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THE COMPARISON OF TRANSPORT INFRASTRUCTURES IN INDIVIDUAL SLOVAK REGIONS BY APPLYING PCA AND CLUSTER ANALYSIS

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Abstract: The development of the transport segment is currently an essential process which affects several other industries. The transport infrastructure and the services provided in this sector influence economic growth, the efforts aimed at increasing competitiveness, as well as prosperity of the society. One of the key problems Slovakia is facing is the long-term growth of differences between individual regions. The present article deals with the evaluation and comparison of selected transport infrastructure indicators in eight regions of Slovakia. The evaluation was carried out by applying basic statistical methods and multiple-criteria statistical methods. Every region was characterised by 20 selected variables describing its uniqueness (e.g. population, area, GDP per capita, road infrastructure etc.). The evaluation of similarities between individual regions in terms of selected variables was carried out by applying the Principal Component Analysis (PCA) and Hierarchical Cluster Analysis. Within the PCA, the original input variables were replaced with three principal components describing as much as 86.68% of the cumulative variance. The average linkage method, as one of the hierarchical methods, was applied to create a dendrogram representing the similarities between the regions of Slovakia. The cophenetic correlation coefficient value of CC=0.936 confirmed the proper selection of the average linkage method. The output of the cluster analysis was that 8 regions of Slovakia were divided into five similar homogenous clusters based on the examined variables. The final analysis indicated that the transport infrastructure and the development thereof significantly affect the differences between individual regions of Slovakia and, as a matter of fact, they belong to the factors creating such differences.

1 Introduction

The key preconditions and factors of social and economic development of countries and their regions include the transport infrastructure. As stated by OECD, transport infrastructure represents a key component of the economic development at all income levels and supports personal well-being and economic growth. Due to its central economic function, transport infrastructure is often referred to as a pillar of modern economy [1]. Transport infrastructure as a complex network connects towns and villages and affects human activities which interconnect social, economic and environmental systems with urbanisation and population growth [2].

According to paper [3], transport infrastructure is an integral part of the transport system in every town or country. The article emphasised the fact that as the society develops and the globalisation intensifies, the importance of transport as a factor affecting the economic and social development increases. Moreover, a transport network contributes to the social and economic development and increases the quality of life by creating intercity connections during urbanisation [4]. According to paper [5], a high quality of transport infrastructure significantly affects the transport logistics as well.

On the other hand, unreasonable planning of transport infrastructure has certain negative effects, such as increased traffic accident rate, lower transport efficiency, climate change and increased emissions of CO_2. Tang et al. monitored potential effects of changes in transport infrastructure on air quality and public health in connection with air pollution [6]. According to Doyle [7], transport is one of the most intensive sources of air pollution and may have a significant effect on public health.

A correlation between investments in transport infrastructure and regional development in 30 member states has been investigated by the OECD Programme of Research on Road Transport and Intermodal Linkages (RTR) in years 1998 to 2000 [8]. The work group analysed the evaluation studies examining the key projects dealing with transport infrastructure in OECD member states with the aim to identify the impact of investments in transport infrastructure on the regional development and improve the existing evaluation methods. Similarly, authors [9] analysed transport infrastructure and its influence on the development of regional economies in three provinces of China and obtained important data on human mobility, production-related interconnections and logistics which may subsequently be used in regional management and planning.

Hong et al. [10] stated that transport infrastructure may have various effects on economic growth in individual regions. Based on the research results, they claim that the infrastructure of land transport (including roads and railways) and water transport significantly contributed to the economic growth in the region. The influence of transport infrastructure on economic growth in regions and sectors, depending on a transport modality, was described in paper [11]. According to Gunasekera et al. [12], development of transport infrastructure efficiently reduces the journey duration and passengers and carriers significantly benefit from the saved time and reduced costs of a vehicle operation. A positive correlation between the development of transport infrastructure and economic growth was observed by Démurger [13]. Similarly, Banister and Berechman [14] stated that transport infrastructure significantly affects economic growth of a country. A support of regional development in the eastern part of Macedonia and Thrace in Greece through the road transport projects has been discussed by Mavraki et al. [15]. In the article, the authors described the analysis of the extent to which road transport projects, implemented within the Greek National Strategic Reference Framework (NSRR) for 2007-2013, contributed to the economic development in the analysed region. The influence of transport infrastructure on regional economic growth in 31 provinces in China in years 1998 to 2007 was dealt with by authors of paper [10]. Based on the analysis, the authors assumed that transport infrastructure plays an important role in economic growth. The role of the infrastructure in the regional development strategy was discussed in paper [16] by means of a case study of the Netherlands, and the analysis was carried out by applying selected statistical methods (e.g. cluster and scaling methods). Authors [17] introduced a new Road Funding Priority Index (RFPI) as a tool to be used in decision-making on road building projects of high priority. Relevant indicators are selected on the basis of, among other factors, the Principal Component Analysis (PCA). Monitoring effects of selected indicators of regional macroeconomy on the development and planning of transport infrastructure using neutron networks was presented by authors of paper [18]. Authors selected important macroeconomic indicators by applying the Principal Component Analysis. Paper [19] dealt with monitoring and control of urban traffic. Identification of critical traffic points is also based on the PCA.

