ISSN 1648-4142 / eISSN 1648-3480

TRANSPORT

2024
Volume 39
Issue 2
Pages 114–128
https://doi.org/10.3846/transport.2024.19802

Original Article

RAIL FREIGHT ACCESSIBILITY OF THE VISEGRÁD GROUP COUNTRIES AND BALTIC STATES IN THE CONTEXT OF EURASIAN RAIL TRANSPORT SYSTEM

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Highlights:

- countries' rail freight accessibility and rail freight performance scores were established based on values of several numerical indicators relating to rail transport;
- Czechia and other Visegrád Group countries' achieved high accessibility levels, possibly due to their favourable geographical locations and their relatively large logistics markets;
- Lithuania and other Baltic States' high performance levels might be linked to their growing freight markets, as well as the fact that the utilized unit of measure was related to countries' population, thus favouring smaller countries;
- countries' accessibility and performance levels carry a considerable information value by pointing to various strengths and weaknesses of rail freight systems.

Article History:

- submitted 13 January 2023;
- resubmitted 20 April 2023,
- accepted 2 August 2023;

Abstract. This study aimed to determine the level of infrastructure-based rail freight accessibility and rail freight performance of several Central and Eastern European (CEE) countries in the context of their presence in the Eurasian rail freight transport system. The study's object was 7 CEE countries: Estonia, Lithuania, Latvia, Poland, Czechia, Slovakia and Hungary. The research methodology was based on the TOPSIS method supplemented with literature and statistical analyses. Several selected numerical indicators were considered to create 2 rankings that displayed the results achieved by countries in terms of accessibility and performance. Results showed that Czechia is the leader in infrastructure-based accessibility, with Latvia closing the ranking, and Lithuania is the leader in rail freight performance, with Hungary closing the ranking. Even though the study did not allow to confirm that a country's rail freight accessibility affects its rail freight performance and vice versa, it can be assumed that both parameters are crucial in the context of the incoming modal shift to rail freight in Eurasia; therefore, they constitute a valuable research endeavour.

Keywords: transport accessibility, rail freight, Eurasian transport system, Belt and Road Initiative, Trans-European Transport Network, Visegrád Group countries, Baltic States, TOPSIS analysis.

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Notations

BRI – Belt and Road Initiative;
CEE – Central and Eastern Europe;
COV – coefficient of variation;
EC – European Commission;
EEC – European Economic Community;
EU – European Union;
GDP – gross domestic product;
IRG Rail – independent regulators' group – rail;
TEN-T – Trans-European Transport Network;
TEU – twenty-foot equivalent unit;
TOPSIS – technique for order of preference by similarity to ideal solution;
USD – US dollar.

1. Introduction

The national transport network's development and integration into the international transport system are among the critical factors in a country's development, although not an end in itself. It significantly impacts many spheres of country's functioning, its economic growth and diversification or technological development. However, emerging global transport systems are a complex matter, necessitating countries to balance cooperation in creating a shared, efficient network and competition when their interests oppose or conflict. Freight transport is the backbone of the supply chain, enabling international commerce and meeting the growing demand for goods and services, among other functions; thus, developing global freight transport systems is particularly important from an economic standpoint.

This article examines the Eurasian rail freight transport system. Its dynamic and ambitious development plans, including the TEN-T and the BRI, make it an interesting and timely scientific research object. This research focuses on several CEE countries of the system: the Baltic States, i.e., Estonia, Latvia, Lithuania, and the Visegrád Group countries, i.e., Poland, Czechia, Slovakia and Hungary. The geographical location of these countries at the intersection of North–South and East–West rail freight transit routes makes the development of their rail freight networks crucial for the whole system's development. Since their joint accession to the EU in May 2004, these countries' transport development strategies have been strongly influenced by EU regulations, and their budgets for infrastructural development have been supplemented by structural funds. Their transport markets can be considered homogenous and comparable, although varying in size.

The study aimed to determine the rail freight accessibility and performance of the analysed countries in the context of their presence in the Eurasian rail freight transport system. The research methodology is based on the TOPSIS method supplemented with literature and statistical analyses. It allowed the development of 2 separate rankings: 1st, depicting the accessibility of the analysed countries, considering infrastructural and cost factors, and 2nd, showing their rail freight performance, considering rail freight statistics and measures reflecting their participation in the Eurasian transport system. The research question is formulated as follows: "what is the level of transport accessibility of analysed countries, and how does that level translate into their rail freight performance?". Whereas the research hypothesis assumes that the 2 measures are interrelated, and the country's level of rail freight performance can also be regarded as the level of utilisation of the country's rail freight accessibility.

