Thesis booklet

Budapest University of Technology and Economics,
Faculty of Transport and Vehicle Engineering

Evaluation of the operational models of the rail freight transport, research of its development possibilities

An overview of the scientific work– PhD. thesis

Bálint Farkas
Transport Engineer
Engineer - Economist

May 2020 Budapest

Acknowledgments

The Department of Transport Technology and Economics of the Faculty of Transportation Engineering and Vehicle Engineering of the Budapest University of Technology and Economic gave me opportunity to carry out my doctoral research and provided me a professional background.

I would like to thank Dr. Zoltán Bokor †, associate professor, for his outstanding support. Without his encouragement my doctoral research could not have started.

I am especially grateful to Dr. habil. Szabolcs Duleba associate professor, my current supervisor for the support of my scientific work. His economic view, international experience and professional remarks helped me a lot in completing the research.

I would like to thank those people who have joined my unusual life and accepted the challenges of this journey.I would also like to thank the head of the department, who, despite my sharing personality, gave me the opportunity to take an active part in the work of the department. Special thanks go to the former dean who supported my work throughout his personal conversations. I am grateful to all the staff in the faculty I work with, I would have been less without them.

I am grateful to every single member of the railway profession, those with whom I have been able to work and those without whom trains would not be able to leave every day. I believe that with my modest work, I can thank the railway somewhat for all it has done for humanity.

I, the undersigned Bálint Farkas, declare that I have prepared the thesis booklet of my PhD dissertation myself, and I have used only the given sources. Any part that I have taken from another source, either verbatim or in the same content, but reworded, has been clearly marked with the source indicated.

05. may 2020 Budapest,

……………………

Bálint Farkas

TABLE OF CONTENTS

LIST OF FIGURES

1.
Definition of the scientific research objects

1.1. Definition of the subject matter

After obtaining my degree in Transport Engineering (MSC), which subject was the liberalization of the rail freight market, I decided to continue my studies, as in my research I had found just a few economic studies in this subject. The topic of my dissertation, which was completed at the end of my economics studies, was also rail freight transport. In connection with my dissertations, I realised that the research of the rail freight market is reasonable and necessary.

Nowadays the improving of the rail freight's competitiveness is becoming increasingly important, as the European Union has set itself to increase continuously the share of the rail freight market compared to other modalities. I considered it appropriate to analyze the Central and Eastern European rail freight market for the last few years, as I have not encountered such a diversified study in my literature review. The rail freight markets of the selected countries can be well studied, at both macro- and microeconomic levels. I have set a target of researching the rail freight market of the Czech Republic, Hungary, Slovakia, Poland and Romania from the year before the economic crisis (2008) to 2015.

My research provided answers to the questions of how rail freight market is related to each other and which attributions are the most characteristic of the given rail freight markets.

The result of my research points to the context of the rail freight markets, and makes suggestions for making them more competitive. The research also takes a view of how the structure of the rail freight market of the countries has changed after the liberalization.

1.2. Formulation of research topics

In the course of my research, I examined the changes in the rail freight market of the Czech Republic, Slovakia, Hungary, Poland and Romania between 2008 and 2015. I have determined the most characteristic attributes of rail freight transport (hereinafter referred to as factors), which can be accurately measured and are also available in each market. In my doctoral research, I defined 15 attributes according to the table below.

		factor name	contraction	[unit]
Competitiveness	1	Biggest Market Player	BMP	percentege
Productivity	2	Domestic Traffic	DT	mill. Tonns
Productivity	3	Export	EX	mill. Tonns
Efficiency	4	GCI 6 Pillar (6) Goods Market Efficiency	GCI6P	no unit of measurement
Competitiveness	5	GCI index	GCI	no unit of measurement
Competitiveness	6	GCI 2. Pillar 2. 03 Quality Of Railway Infr.	GCI2P	no unit of measurement
Productivity	7	Import	IM	mill. Tonns
Productivity	8	International (Export+Import+Transit)	INT	mill. Tonns
Competitiveness	9	Market Concentration	MC	percentage
Competitiveness	10	Number Of Market Players	NMP	piece
Efficiency	11	Rail Share From The Total Vol.	RS	percentage
Competitiveness	12	Smallest Market Player	SMP	percentage
Productivity	13	Total Rail Traffic	TRT	mill. Tonns
Efficiency	14	Track Access Fee	TAF	Euro/ 1000 Tonns
Productivity	15	Transit Traffic	TT	mill. Tonns

table 1: Influencing factors applied for rail freight market competitiveness

1.3. Overview of the test methods used

In my dissertation I used the following mathematical methods:

1. I used the **Herfindhal-Hirsmann Index** to examine the structure of the rail freight markets of the countries.

The Herfindalhl-Hirschmann Index (Hirschmann, 1964) shows how concentrated a given market is, so how well the share is distributed among the participants. The more consistent is the share of market participants, the smaller the HHI, or the lesser participants own the bigger share, the higher the HH Index will be.

It is formed by the sum of squares of the shares of market participants:

$$\mathrm{HHI} = \sum_{i=1}^{n} r_i^2$$

where:

n: number of market players

r_i: the i.participant' s share.

The value of the index is between $\frac{1}{n}$ and 1, or it is usual to replace r_i with the numerical value of the percentages, then the upper threshold is 10000, this is more illustrative.

Based on the HHI, we distinguish three levels of classification for market concentration

According to the American classification:

- unconcentrated market: HHI below 1500
- less concentrated market: HHI between 1500-2500
- highly concentrated market: HHI above 2500

According to the Hungarian classification:

- unconcentrated market: HHI below 1000
- less concentrated market: HHI between 1000-1800
- highly concentrated market: HHI above 1800

An unconcentrated market in the UK, for example, is the gas market, which has a HHI below 1000.

2. I used **principal component analysis (PCA analysis)** to determine the more detailed correlations of the rail freight markets with the help of the R program.

In my doctoral research I used a large number of factors (15) and I worked with a larger amount of data, therefore I found it expedient to use multivariate analysis. I chose principal component analysis because I aimed to explore such relationships that are not trivial.

Principal component analysis is a procedure commonly used in medicine (Harrou et al, 2015), it has been used effectively in many other fields too. According to one recent study, the procedure was used to analyze water management in central China. (Li et al, 2019).

A parallel can be drawn between the diagonalization of the moment of inertia tensor in dynamics and the diagonalization of the matrix used during the principal component analysis procedure, but the mechanics and the principal component analysis later become sharply separated.

Although in both cases the goal is to eliminate the off-diagonal (i.e. outside the main diagonal) matrix elements (finding the main directions or principal components / main second-order torques), in the case of mechanics it means exactly X, Y, Z, axes, (3-dimensional space), while principal component analysis counts according to the attribute number in multiple dimensions.

It is also a common goal to arrange the principal components (or major second-order torques) in non-ascending order (monotonic decrease), but while all three major second-order torques are retained in mechanics, in principal component analysis only the first few that are relevant (the largest). That is, reduction occurs with little loss of information, but at the same time the problem becomes more manageable.

The stress tensor, deformation tensor, etc. behave similarly in mechanics. These are also symmetric matrices, so that all their own values are real and their own vectors are perpendicular in pairs. (The covariance matrix is even positive definite, so all its own values will be positive.)