High-quality and functional transport infrastructure is one of the key preconditions for the fast development of regions in the Slovak Republic. Article [20] deals with the transport sector as a part of the infrastructure in EU countries, especially in Slovakia. According to paper [21], Slovakia exhibits regional differences in quality of individual transport networks, and this has far-reaching consequences for the growth of economic and social differences between individual regions in the country. Authors Masarova and Ivanova [22] compared road infrastructures in Slovakia and Poland in years 2005 through 2013 and pointed out regional differences in road infrastructure between those two countries. The trends developing in the road and railway transport in the Slovak Republic were analysed in article [23] by applying statistical methods. Authors Brumercikova and Bukova applied the regression and correlation analysis to the evaluation of the public passenger transport in the Slovak Republic [24]. According to Golias [25], the Slovak Republic is one of the countries with the greatest regional differences in income indicators based on OECD data for 2014. Document [26] described individual regions from several points of view; authors stated that in less developed regions the transport infrastructure was of inferior quality and this impaired the local business environment.

The transport segment began to develop in Slovakia after the country joined the EU. Hence, Slovakia was allowed to receive finances from the European funds for the purpose of transport infrastructure development. In 2013, Phase I of the preparation of the strategic transport infrastructure development plan was implemented as this was a requirement to be met by Slovakia in order to be able to use the finances from the European funds. The ongoing Phase 2 is not focussed merely on the development of the transport infrastructure, but on the complex development of the entire transport sector in the Slovak Republic [27].

Development of Slovakia is closely connected with a functional transport infrastructure. The key factors which significantly affect the quality thereof include also regional social and economic conditions. The purpose of the article is to compare regions of Slovakia in terms of transport infrastructure and selected social and economic indicators which characterise the regions. The result of the analysis is the formation of homogeneous clusters of regions with similar characteristics on the bases of selected indicators.

2 Methodology

2.1 Slovakia

Slovakia (Slovak Republic) is an inland country in Central Europe (Figure 1) with the total area of 49,035 km². The population is approximately 5.45 million inhabitants. The capital is Bratislava. Since 2004, it is a member of the European Union.

The road structure in Slovakia consists of motorways, expressways and roads of Classes I, II and III. Highways, expressways and Class I roads are roads of international as well as national importance which represent the basis of the road network in Slovakia. According to the Strategic Development Plan of Road Infrastructure in Slovakia until 2020 [28], motorways and expressways connect important places in the country, while the motorways also connect Slovakia with neighbouring countries. They are mostly built on the routes with the most intensive traffic burden.

Class II roads interconnect the centres of the regions and usually supplement the network of motorways, expressways and Class I roads. Class III roads represent the longest part of the road network. They are roads of regional to local importance and interconnect villages and the higher-level road network [29].

Figure 1 Slovakia and neighbouring countries

In 2018, the total length of the Slovak road network managed by the state amounted to 18,059 km. The largest component of the road network represented Class III roads (10,358 km; 57.4 %). In 2018, motorways and expressways represented only 4.3 % of the road network (778 km out of 18,059 km). Class I roads represented 18.3 % of the total length of the road network (3,311 km), and similar percentage was observed for Class II roads (3,610 km; 20 %). In 2018, 3,580 km of railway lines were used [28].

At present, Slovakia consists of eight regions (Bratislava Region SK-BL, Trnava Region SK-TA, Nitra Region SK-NI, Trenčín Region SK-TC, Žilina Region SK-ZI, Banská Bystrica Region SK-BC, Prešov Region SK-PV and Košice Region SK-KI), 79 districts, 140 towns and 2,933 villages (Figure 2).

