section	Number of sidings	Number of stations holds	Transit traffic
Wrocław Gł. - Legnica	2	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	1	1	occurs
Żary - Zielona Góra	4	2	lack
Łódź Kaliska - Sieradz	3	2	occurs
Łódź Kaliska - Kutno	3	0	occurs
Cracow Gł. - Tarnów	5	2	occurs
Nowy Sącz - Muszyna	1	0	occurs

4.3. Comparison of the analysed railway lines in general

Both passenger and freight trains are carried out on the analysed railway lines. Hence, the obtained values during comparisons of lines in terms of passenger and freight transport using the AHP method were added to each other. Tab. 7 presents the results obtained for the analysed railway lines, separately for passenger and freight transport, and the sum of these results, considering all transport on these lines.

Tab. 7

The results of the comprehensive comparison of analysed railway lines

Section	Passenger transport	Freight transport	General
Cracow Gł. - Tar.	0.208	0.152	0.360

Łódź Kal. - Sieradz	0.163	0.126	0.289
Wroc. Gł. - Legnica	0.150	0.112	0.262
Łódź Kal. - Kutno	0.160	0.061	0.221
Bydg. Gł. - Tor. Gł.	0.101	0.068	0.169
Lublin - Rejowiec	0.071	0.095	0.166
Żary - Ziel. Góra	0.038	0.127	0.165
Zam. W. - Zwierzyn.	0.022	0.095	0.117
Kłodz. Gł. - Wał. Gł.	0.028	0.056	0.084
Zbąszynek - Rzepin	0.011	0.054	0.065
N. Sącz - Muszyna	0.026	0.034	0.060
Grudziądz - Chełmża	0.023	0.022	0.045

5. CONCLUSIONS

The calculations carried out using the AHP analysis allowed determining the weight of factors affecting the volume of both passenger and freight rail transport. Subsequent comparison, considering the same criteria using predetermined weights, allowed the assessment of selected railway lines in terms of their use in passenger and freight traffic.

The highest rating in terms of both passenger and freight transport (0.360) was received by the main railway line connecting Cracow with Tarnów. The main lines from Łódź to Sieradz (0.289) and from Wrocław to Legnica (0.262) also received a high overall rating. Furthermore, the local line connecting Łódź with Kutno received a high overall rating (0.211). The main railway lines, apart from the main line connecting Zbąszynek with Rzepin, which passes through very sparsely populated areas, received a high rating in terms of use in passenger traffic. However, when it comes to using the line in freight traffic, the local railway line from Żary to Zielona Góra received a high rating. There are small passenger services on this line, however, it allows access to plants generating high freight traffic. The lowest score in terms of freight traffic was given to the route from Grudziądz to Chełmża, where freight traffic is practically non-existent due to lack of demand.

This analysis has shown that it is possible to make a comparison of selected rail lines taking into account factors affecting the volume of passenger and freight transport using the AHP analysis. When comparing railway lines, the existing comparative scale was used in almost all criteria, thus, avoiding expert evaluations wherever possible.

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