It is important to note that the principal component analysis procedure does not assume that the population is derived from a normal distribution (Ketskeméty I.2018.) That is, it is not necessary for the elements of the original data set to come from a normal distribution in order to matrix the empirical correlation coefficients and covariances.

Therefore, no analysis of the data set resulting from a normal distribution (Of course, it is true that in the case of a normally distributed data set, the zero of the covariance or correlation coefficient would imply independence, while otherwise it is not certain.)

In other words:

If the correlation coefficient between two random quantities is 0 and we know that both are normally distributed, then they are certainly independent as well. If, on the other hand, the correlation coefficient is 0, but it is not certain (or we do not know for sure) that they are normally distributed, then their independence cannot be decided yet.

But it also measures the strength and direction / sign of the relationship well if it comes from an abnormal distribution. In the case of my doctoral research, it can also be decided visually that the processed data follow a normal distribution based on the figures examining the changes in time over 15 properties in the appendix of the dissertation.

In my case, none resemble the Gaussian curve. In addition, since I left only the first few items and none of them became zero, they do not affect my results.

Taking all this into account, surprisingly, even the PCA was not used at all to examine the transport market, including the rail freight market. That is why I chose principal component analysis for my research.

Principal Component Analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of linearly uncorrelated variables which are called principal components. Consequently, this method is mainly applicable for complex statistical problems and phenomena in which the interdependencies of the factors are subject to analyze and clustering the observation entities is also interesting. Moreover, in case of dependencies of factors from background variables can be assumed, PCA is highly recommended. This attractive characteristic has led us to consider using PCA for analyzing different influencers of rail freight market competitiveness, expecting that these “background variables” will help us in more understanding the connections of market competitiveness.

The goal of the method is generally (Szelényi, L. (**2009**):

- to uncover correlations (interdependencies) among the variables;
- to reveal and describe variable groups in mutual interdependence;
- to find the direction and closeness of relationships within the groups;
- to seek and discover the common cause behind the groups of variables (*principal component* or *factor*);
- to reduce the number of originally chosen coordinates and to visualize the observations accordingly;
- to group the observations, to find the closeness or similarity (recognizing *clusters*).

Since the influencing factors of rail freight competitiveness has not been tested by PCA yet, all general points are interesting for us, including cluster recognition for Central-Europian countries, in which all markets are liberalized from 2008 but their development is evidently very different.
Being a less applied methodology in transportation economics field in the following we introduce PCA step by step with explanation for each phase.

Phase 1. Constructing and standardizing the extended raw data matrix of the problem.

Let us suppose that we have *n* entities $(M_1, \ldots, M_n)$ characterized by *p* variables $(X_1, \ldots, X_p)$ for each entity. Based on this an **X** matrix can be constructed in which x_{ij} denotes the *i*-th value of the sample (entity) for the *j*-th variable. This can be extended by the arithmetic means and standard deviations of each variable. Note that the final objective of PCA is substituting $X_1, \ldots, X_p$by the principal components $C_1, \ldots, C_p$and reduce the *p* dimensions by selecting the principal components with the highest explanation powers (of variance) and omitting the rest.

However, these variables and values are not directly comparable e.g. due to the different unit of measure. From procedural point of view, we also need to make these variables dimensionless. For these two reasons, the values have to be standardized. Standardization is performed by first subtracting the mean from each value of the variable. The differences are then divided by the standard deviation of the values in question, as shown by the expression:

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j}$$

It is easy to prove that by standardization all means of standardized variables Z_j will be 0 and all the standard deviations will be equal to 1.

Since one of the main objectives of PCA is determining the correlations of the variables, covariance has to be introduced. For the raw, observational data the covariance of the e.g. *j*-th and *l*-th variable is:

$$s_{jl} = \frac{1}{n}\sum_{i=1}^{n}(x_{ij} - \bar{x}_j)(x_{il} - \bar{x}_l)$$

In general, the strength of interrelation between two variables or between the properties of a particular phenomenon represented by these two data is expressed by the correlation coefficient:

$$r_{jl} = \frac{s_{jl}}{s_j s_l}$$

where $0 \le |r_{jl}| \le 1$.

The closer the absolute value of r_{jl} lies to unity, the stronger the linear relationship that exists between the two variables. This is the basis behind formulating the model through linear functions. The correlation coefficients can be arranged in a correlation matrix:

$$\mathbf{R}=\begin{pmatrix} 1 & r_{12} & \dots & r_{1l} & \dots & r_{1p} \\ r_{21} & 1 & \dots & r_{2l} & \dots & r_{2p} \\ \vdots & \vdots & & \vdots & & \vdots \\ r_{j1} & r_{j2} & \dots & r_{jl} & \dots & r_{jp} \\ \vdots & \vdots & & \vdots & \dots & \vdots \\ r_{p1} & r_{p2} & \dots & r_{pj} & \dots & 1 \end{pmatrix}$$

Applying the formula for covariance to the standardized values:

$$r_{z_j z_l} = s_{Z_j Z_l} = \frac{1}{n}\sum_{i=1}^{n} z_{ij} z_{il} = \frac{1}{n}\mathbf{z}_j^T \mathbf{z}_l$$

Accordingly, the correlation matrix can be written using the following equation:

$$\mathbf{R}=\frac{1}{n}\mathbf{Z}^T\mathbf{Z}$$

The R matrix for the standardized variables will be the basis of conducting principle components determination.

Phase 2. Determining the principle components.

The objective of this step is to find $C_1, \dots, C_p$ principle components for which the following is verified:

$$\begin{aligned} Z_1 &= a_{11}C_1 + a_{12}C_2 + \dots + a_{1k}C_k + \dots + a_{1p}C_p \\ Z_2 &= a_{21}C_1 + a_{22}C_2 + \dots + a_{2k}C_k + \dots + a_{2p}C_p \\ &\vdots \\ Z_j &= a_{j1}C_1 + a_{j2}C_2 + \dots + a_{jk}C_k + \dots + a_{jp}C_p \\ &\vdots \\ Z_p &= a_{p1}C_1 + a_{p2}C_2 + \dots + a_{pk}C_k + \dots + a_{pp}C_p \end{aligned}$$

That means that all standardized variables can be constructed by the linear combinations of the principal components. It also can be proven that the principal component weight (loading) a_{jk} is just equal to the correlation coefficient providing the strength of relationship between the jth (Z_j) observational variable and the kth (C_k) principal component (main factor), i.e.:

$$r_{z_j c_k} = a_{jk}$$

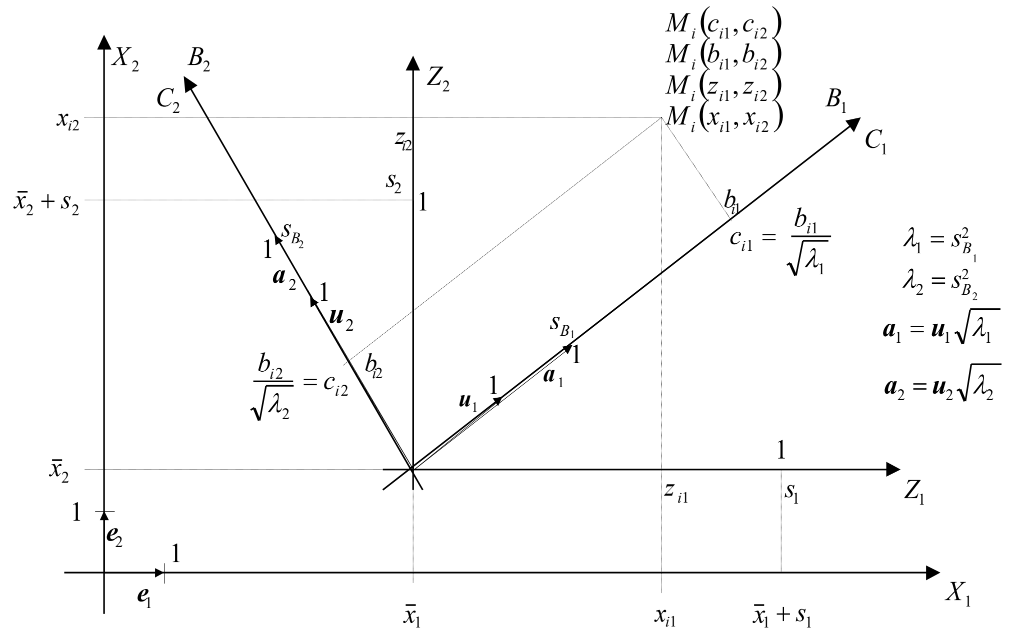
The task now is to find the principal components fulfilling the following criteria:

1. they are linearly dependent on the observational variables (linear combination);
2. they are uncorrelated;
3. the sum of squares of the coefficients (loadings) per component totals unity;
4. the standard deviation of the components is monotonically decreasing (the spread of the first component being the largest one).

Figure 1. demonstrates the required transformation graphically just for one point (M_i) of the raw data. X denotes the raw variables, Z the standardized variables, B is the matrix for the principal component coordinates and C is the matrix for standardized principle coordinates.

(C_1, C_2)

Figure 1. Transformations of two raw data variables (X_1, X_2) to two principal components (C_1,C_2)
Source: Szelényi 2019



Phase 2.a. First the unstandardized principal component coordinates have to be constructed. (We demonstrate this calculation also for two variables)

For this, the B_1, B_2 coordinate system, let us denote the basic unit vectors $\mathbf{u_1}$ and $\mathbf{u_2}$ so their absolute value equals one. The original entity point $M_i$has to be pointed by the vector ***v***. This vector can be written as [Li, Y., Wang, N. & Carroll, R. J. **(2013**)]:

$$\mathbf{v} = b_{i1}\mathbf{u}_1 + b_{i2}\mathbf{u}_2 \quad (6)$$

The unit vectors have coordinates in the Z_1, Z_2 standardized space as

$$\mathbf{u}_1 = \begin{pmatrix} u_{11} \\ u_{21} \end{pmatrix} \quad \text{és} \quad \mathbf{u}_2 = \begin{pmatrix} u_{12} \\ u_{22} \end{pmatrix}$$

Based on this, the transformation matrix U can be constructed.

$$\mathbf{U} = \begin{pmatrix} u_{11} & u_{12} \\ u_{21} & u_{22} \end{pmatrix}$$

Thus the standardized *z* coordinates can be compiled as

$$z_{i1} = u_{11}b_{i1} + u_{12}b_{i2}$$
$$z_{i2} = u_{21}b_{i1} + u_{22}b_{i2}$$

The relation between the standardized variables and principal component variables is:

$$Z_1 = u_{11}B_1 + u_{12}B_2$$
$$Z_2 = u_{21}B_1 + u_{22}B_2$$

Generalizing this transformation (extending from two variables to *p* variables) it also trivial that the variances of the (unstandardized) principal components $B_1, \dots, B_p$ are:

$$\mathbf{Ru} = \lambda\mathbf{u}$$

the eigenvalues of the correlation matrix; whereas, the unit vectors, indicating the directions of the axes, are the normalized eigenvectors. We determine the eigenvalues in a monotonically decreasing order [d'Ovidio, F. D.,et al 2014)], so that the eigenvalue of the B_1component will be the largest, and $B_p$will be the smallest among them.

Phase 2.b. Standardizing the principal components

In this step **A** matrix is constructed by multiplying each column of the **U** matrix by the standard deviation of the appropriate principal component variables.

$$a_{jk} = u_{jk}\sqrt{\lambda_k}$$

By using **A** and the variance-covariance matrix **V**, the final, standardized principle component matrix **C** for all entities M_n can be written as

$$c_{ik}=\frac{b_{ik}}{\sqrt{\lambda_k}}$$

The matrix C *for the standardized principal component scores*

	C_1	C_2	$\cdots$	C_k	$\cdots$	C_p
	$\mathbf{c}_1$	$\mathbf{c}_2$	$\cdots$	$\mathbf{c}_k$	$\cdots$	$\mathbf{c}_p$
M_1	c_{11}	c_{12}	$\cdots$	c_{1k}	$\cdots$	c_{1p}
M_2	c_{21}	c_{22}	$\cdots$	c_{2k}	$\cdots$	c_{2p}
$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$
M_i	c_{i1}	c_{i2}	$\cdots$	c_{ik}	$\cdots$	c_{ip}
$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$
M_n	c_{n1}	c_{n2}	$\cdots$	c_{nk}	$\cdots$	c_{np}
mean	0	0	$\cdots$	0	$\cdots$	0

2.

Presentation of the scientific results achieved

2.1. Thesis I.

There are background variables that, on the one hand, explain a large percentage the variance of the variables used, and, on the other hand, that create a space, where both the observation units and the variables can be interpreted.

As similar scientific research had not yet been carried out at the examination of the rail freight markets, especially for several countries, it did not seem at all certain that a correlation could be established between the countries studied and the characteristics examined.
Therefore, from the point of view of the research, the result of the principal component analysis has proved successful, as the analysis was not only feasible, but also successful; the two principal components, i.e., the background variable, adequately explained the variance. I have interpretable results that can be used to improve the competitiveness of rail freight markets.

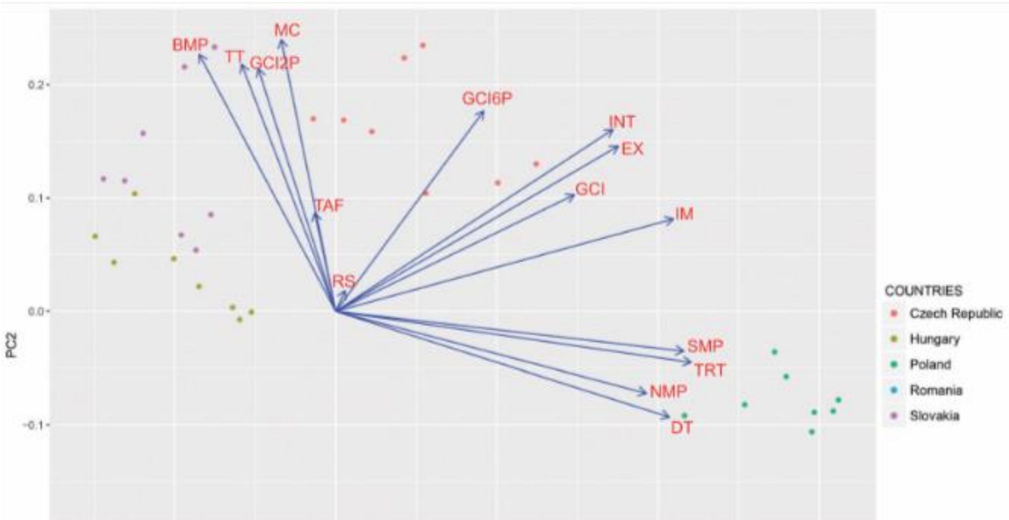


Figure 2: Influencing factors and entities in the space generated by the selected principal components

The figure above explains the factors that include the rail freight characteristics of the given groups in an integrated way. The names of the factors are included in Table 1.