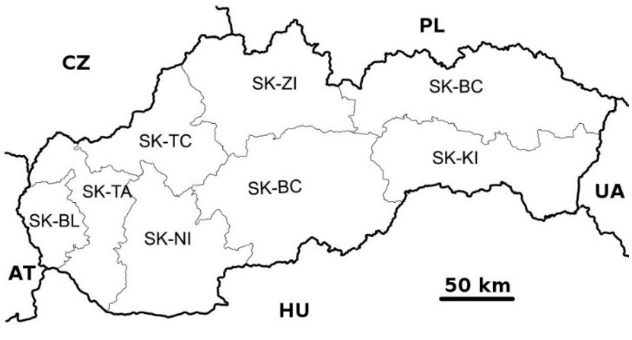

Figure 2 Regions in Slovakia [30]

The analysis of differences between individual regions in Slovakia in terms of transport infrastructure was carried out while considering several input variables: transport infrastructure by regions (motorways and motorway feeder roads, expressways, roads of Classes I, II and III; construction length of operated railway lines); and transport operating indicators by regions (motorisation rate, number of cars, trucks, buses and truck tractors). The motorisation rate expresses the number of passenger cars relative to the total number of inhabitants.

For the purpose of a more complex assessment of the regions, the analysis was carried out while using the data on the region area and population, and the indicators characterising a social and economic level of the region (average age, ageing index, regional GDP per capita, unemployment rate and average monthly nominal wage). The average age represents the weighted arithmetic mean of the number of years lived by inhabitants to a certain date. It is the average age of the living inhabitants. The ageing index (Sauvy’s index) expresses the number of persons in the post-productive age (65+ years) per 100 people in the pre-productive age (0–14 years). The productive age percentage is the percentage of inhabitants who are economically active. The list of selected input variables is presented in Table 1.

Table 1 Selected input variables in regions

Designation	Description	Designation	Description
A1	Country area (km^2)	A11	Class I roads (km)
A2	Population (number)	A12	Class II roads (km)
A3	Average age (year)	A13	Class III roads (km)
A4	Ageing index (%)	A14	Motorisation rate
A5	Percentage of productive age (%)	A15	Number of cars (pc)
A6	Regional GDP per capita (Euro/1 inhabitant)	A16	Number of trucks (pc)
A7	Average nominal monthly wage (Euro)	A17	Number of buses (pc)
A8	Unemployment rate (%)	A18	Number of truck tractors (pc)
A9	Motorways and motorway feeder roads (km)	A19	Number of transport and warehousing companies (pc)
A10	Expressways (km)	A20	Construction length of operated railway lines (km)

The analysis was carried out while using the 2018 data which are publically available in the statistics published on the website of the Ministry of Transport and Construction of the SR [31] and at the Central Office of Labour, Social Affairs and Family [32], as well as the data from the database published at Datacube.stastistic.sk [33].

2.2 Statistical methods

The analysis of selected variables characterising the regions in Slovakia was carried out by applying basic statistical methods and multidimensional statistical methods: Principal Component Analysis and Cluster Analysis.

Correlations between variables and PCA

The correlations were investigated using the correlation matrix which does not require the input data to be expressed in identical units. A correlation between two variables is represented in the correlation matrix by means of the Pearson's correlation coefficient *r*. In order to determine the rate (degree) of the dependence, the scale that may be applied is as follows: no correlation (|r| <0.29); weak correlation (0.30 <|r| <0.49); moderate correlation (0.50 <|r| <0.79); and strong correlation (S, 0.80 <|r| <1). If the correlation coefficient *r* is positive (or negative), it means that there is a direct (or negative) linear correlation between the variables.

Principal Component Analysis (PCA) belongs to multidimensional analysis methods. The purpose of this method is primarily to reduce the number of input dependent (correlated) variables at the lowest possible loss of information. New latent variables, i.e. the principal components, are not mutually dependent and represent a linear combination of the original variables. Every principal component is characterised by a rate of variance. The first principal component accounts for the largest possible variance of the original values. The contributions of the other principal components to the variance are always lower. An adequate number of principal components may be identified by applying several methods. The one frequently used in practice is the Kaiser-Guttman rule which takes into consideration all eigenvalues higher than 1. Another rule recommends considering only those principal components which explain 70 to 90% of the cumulative variance [34].