This article's contribution to the body of knowledge in the area of transport systems is both of theoretical and applicational value. 1st, the study proposes a 2-dimensional approach to investigating national transport systems, considering their passive (accessibility) and active (performance) sides. It compares these 2 measures to provide a comprehensive picture of a country's presence in the defined part of the transport system. 2nd, it offers an original way to define and quantify countries' rail freight accessibility and performance by proposing a set of illustrative indicators with an example of inclusion and exclusion criteria. Lastly, it proposes to use a linear ordering method for assessing national transport systems, contributing to the methodological development in the area of transport systems. To the best of the author's knowledge, this goes beyond the most typical application of these methods.

The rest of the article is structured as follows. The Section 2 provides a literature overview, including information on the analysed part of the Eurasian rail freight transport system, i.e., the Visegrád Group countries and the Baltic States, and the investigated concept of transport accessibility. Section 3 describes the research methodology based on the TOPSIS method. Section 4 presents the list of indicators selected for the analysis of numerical data. Section 5 informs on the course and results of the study. Section 6 presents a discussion of the results. The article ends with Section 7 – conclusions.

2. Background literature

2.1. Eurasian rail freight transport system

Transport and mobility are essential components of the modern economy, as reflected in statistical data (EC 2019; Brumbaugh *et al.* 2018) and research studies. Various analyses confirm the evident benefits resulting from the high level of transport system development, including higher levels of productivity and growth (Chen, Vickerman 2017), higher levels of employment and business activity (Miljković *et al.* 2018) or increased investment attractiveness (Czech 2021).

Developing a common transport system is one of the cornerstones of the EU's integration processes. The emergence of the common transport policy and the provision of free movement of goods, services and people had been among the priorities mentioned in the Treaty of Rome to be realised by the EEC. A few decades later, the Treaty of Maastricht established the EU in its current form and empowered the former provisions of the common transport policy. To turn the European transport system's unification plans into action, the TEN-T concept was established in the 1990s. Its initial aim was to integrate and further develop the existing transport networks of member countries. Due to the revision of the TEN-T guidelines in 2013, the present corridor alignment has been established, including both western and eastern parts of the previously fragmented network. At present, TEN-T comprises 2 levels: the core network, which includes 9 strategically most important corridors, and the comprehensive network, which is intended to support the main connections (Czech 2021).

Efforts towards the European railway network's unification are brought together under the single European railway area framework (CoEU 2024b). This programme closely correlates with European sustainability goals. According to the European green deal plan, the whole Community is to cut emissions by at least 55% by 2030 and achieve climate neutrality by 2050 (CoEU 2024a). The modal shift to railways for transporting goods (and passengers) is intended to be one of the measures to achieve these objectives. The plan is to increase the share of rail freight transport from 18% in 2018 to 30% in 2030 (Rail Freight Forward 2018). At the same time, other important objectives must also be handled, e.g., the modernisation of information and traffic management systems or congestion reduction (EC 2011). To ensure the successful development of such a scale, the EU provides various financial mechanisms (such as *Connecting Europe Facility*, *Shift2Rail* or *Cohesion Fund*), but despite the significant level of financial aid, the implementation of these plans will be a challenge for the whole Community and especially the CEE countries, whose transport networks require more upgrading.

Apart from the efforts to harmonise the EU's transport network into one well-functioning structure, the Asian part of the Eurasian transport system constitutes another interesting research topic. One of the most prominent examples of Asian-based initiatives aimed at advancing transport systems is the BRI, also referred to as the New Silk Road. Like EU leaders, Chinese authorities seemed to recognise the need to integrate the region's transport networks a long time ago, as evidenced by references to the desire to restore the ancient Silk Road appearing as early as 1994. However, the plan was actioned years later as a result of seeking new measures to sustain the country's economic growth and cope with its domestic overcapacity during the years following the global financial crisis of 2008 (He 2020). Since 2013, the BRI has encompassed a wide range of dimensions, including infrastructure, trade, finance, research and development or culture. China is the initiator of the whole undertaking, but unlike the EU, which holds formal and financial authority over the development of the TEN-T, China plays a role of a conceptual organiser and supervisor, leaving the planning and implementation of specific projects to state and private enterprises. When analysing the BRI subject matter, especially in comparison to TEN-T, the general impression of vagueness and ambiguity of the project remains, e.g., when it comes to determining the conclusive list of rationales behind the project's initiation, its geographical scope or its future implications for China and member states (Blanchard 2021).