The practical utility of the scientific conclusion:

I found from the selected attributes the most characteristic ones for each market, by changing which I can change the rail freight markets. I have found that markets are not necessarily the same.

The application of the PCA has made it possible to identify the critical influencing factors of each rail freight market. On this basis both strategically and operationally effective measures can be taken. The strategic aspect can provide lessons principally for managing and decision-making authorities, while operational conclusions can be useful for freight companies in the market.

My publications related to the thesis:

Duleba, S.; Farkas, B. Principal Component Analysis of the Potential for Increased Rail Competitiveness in East-Central Europe. Sustainability 2019, 11, 4181.

IF 2.592 (2018);5-Year Impact Factor: 2.801 (2018)

A vasúti árufuvarozás versenyképességének vizsgálata
HADTUDOMÁNYI SZEMLE 9 : 4. pp. 77-89. , 12 p. (2016)

A szórt kocsis árufuvarozás liberalizációjának akadályai
HADTUDOMÁNYI SZEMLE 9 : 1 pp. 431-435. , 5 p. (2016)

A szétválasztás szerepe a vasúti liberalizációban
LOGISZTIKAI TRENDEK ÉS LEGJOBB GYAKORLATOK 2 : 1 pp. 20-23. , 3 p. (2016)

THE ANALYSIS OF RAIL INFRASTRUCTURE BASED ON THE FUNCTION OF HUMAN PERIPHERAL CIRCULATION
HORIZONS OF RAILWAY TRANSPORT 1 : 1 pp. 70-78. , 8 p. (2016)

2.2. Thesis II.

It can be stated that there is a multiple correlation between the characteristic competitiveness factors of the rail freight market, which relationships are not trivial, the factors can be clustered and typified.

To explore non-trivial relationships, I used the principal component analysis method, which is rarely used in transport economics, however it can also bring indirect relationships to the surface. Using the formulas described in the methodological section, I performed the steps of determining the main components.
In the studied problem, the 15 influencing factors are replaced by 15 main components, however, due to the reduction of sizes, only the main components remain in the model, which explains the dominant part of the total variance. (This can be achieved by determining the eigenvalues because it can be proved that the standard deviation of the main components is equal to the square root of the eigenvalues.) After calculating the non-standardized and then the standardized main components, I obtained the following results.

	PC 1 (dimension)	PC 2 (dimension)	PC 3 (dimension)	PC 4 (dimension)	PC 5 (dimension)	PC 6 (dimension)
Standard deviation	2,4760	2,2017	1,3165	1,08410	0,84645	0,74912
Variance of deviaton	0,3832	0,3030	0,1083	0,07346	0,04478	0,03507
Cumulative ratio	0,3832	0,6861	0,7944	0,86790	0,91268	0,94775
	PC 7 (dimension)	PC 8 (dimension)	PC 9 (dimension)	PC 10 (dimension)	PC 11 (dimension)	PC 12 (dimension)
Standard deviation	0,54208	0,44923	0,35808	0,2829	0,25118	0,18099
Variance of deviaton	0,01837	0,01261	0,00801	0,0050	0,00394	0,00205
Cumulative ratio	0,96612	0,97873	0,98675	0,9918	0,99569	0,99774
	PC 13 (dimension)	PC 14 (dimension)	PC 15 (dimension)			
Standard deviation	0,16554	0,09359	3,095e-16			
Variance of deviaton	0,00171	0,00055	0,000e+00			
Cumulative ratio	0,99945	1,000000	1,000e+00			

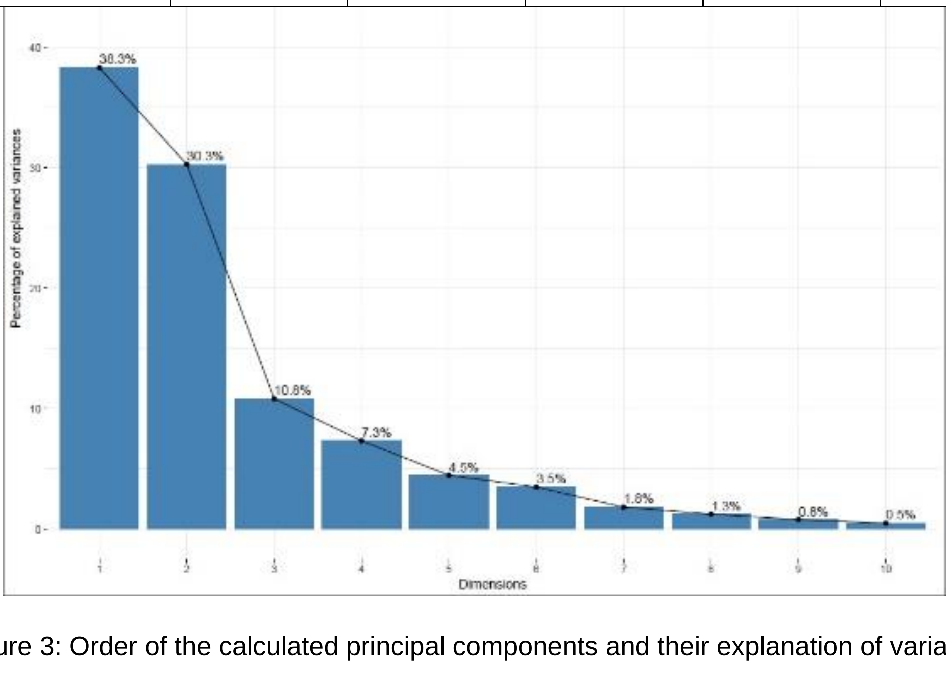


Figure 3: Order of the calculated principal components and their explanation of variance

The figure shows that the first two principal components explain 69% of the total variance, so their selection may be sufficient for analysis (the requirement of at least two-thirds follows from the mathematical rule of thumb.) Therefore, the space generated by PC1 and PC2 (which is the rotated and projected space compared to the original 15-dimensional space of the raw variables) is suitable for describing the relationships between influencing factors and observation units. The following figure shows the position of the 15 influencing factor in this two-dimensional space.