Cluster analysis

A cluster analysis belongs to multidimensional statistical methods that deal with similarities between multidimensional objects and it comprises dividing the objects into homogeneous groups, i.e. clusters [35]. The information on such similarities is obtained through various metrics of estimated distances between two objects (e.g. Euclidean distance). Depending on the method of forming such homogeneous groups, we distinguish between hierarchical and non-hierarchical methods. Hierarchical clustering methods are based on gradual grouping of objects, ranging from the most similar to the most different objects. There are several methods of hierarchical clustering (e.g. the nearest neighbour method, the furthest neighbour method, the average linkage method, Ward's method etc.). A graphical representation of hierarchical clustering is a tree referred to as a dendrogram. All the results were obtained using the R-package software.

3 Result and discussion

The research was carried out with the aim to:

- Analyse the input variables by basic statistical methods and PCA;
- Compare the regions in Slovakia in terms of their road infrastructure and other parameters characterising individual regions by applying a hierarchical cluster analysis.

3.1 Characteristics of variables and PCA method

The structure of road networks in the regions of Slovakia existing in 2018 is shown in Fig. 3. In all regions, the roads representing the highest percentage of the road network were the Class III roads (44–60%; A10). The data indicate that Nitra Region (SK-NI) and Banská Bystrica Region (SK-BC) comprised 0 km of motorways and motorway feeder roads. The highest percentage of motorways and expressways was in Bratislava Region (SK-BL, 14%).

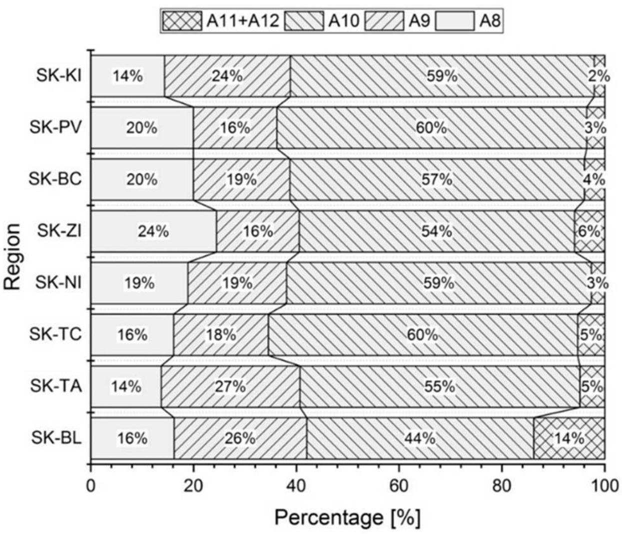

Figure 3 Road networks in regions of Slovakia [%]

Other additional data on the regions of Slovakia (area, population, average age, ageing index, percentage of productive age, regional GDP per capita, average monthly nominal wage and unemployment rate) are listed in Table 2.

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Table 2 Regional characteristics

Region	Regional characteristics							
	A1 [km^2]	A2 [number]	A3 [year]	A4 [%]	A5 [%]	A6 [euro/1 inhabitant]	A7 [euro]	A8 [%]
SK-BL	2052.2	655,218	40.92	97.67	66.08	38,836.00	1,330	2.62
SK-TA	4146.6	562,982	41.72	114.39	68.96	17,917.48	1,005	2.31
SK-TC	4502.0	586,623	42.50	128.30	68.54	13,741.78	984	2.93
SK-NI	6343.8	677,682	42.49	128.56	68.73	13,768.71	880	3.12
SK-ZI	6808.7	691,196	50.27	96.88	69.04	14,048.54	946	4.04
SK-BC	9454.4	648,831	41.70	114.77	68.41	12,064.00	912	7.03
SK-PV	8973.9	824,424	38.59	77.28	68.15	10,388.51	813	8.61
SK-KI	6754.5	799,816	39.53	86.13	67.97	13,352.94	957	8.17

The first step of the analysis of the parameters was to search for any potential correlations between individual input variables. Because the values of the variables were expressed in different units, the correlations between them were identified using a correlation matrix (Figure 3), while the correlations between two different variables were identified using the correlation coefficient *r*.

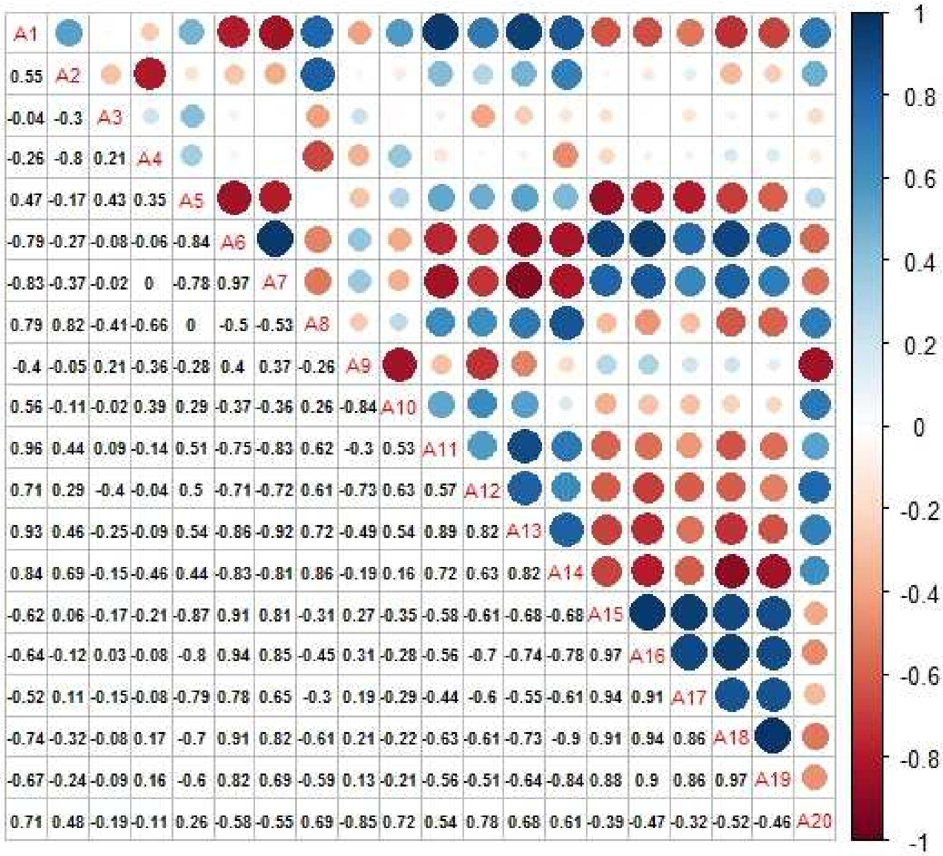

Figure 4 Correlation matrix (R package)

The resultant correlation matrix (Figure 4) indicates, for example, that there is a very strong direct correlation ($0.80 < |r| < 1$) between variables A11 and A1 (r=0.96); A13 and A1 (r=0.93); A16 and A6 (r=0.94); A16 and A15 (r=0.97); A18 and A16 (r=0.94); A17 and A15 (r=0.94); and between A19 and A18 (r=0.97). Moreover, several variables exhibited very strong indirect correlations, e.g. A19 and A14 (r=-0.84); A10 and A9 (r=-0.84); and A13 and A (r=-0.92). It seems that there are relatively strong correlations between multiple pairs of variables. Therefore, new independent variables were determined by applying the Principal Component Analysis (PCA).

Within the PCA, the original input variables were replaced with new independent variables, i.e. the principal components. The main components were identified using the eigenvalues depicted in a scree plot (Figure 5). The eigenvalues and variability of PCA components for 7 new components are listed in Table 3.

The eigenvalue of the first principal component Dim1 was 11.39, the second was 3.40, and the third component exhibited the eigenvalue of 2.54 (Table 3). The first component Dim1 described approximately 56.93% of the cumulative variance of data. The second component Dim2 explained 17.02 % and the third component Dim3 explained 12.72% of the cumulative variance of data. These three principal components explained altogether as much as 86.68% of the cumulative variance. Therefore, the first three components represented the new input variables.