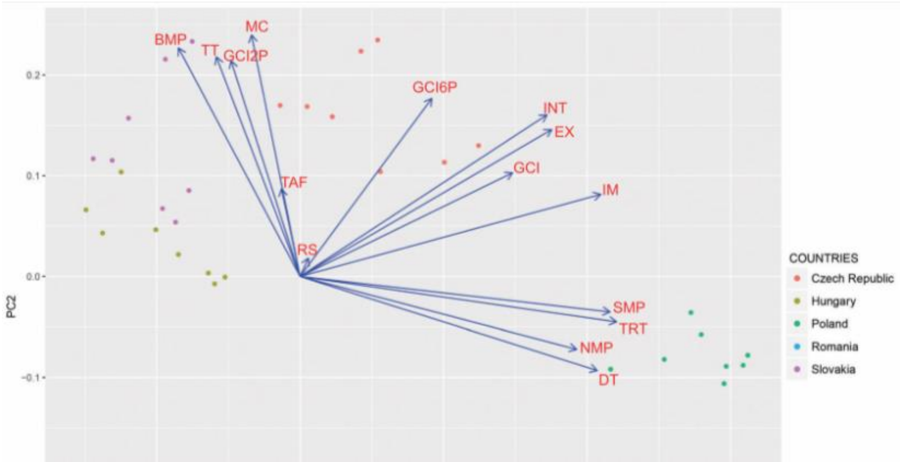


Figure 4: Influencing factors and entities in the space generated by the selected principal components

From the figure can be clearly seen the groups of factors, which clearly show that there are non-trivial relationships between the factors, and that the factors can also be typified and clustered. Thus, my second hypothesis can be considered supported.

The practical utility of the scientific conclusion:

The procedure is applicable to the rail freight market of any country.

My publications related to the thesis:

Duleba, S.; Farkas, B. Principal Component Analysis of the Potential for Increased Rail Competitiveness in East-Central Europe. **Sustainability** 2019, 11, 4181.

IF 2.592 (2018);5-Year Impact Factor: 2.801 (2018))

2.3. Thesis III:

There is a connection between the observation units (freight markets in a given country) and the connections can be used to form groups.

With the help of the principal component analysis used for the previous thesis, I examined the given observation units (the countries.) One point represents one year of a given country, so in our case the rail freight market of a country consists of 8 points, as the research covers 8 years. During the principal component analysis study, I obtained the following locations in the space generated by PC1 and PC2.

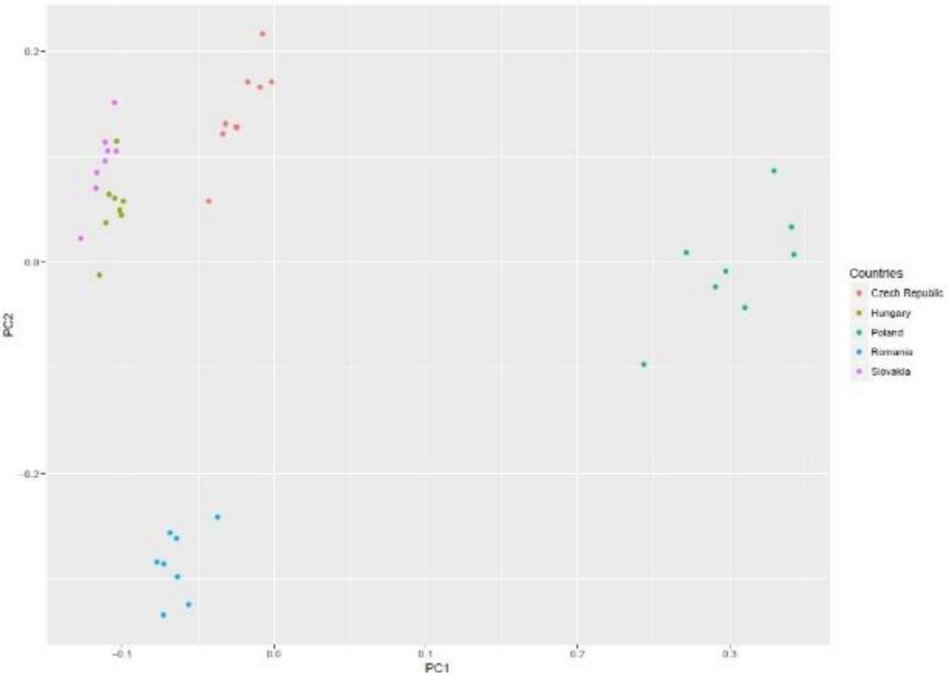


Figure 5: Positions of data by countries in the principal component space

It is clear from the figure above that the rail freight markets can be grouped. Thus, my third hypothesis can be supported.

The practical utility of the scientific conclusion:

The liberalized rail freight markets can be compared and grouped according to the characteristics examined. That is, the example of one market can be applied to another freight market belonging to the same group.

My publications related to the thesis:

<u>Increasing Competitiveness in a Liberalised Rail Freight Market the Hungarian Case</u>
TRANSYLVANIAN REVIEW 26 : 24 pp. 6369-6377. , 8 p. (2018)

IF: 0.034

2.4. Thesis IV:

The results show that the timing of liberalization does not determine the characteristics of certain rail freight market.

The rail freight market of the countries examined in the research can be divided into two parts according to the terms of liberalization, we can talk about the markets that were liberalized earlier and later. According to my hypothesis the trade processes could have started earlier in the previously liberalized markets, so the number of market participants could have steadily increased there, as opposed to the markets that opened later in time. Therefore, I assume that the importance of trade-related traffic has also increased, so the most characteristic factors of the rail freight market are export, import, transit traffic. The principal component analysis also helped my proof, the results are proved by the figure presented earlier.

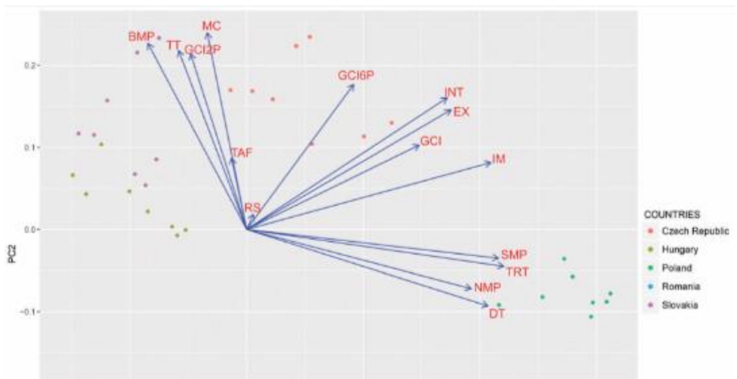


Figure 6: Influencing factors and entities in the space generated by the selected principal components

The practical utility of the scientific conclusion:

The figure above shows that the Czech Republic, Poland and Romania can be characterized by completely different attributes than I assumed, so it can be stated that the timing of the start of liberalization is unrelated to market characteristics. Based on the results, it is not the date of liberalization that determines the characteristics of each rail freight market. Thus, this hypothesis is rejected.

My publications related to the thesis:

Duleba, S.; Farkas, B. Principal Component Analysis of the Potential for Increased Rail Competitiveness in East-Central Europe. Sustainability 2019, 11, 4181.

IF 2.592 (2018);5-Year Impact Factor: 2.801 (2018)

THE INTRODUCTION OF THE MOST POWERFUL RAILWAY OF THE EU, AND ITS SUPPORT WITH ECONOMIC ANALYSES
NAUKA TA PROGRES TRANSPORTU / SCIENCE AND TRANSPORT PROGRESS 2 : 68 pp. 25-35. , 10 p. (2017)

REBALANCING HUNGARY'S ECONOMY BY RAIL FREIGHT
HORIZONS OF RAILWAY TRANSPORT 1 : 1 pp. 70-78. , 8 p. (2015)

2.5. Thesis V:

The Romanian rail freight market is completely different from all the rail freight markets I have examined. The Romanian freight market is not characterized by any of the examined characteristics.