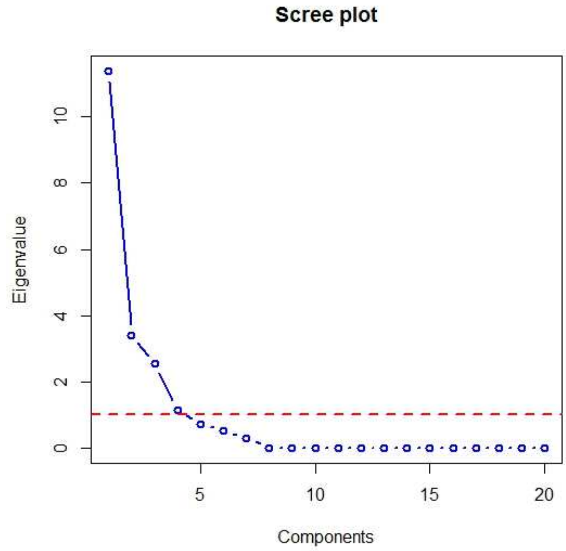

Figure 5 Scree plot (R package)

Table 3 PCA results

Components	Dim1	Dim2	Dim3	Dim4	Dim5	Dim6	Dim7
Eigenvalue	11.39	3.40	2.54	1.14	0.71	0.51	0.30
Variance (%)	56.93	17.02	12.72	5.72	3.57	2.54	1.49
Cumulative Variance (%)	56.93	73.96	86.68	92.39	95.97	98.51	100.00

Coefficients of eigenvalues, i.e. the component coefficient matrix, for the first three principal components are listed in Table 4. The first component Dim1 mostly consisted of the variables describing transport infrastructure in regions (A1, A5, A6, A7, A8, A11 through A20, the highlighted numbers in Table 4). The second principal component Dim2 consisted mainly of the variables related to population (A2), average age (A3) and ageing index (A4). The last principal component Dim3 consisted mostly of motorways (A9) and expressways (A10).

Table 4 New input variables identified by PCA

Principal components	Original variables (Part 1)									
	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**
Dim1	**0.90**	0.39	-0.05	-0.10	**0.70**	**-0.95**	**-0.93**	**0.70**	-0.47	0.50
Dim2	0.24	**0.85**	**-0.54**	**-0.81**	-0.63	0.20	0.08	0.69	0.04	-0.14
Dim3	0.07	-0.18	-0.30	0.47	-0.12	0.09	0.06	-0.04	**-0.83**	**0.77**

Principal components	Original variables (Part 2)									
	A11	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**	**A18**	**A19**	**A20**
Dim1	**0.81**	**0.82**	**0.92**	**0.89**	**-0.86**	**-0.90**	**-0.77**	**-0.92**	**-0.85**	**0.72**
Dim2	0.13	0.10	0.16	0.32	0.46	0.28	0.43	0.10	0.12	0.28
Dim3	0.05	0.40	0.16	-0.29	0.18	0.18	0.24	0.33	0.36	0.51

A graphical representation of the data on the original variables in the coordinate system of the first principal component Dim1 relative to the second principal component Dim2 is shown in Figure 6.