In my opinion, the larger the area and coverage of a railway, the more economical the operation. In addition to economical operation, another argument is that the two countries mentioned in my dissertation (Romania, Poland) have maritime connections, which has paramount importance from the railway point of view, as the endpoints of railway networks are always connected to a seaport. Taking all this into account, the internal market of the country raised in the hypothesis is already very important by its territory. An example is Poland's mining industry. Similarly, agriculture plays a significant role in Romania. Consequently, rail freight transport is decisive for the country's competitiveness, so in my opinion, the competitiveness factors as well as the total amount of rail transported are typical for the two countries.

The practical utility of the scientific conclusion:

During the principal component analysis procedure I discovered very surprising results. The rail freight markets of Romania and Poland are not comparable in terms of the comparison mentioned in my hypothesis. It is true that domestic traffic, as well as total rail freight, is typical of the Polish market, but surprisingly, the Romanian freight market is not characterized by any of the characteristics I have examined.

My publications related to the thesis:

Increasing Competitiveness in a Liberalised Rail Freight Market the Hungarian Case
TRANSYLVANIAN REVIEW 26 : 24 pp. 6369-6377. , 8 p. (2018)

Impact Factor: 0.034

2.6. Thesis VI:

Smaller rail freight markets are characterized by transit traffic (TT) and the level of track access charges (TAF).

I hypothesize that the rail freight market of smaller countries is less characterized by domestic rail transport, as it is not large enough in terms of territory, and the smaller countries do not have an industry that makes rail freight activity particularly important. Consequently, such smaller countries will be characterized by transit traffic.
In transit traffic, especially in Central and Eastern Europe, the most important influencing factor may also be the track access fee. Therefore, in my opinion, in the case of smaller countries, the two characteristics mentioned above play a key role. In the previous principal component analysis, it was proved that the rail freight markets of the Czech Republic, Slovakia and Hungary are characterized by transit traffic and the level of track access charges.

The practical utility of the scientific conclusion:

In the case of the Czech Republic, Hungary and Slovakia, it would be worthwhile to change the value of the track access fee, typically to reduce it in order to bring even more transit traffic to the given country, thus increasing the size of the country's rail freight market.

My publications related to the thesis:

Duleba, S.; Farkas, B. Principal Component Analysis of the Potential for Increased Rail Competitiveness in East-Central Europe. Sustainability 2019, 11, 4181.

IF 2.592 (2018);5-Year Impact Factor: 2.801 (2018)

3. *Bibliography*

Abramović, B.; Šipuš, D. (2019).*A Case Study of the Railway Engineering Programme; Sustainable Rail Transport*; University High Education in Croatia; Springer: Berlin/Heidelberg, pp. 101–109

Aditjandra, P. T. (2018). *Europe's Freight Transport Policy: Analysis, Synthesis and Evaluation. Preparing for the New Era of Transport Policies: Learning from Experience, 197–243.* doi:10.1016/bs.atpp.2018.07.006

Agamez-Arias, A.-M., Moyano-Fuentes, J. (2017). Intermodal transport in freight distribution: a literature review. Transport Reviews, 37(6), 782–807. doi:10.1080/01441647.2017.1297868

Andersen, J., & Christiansen, M. (2009). Designing new European rail freight services. *Journal of the Operational Research Society*, 60(3), 348–360. doi:10.1057/palgrave.jors.2602559

Baksay, G., Palotai, D. (2017). Válságkezelés és gazdasági reformok Magyarországon, 2010–2016. *Közgazdasági szemle*, pp. 698–722. o

Bergantino, A., Capozza, C., Capurso, M. (2015). The impact of open access on intra- and inter-modal rail competition. A national level analysis in Italy. *Transport Policy,* 39, 77-86.

Blahó, A. (2012): Globális Világgazdasági válság. A megoldások vitája. In: Régi dilemmák - új megoldások. Tomori Pál Főiskola, Kalocsa, pp. 15-32. ISBN 978-963-88162-9-0 http://unipub.lib.uni-corvinus.hu/1067/1/Blaho_2012_globalis.pdf

Bokor, Z. (2007) Hungary: role of the state in intermodal transport logistics services. Logistics and Transport Focus, 9 (8). pp. 37-41.

Bokor, Z. (2012) Cost Calculation Model for Logistics Service Providers. *Promet - Traffic & Transportation*, 24(6), pp.515-24.

Bokor, Z. (2009). Elaborating Cost and Performance Management Methods in Transport. *Promet - Traffic & Transportation*, 21(3), pp.217-24.

Bokor, Z., Török, Á. (2005). Situation and Perspectives of Intermodal Logistics in Hungary. *Promet - Traffic & Transportation*, 17(6):349-52.

Bougna, E., Crozet, Y. (2016). Towards a liberalized rail transport: Analyzing and modelling the impact of competition on productive efficiency. *Research in Transportation Economics,* 59, 358-367.

BUŞU, M., BUŞU, C. (2015). The liberalization process of the railway sector in Romania and some infringement case studies, Management and Innovation For Competitive Advantage", November 5th-6th, 2015, Bukarest, Románia

Campos, N, F., Coricelli, F., Moretti, L. (2018) Institutional integration and economic growth in Europe. *Journal of Monetary Economics*, ISSN 0304-3932
https://doi.org/10.1016/j.jmoneco.2018.08.001.

Cantos, P., Pastor, J. M., Serrano, L. (2010). Vertical and horizontal separation in the European railway sector and its effects on productivity. *Journal of Transport Economics and Policy,* 44, 139-160.

Cemberci, M., Civelek, M. E., Canbolat, N. (2015). The moderator effect of Global Competitiveness Index on dimensions of Logistics Performance Index. *Procedia – Social and Behavioral Sciences,* 195, 1514-1524.

Chinn,M.; Frankel J. (2008) Why the Euro will Rival the Dollar, *International Finance* 11:1 ,2008 pp 49-73 DOI: 10.1111/j.1468-2362.2008.00215.x
https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1468-2362.2008.00215.x

Crafts N., Toniolo G (1996). Economic growth in Europe since 1945; B. Eichengreen Institutions and economic growth: Europe after World War II - Economic growth in Europe since, 1945 pp 38-65

Crozet, Y., Nash, C., Preston, J. (2012) Beyond the quiet life of a natural monopoly: Regulatory challenges ahead for Europe's rail sector - CERRE, Brussels, 2012 - cerre.eu

Crozet, Y. (2017). Rail freight development in Europe: how to deal with a doubly-imperfect competition? World Conference on Transport Research WCTR 2016 Shanghai - 10-15 July 2016 (SIG E3) *Transportation Research Procedia* 25C, pp 425–442

Dénesfalvy, Á. (2009). Pályavasúti szolgáltatási rendszer elemek minőségi paramétereinek meghatározása és a szolgáltatások minősítési folyamatának modellezése, Ph.D. értekezés,http://hdl.handle.net/10890/82

Dolinayova, A., L'och, M., Camaj, J. (2016). Liberalization of the railway freight market in the context of a sustainable transport system. *Transportation Research Procedia,* 14, 916-925.

d'Ovidio, F. D., Leogrande, D., Mancarella, R., Schinzano, A., Viola, D. (2014). A multivariate analysis on the quality of transport services. *Procedia Economics and Finance,* 17, 238-247.

Erb, Sz. dr (2018). A vasúti közlekedést érintő EU konform jogi szabályozás jelenlegi és várhatóan bevezetésre kerülő rendelkezései, A magyar közlekedés helyzete az EU-ban tárgyú konferencia (2018, február 22-23.) előadása

Édes, B., Gerhardt, E.,Micski, J. (2011). A liberalizáció első időszakának versenyszempontú értékelése a magyar vasúti teherszállítási piacon. *Verseny és szabályozás*, 5. évfolyam 1. szám, pp. 261-302

Farkas, B. (2016) A szétválasztás szerepe a vasúti liberalizációban, *Logisztikai trendek és legjobb gyakorlatok,* pp 19-22, HU ISSN: 2416-0555

Farkas, B (2017). The introducion of the most powerful railway of the EU, and its support with economic analyses. *Science and Transport Progress* (No2/68) 2017. pp 25-35) doi 10.15802/stp2017/99944

Farkas, Gy. (2001). A vasúti pályahasználati díj meghatározásának módszertana. PhD értekezés, Budapesti Műszaki és Gazdaságtudományi Egyetem

Feuerstein, L., Busacker, T., Xu, J. (2018). Factors influencing open access competition in the European long-distance passenger rail transport – a Delphi study. *Research in Transportation Economics,* xxx, 1-10.

Gaal, Gy., Csete, M., Török, Á. (2017) Uniós források és közlekedési infrastruktúra a magyar gazdaságbanIn: Péter, Tamás (szerk.) IFFK 2017 : XI. Innováció és fenntartható felszíni közlekedés Budapest, Magyarország : Magyar Mérnökakadémia (MMA), Paper: 16 , 4 p

Gathon, H. J., Pestieau, P. (1995). Decomposing efficiency into its managerial and its regulatory components: The case of European railways. *European Journal of Operational Research,* 80, 500-507.

Evans, A. W. (2011). Fatal train accidents on Europe's railways: 1980–2009. *Accident Analysis & Prevention*, 43(1), 391–401. doi:10.1016/j.aap.2010.09.009

Halászné Sipos E., (2003) Logisztika - Szolgáltatások, versenyképesség... című könyv, Logisztika és marketing viszonya, marketinglogisztika, 67.o.

Hansut, L.; David, A.; Gasparik, J. (2017). The Critical Path Method as the Method for Evaluation and Identification Of The Optimal Container Trade Route Between Asia And Slovakia. *Bus. Logist. Mod. Manag*, *17*, 29–42.

Harrou, F., Kadri, F., Chaabane, S., Tahon, C., & Sun, Y. (2015). Improved principal component analysis for anomaly detection: Application to an emergency department. Computers & Industrial Engineering, 88, 63–77. doi:10.1016/j.cie.2015.06.020

Hirschman, A. (1964). The Paternity of an Index. *The American Economic Review*, Vol. 54, No. 5 p. 761
Hokstok, Cs. (2013). Vasúti infrastruktúragazdálkodás kontrolling bázisú döntéselőkészítő rendszerek alkalmazásával PHD. értekezés

Holvad, T. (2009). Review of railway policy reforms in Europe. *Built Environment,* 35(1), 24-42.
Jarzemskis, A., Jarzemskiene, I. (2017). Comparison of rail freight transportation markets in Lithuania and Poland. *Procedia Engineering,* 187, 492-497.

Koós, G. (2013). Piacnyitás a vasúti szektorban- a negyedik vasúti csomag. *Verseny és szabályozás* 2013.1. szám pp.324-374 MTA Közgazdaságtudományi Intézet, http://econ.core.hu/file/download/vesz/verseny_13_KoosG_vasut.pdf 13

Kovács Ferenc, (2015) *Az ipari parkok és a logisztika kapcsolatrendszere a Sopron Dél- Keleti Ipari Park és a GySEV Cargo Zrt. példáján.* BA/BSc diplomamunka, Közgazdaságtudományi Kar

Kozerska M. (2016). Analysis of implementation of investment PKP Cargo S.A. in the years 2012-2014, *Autobusy : technika, eksploatacja, systemy transportowe* R. 17, nr 6 1399—1403

Kurmai, V. (2016). A piaci verseny és koncentráció az almasűrítmény világpiacán Agrártudományi Közlemények, 2016/69, pp. 129-135

Li, Y., Wang, N., Carroll, R. J. (2013). Selecting the number of principal components in functional data. *Journal of the American Statistics Association,* 108, 1284-1294.

Lippmann, W.: The cold war : a study in U.S. foreign policy New York : Harper & Bros., ©1947.

Locsmándi, S. (2009) „A határon átnyúló vaspálya. A GYSEV fejlődése és szerepe a határ menti kapcsolatokban Eisenstadt (Kismarton)-Sopron térségében", *Tér és Társadalom*, 23(2), o. 135-153. doi: 10.17649/TET.23.2.1239.

Nagy, A. (1999): A dél-európai országok európai integrációja és annak tanulságai – I. Közgazdasági Szemle, XLVI. évf., (176–193. o.)

Nash, C. A. (2008). Passenger railway reform in the last 20 years-European experience. *Research in Transportation Economics,* 22(1), 61-70.

Nash, C. (2010). European rail reform and passenger services – the next steps. *Research in Transportation Economics,* 29, 204-211.

Nash, C. A., Smith, A. S. J., Van de Velde, D., Mizutani, F., Uranishi, S. (2014). Structural reforms in the railways: Incentive misalignment and cost implications. *Research in Transportation Economics,* 48, 16-23.
Neményi, J.; Oblath, G. (2012). Az euró hazai bevezetésének újragondolása. *IEHAS Discussion Papers* MT-DP - 2012/14a http://hdl.handle.net/10419/108255

Marschnig, S. (2016). Innovative track access charges. *Transportation Research Procedia,* 14, 1884-1893.

Martin, J.P. (2016). Felzárkózás vagy bezárkózás? A magyar gazdaság teljesítménye és az euroszkepticizmus alakulása az EU-csatlakozás után, összehasonlító keretben. DOI: 10.14267/phd.2016009 JP Martin - 2016 - phd.lib.uni-corvinus.hu

Matsumoto, A., Merlone, U., Szidarovszky, F. (2012). Some notes on applying the Herfindahl-Hirschman Index. *Applied Economics Letters,* 19(2), 181-184.

Odolinski, K., Wheat, P. (2017). Dynamics in rail infrastructure provision: Maintenance and renewal costs in Sweden. *Economics of Transportation,* xxx, 1-10.

Oum, T. H., Yu, C. (1994). Economic efficiency of railways and implications for public policy: A comparative study of the OECD countries' railways. *Journal of Transport Economics and Policy,* 28, 121-138.