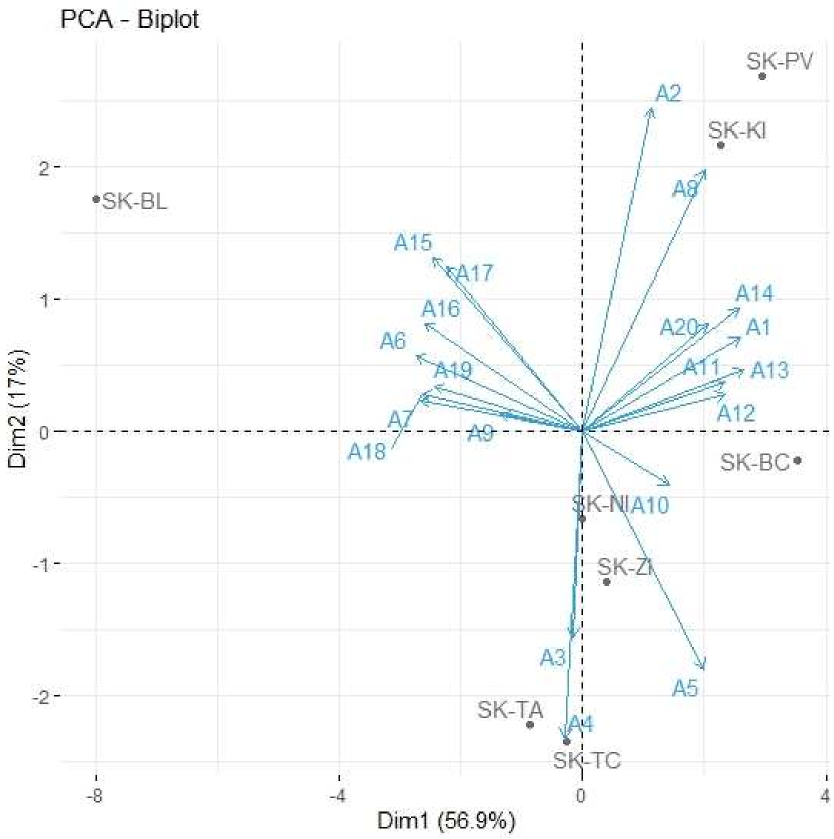

Figure 6 Biplot. (R package)

It seems that SK-BL region (Bratislava region) deviates from the other regions (Figure 6). The graph indicates a similarity between SK-PV region (Prešov Region) and SK-KI region (Košice Region). An analysis of the results of PCA facilitated identification of certain similarities between other regions: SK-TC (Trenčín Region) and SK-TA (Trnava Region).

3.2 Cluster analysis

A comparison of the regions of Slovakia in terms of selected transport infrastructure, as well as other analysed variables, was carried out by applying the cluster analysis. The input variables were three new independent variables (three principal components - Dim1, Dim2 and Dim3) obtained by PCA. These variables also represented, to a large extent, the road infrastructure in a given region. The Euclidian distance was used as a distance measure. Four different agglomerative hierarchical clustering methods were gradually applied: the average linkage method, the nearest neighbour method, the Ward's method and the median method.

The best clustering method was identified using the cophenetic correlation coefficient; the resultant value thereof indicated that the best clustering method was the average linkage method (the average linkage method: CC=0.936; the nearest neighbour method: CC=0.930; the Ward's method: CC=0.907, the median method: CC=0.886). An output of the cluster analysis was the formation of homogeneous clusters of analysed regions, as depicted in a dendrogram (Figure 7).

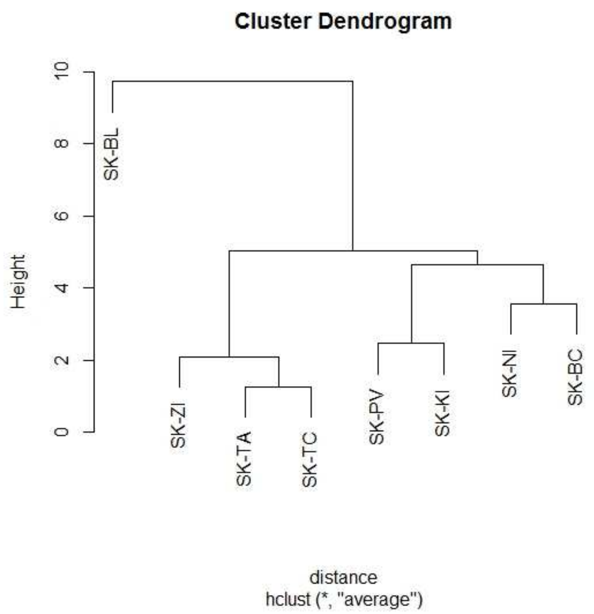

Figure 7 Dendrogram – the average linkage method (R package)

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The dendrogram (Figure 7) indicates that SK-BL region (Bratislava Region) represented a separate cluster. Similarly, SK-ZI region (Žilina Region) may be regarded as a separate cluster, but with certain characteristics similar to those of other two regions - SK-TA (Trnava Region) and SK-TC (Trenčín Region). SK-PV (Prešov Region) and SK-KI (Košice Region) regions formed a separate cluster. Another separate cluster consisted of SK-NI (Nitra Region) and SK-BC (Banská Bystrica Region) regions. The result of the clustering is shown in Figure 8. Regions forming one cluster are designated with the same colour.