Papp Róbert, (2016) *A GYSEV CARGO Zrt. intermodális logisztikai központ régiós szerepe.* Diplomamunka, Közgazdaságtudományi Kar

PĂUN, I. G. (2017) Impication ont he number and concentration of suppliers on romanian transport servies. Annals of the „Constantin Brâncuşi" University of Târgu Jiu, Economy Series, Issue 1/2017 pp154-157

Pelkmans, J. (2001). Making EU Network Markets Competitive. *Oxford Review of Economic Policy*, Volume 17, Issue 3, 1 September 2001, Pages 432–456 https://doi.org/10.1093/oxrep/17.3.432 8

Pop, I.L. (2015). Cartels: a Good or a Bad Strategy? Technical University of Cluj-Napoca, North University Center of Baia Mare EICU, Volume 6, Number 9 pp 29-38

Purwanto, A. J., Heyndrickx, Kiel, J., Betancor, O., Socorro, M. P., Hernandez, A., Eudenio-Martin, J. L., Pawlowska, B., Borkowski, P., Fiedler, R. (2017). Impact of transport infrastructure on international competitiveness of Europe. *Transportation Research Procedia,* 25, 2877-2888.

Rodrigue,J.P., Notteboom T. (2010). Comparative North American and European gateway logistics: the regionalism of freight distribution. *Journal of Transport Geography*, Volume 18, Issue 4, pp. 497-507 https://doi.org/10.1016/j.jtrangeo.2010.03.006.
(http://www.sciencedirect.com/science/article/pii/S0966692310000384)

Royde-Smith J. T., Hughes T.A.: World War II 1939–1945 Encyclopædia Britannica, Inc. https://www.britannica.com/event/World-War-II 2018.02.09.

Rudowski, M.H. (2015). Information systems in management of polish railway companies of PKP group in aspects of technology and economy. *Information Systems in Management*, pp.193-204

Sakalys, R.; Sivilevicius, H.; Miliauskaite, L.; Sakalys, A. (2019) Investigation and evaluation of main indicators impacting synchromodality using ARTIW and AHP methods. *Transport*, *34*, 300–311
SCI/Verkehr Berlin (2016). European Rail Freight Market – Developments, volumes, players. Extract from the study. SCI Verkehr Gmbh.

Schlosser, P. (1979): Report On The Convention ont the Asso Association of the Kingdom of Denmark, Ireland and the United Kingdom of Great Britain and Northern Ireland to the Convention on jurisdiction and the enforcement of judgments in civil and commercial matters and to the Protocol on its interpretation by the Court of Justicie Official

Journal of the European Communities Signed at Luxembourg, 9 October 1978 05. 03. 1979. No. C 59/71 (file:///C:/2019/Doktori%20Dolgozathoz%20anyagok/commercial_reports_schlosser_C_59_79%20(8).pdf

Simlar, L., Wilson, P. W. (1999). Estimating and bootstrapping Malmquist indices. *European Journal of Operational Research,* 115, 459-471.

Siklos, Pierre L. "The End of the Hungarian Hyperinflation of 1945-1946." Journal of Money, Credit and Banking, vol. 21, no. 2, 1989, pp. 135–147. JSTOR, www.jstor.org/stable/1992364. 2019.02.09.)

Stehman,O., Zellhofer, G. (2004) Dominant Rail Undertakings under European Competition Policy, *European Law Journal* Vol. 10 Issue 3, pp 327-353 https://onlinelibrary.wiley.com/doi/full/10.1111/j.1468-0386.2004.00219.x https://doi.org/10.1111/j.1468-0386.2004.00219.x

Szekely, B. (2009). Liberalisation of the railway industry in Europe: Toward a sustainable system through process view. *International Journal of Sustainable Economy*, 1/2, pp. 167–185.

Szelényi, L. (2009). Multivariate methods of econometrics. Educational material, Szent István University Faculty of Economics and Social Sciences. Gödöllő, Hungary.

Szendrő, G., Török Á., (2016) ANALYSIS OF HUNGARIAN RAIL TRANSPORT SECTOR In: prof, Ing Jozef Gnap PhD - prof, Ing Jozef Gnap PhD (szerk.) CMDTUR 2016 Zilina, Szlovákia : University of Transport and Communications of Zilina, pp. 416-420. , 5 p.

Tánczos, K., Bessenyei Gy. (2009). East European Rail: the State of the Network. *BUILT ENVIRONMENT* , Vol. 35 No. 1, pp 44-56

Tasnádi, A. (2013) *Duopólium részben állami tulajdonú vállalattal.* In: Matematikai közgazdaságtan: elmélet, modellezés, oktatás - Tanulmányok Zalai Ernőnek. Műszaki Könyvkiadó, pp. 177-186. ISBN 978 963 166 088 3

Taylor, Z., Ciechański, A. (2006). Deregulation in Polish Rail Transport. *Transport Reviews,* 26(3), 305–324. doi:10.1080/01441640500443856

Tarján M. T.: 1946. július 10. | Világrekordot dönt a magyar infláció Rimiconline (http://www.rubicon.hu/magyar/oldalak/1946_julius_10_vilagrekordot_dont_a_magyar_inflacio/) 2019.02.09.

Tomeš, Z., Kvizda, M., Nigrin, T., Seidenglanz, D. (2014). Competition in the railway passenger market in the Czech Republic. *Research in Transportation Economics*, 48, 270–276. doi:10.1016/j.retrec.2014.09.052

Tomeš, Z., Kvizda, M., Jandová, M., & Rederer, V. (2016). Open access passenger rail competition in the Czech Republic. *Transport Policy*, 47, 203–211. doi:10.1016/j.tranpol.2016.02.0039

Tóth, Zs. (2017). A magyar gazdaságpolitika elmúlt 25 éve – gazdaságtörténeti áttekintés a konvergencia szempontjából = The last 25 years of Hungarian economic policy - an outline of economic history with a view to convergence, *Közép-Európai Közlemények* Évf. 10 szám 3, pp. 120-137

Valentiny, P. (2013). Változások a hálózatos közszolgáltatások szabályozási intézményrendszerében. *Verseny és szabályozás,* 2013.1.sz. pp.281-318 MTA Közgazdaságtudományi Intézet econ.core.hu/file/download/vesz2013/intezmeny.pdf

Vickerman, R. (1989). Measuring changes in regional competitiveness: the effects of international infrastructure investments. *The Annals of Regional Science,* 23, 275-286.

Völgyi K., Lukács E.: A délkelet-ázsiai régió integrációs sikere: az ASEAN egységes termelési bázis Tér és Társadalom / Space and Society:28. évf. 4sz. 2014. pp 98 – 116

Wiegmans, B.; Janic, M. (2019) Analysis, modeling and assessing performances of supply chains served by long-distance freight transport corridors. *Int. J. Sustain. Transp.,* 13, 278–293
Xin, X.; Li, M. (2017) . Correlation Analysis of China's Urban Rail Transit Industry. *Period. Polytech. Transp. Eng.*,45,

148–156. [CrossRef]

Yves CROZET et al. / Transportation Research Procedia 25C (2017) 425–442 4294

Yukawa, T. (2018). European integration through the eyes of ASEAN: Rethinking Eurocentrism in comparative regionalism*. International Area Studies Review, 223386591880803.* doi:10.1177/2233865918808035

Zunder, T.H.; Islam, D.Z.; Mortimer, P.N.; Aditjandra, P.T. (2013).How far has open access enabled the growth of cross border pan European rail freight? A case study. *Res. Transp. Bus. Manag. 6*, 71–80.