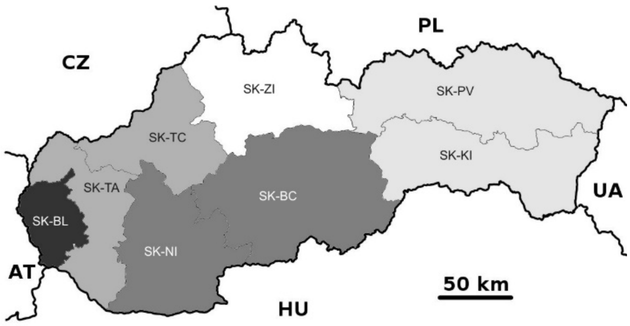

Figure 8 Cluster analysis result – division of regions

Bratislava Region (SK-BL) exhibited significant differences from the other regions. This region is the most developed region in Slovakia; in 2017, it held 8th place in the EU in terms of GDP per capita, amounting to 179% of the EU average value [36]. Its strengths include strong economic interconnection with the capital city, closeness to cities like Wien and Budapest, relatively advanced transport infrastructure and presence of investment capital. This is also related to better business and transport infrastructure. Other regions, especially the regions in Eastern Slovakia (Prešov Region SK-PV and Košice Region SK-KI) are far behind the Bratislava Region (GDP per capita amounted only to 54% of the EU average).

Žilina Region (SK-ZI) belongs to regions which are mostly industrial. It has a convenient geographical location on the most important roads and railway lines connecting the western and eastern parts of Slovakia. Trnava Region (SK-TA) benefits from its geographical closeness to the fast-developing Bratislava Region and from the advanced transport infrastructure. Trenčín Region (SK-TC) is one of the most industrial regions of Slovakia. Nitra Region (SK-NI) is the most developed agricultural region in terms of the agricultural land area (more than 74% of the region area) and productivity rate of the local agricultural production. Banská Bystrica Region (SK-BC) is relatively less developed and its southern part is mostly agricultural with food production. A geographically rugged terrain in this region hinders the construction of adequate transport infrastructure.

Košice Region (SK-KI) is a region with a relatively developed economy. It is a centre of several industries, including metallurgy, mechanical engineering, electrotechnology and food production. However, Košice Region contains the least developed districts of Slovakia. Prešov Region (SK-PV) is a less developed region with a persistently high unemployment rate and significant economic and social differences when compared to other regions. The problems of this region are even deepened by poor transport infrastructure.

4 Conclusions

Adequate transport infrastructure is a key precondition for the transport system of a country and is crucial for the sustainable economic growth. Using the available data, it was possible to compare individual regions in Slovakia. The result of the applied statistical methods was the formation of clusters based on similarities between the regions while considering primarily the influence of transport infrastructure. It seems that the regions may be divided into four to five groups of regions that exhibit similar characteristics. The region where Bratislava, the capital of Slovakia, is located, exhibited the most marked differences. The analysis showed that the quality of transport infrastructure significantly affects regional differences in Slovakia, and to certain extent it even causes such differences.

A complex comparison of regions indicates a direct correlation between the quality and functionality of transport infrastructure and a social and economic level of a particular region. In regions with more accessible and more developed transport infrastructure, the social and economic conditions for the inhabitants are better.

It is therefore essential to pay attention to the development of transport infrastructure in these regions. Furthermore, it is very important to regard as a priority to complete the construction of the road interconnecting the eastern and western parts of the country, the road representing a south-north axis of the country, as well as the road connecting the south and north of Eastern Slovakia. Another very important objective is to complete the construction of roads connecting Slovakia with its neighbouring countries. Slovakia is an important transit territory where the differences between individual regions are largely demonstrated. A region which is important for transit transport is the one around Bratislava (near Budapest and Wien) and Žilina Region (near the north-east of the Czech Republic and the south of Poland). Regions in southern and eastern Slovakia are distant from the main transport routes. However, these regions in particular have great potential thanks to their location with regard to the neighbouring countries.

All the above-mentioned objectives represent the visions and priorities of transport infrastructure which are currently discussed in the Slovak Republic. Development of transport infrastructure of this country is a comprehensive process accompanied with high costs and technological requirements. Measures aimed at completing motorways and motorway feeder roads, extending transport capacities and improving the quality of existing roads will lead to the development of transport infrastructure. Access to high-quality and efficient transport infrastructure in all regions will facilitate elimination of regional social and economic differences and improvement of competitiveness of the country's economy.

Authors regard the monitoring and identification of the impact of transport infrastructure on selected social and economic factors in individual Slovak regions as a promising direction to take. It will also be interesting to monitor the achievement of the objectives within the strategic transport development plan within a few following years and evaluate an expected positive impact thereof on changes in the existing regional differences.

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