Despite the multiplicity of the BRI's declared dimensions, its main focus so far seems to be on the transport and connectivity aspect and the creation of the network of economic transport corridors (He 2020; Nazarko, Kuźmicz 2017). The BRI is implemented through various infrastructure investments in Eurasia and Africa. Some of the European examples are the development of the Greek seaport in Piraeus or the Land–Sea Express Route – a high-speed railway line intended to connect Greece and Hungary through North Macedonia and Serbia (Maró, Török 2022). The BRI is set to affect not only the regional transport infrastructure (Wilczewska *et al.* 2022) but also, perhaps above all, have an important role in enhancing the intercontinental transport of goods (Nazarko *et al.* 2017). Chen *et al.* (2022) indicated various ways in which the BRI is to affect the global logistics market, including the influence through infrastructure investments, increased trade or expansion of industries (which will inevitably cause shifts in transport demand).

According to statistical data for 2021, China was among Europe's largest partners for import and the third largest partner for export of goods (Eurostat 2024a); the trade value has been growing. The vast majority of goods transported between China and Europe is carried by sea, while rail transport accounts for about 4.2% of the total value of deliveries between the 2 partners and about 2.2% of their weight, which, as of 2020, equalled 592000 TEUs (Wiśniewska, Jakóbowski 2021). This result may seem insignificant compared to sea transport, but in 2010, the rail transport from China to Europe was only several thousand TEUs. This growth trend was partially possible through the Chinese government's subsidies, which amounted to as much as USD 5000 per every transported container. However, over time, this mode of transport started gaining logistics operators' attention as a relatively reliable alternative to lengthy but inexpensive sea freight and fast but costly air transport.

The development of the TEN-T and the BRI and their synergy constitutes a vital issue critical to the future development of the overall Eurasian transport system (Dunmore *et al.* 2019). As the CEE countries are positioned at the intersection of these 2 parts of the Eurasian rail freight transport system, they are essential stakeholders in the system's integration. The following section provides insight into the perspective of a group of CEE countries selected as the research object.

2.2. Visegrád Group countries and the Baltic States in the Eurasian transport system

The Baltic States and the Visegrád Group countries are geographically located along the North–South axis of Eastern Europe and their eastern borders, except for Czechia, constitute the EU's external border. Since these countries accessed the EU in 2004, their transport and infrastructure systems became a part of the joint European transport area. However, it had been the responsibility of both parties – candidate countries and the EU – to prepare suitable conditions for cooperation beforehand, also with regard to transport. On the EU side, the assistance included support in planning the candidate countries' infrastructure priorities, e.g., through launching the transport infrastructure needs assessment process in the 1990s or drafting plans for the Pan-European corridors on the territories of CEE countries during the series of Pan-European transport conferences (Fleischer 2016) and financing their implementation through various financing mechanisms.

However, apart from the EU's assistance, the main part of the responsibility for developing transport infrastructure lies primarily with the member states. One of the significant challenges for the Baltic States and the Visegrád Group countries included the quantitative and qualitative expansion of national rail networks to catch up with Western European network density indicators and quality requirements. Another problem was the fact that the dominant direction of existing lines was East–West oriented due to the historical background and economic ties with Eastern countries (Schürmann 2013; Maró, Török 2022), and the number of North–South connections had been lacking. Another remnant of the Eastern block is the operation on (in the case of the Baltic States) or access to (in the case of the Visegrád Group countries) the broad 1520 mm railway gauge, compared to the European gauge of 1435 mm (Czerewacz-Filipowicz 2019). However, even though the integration process has included many substantial and costly challenges, both statistics on investments (Czech 2021) and empirical findings (Górniak 2014) can vouch for slow but steady improvement of these countries' rail infrastructure over time.

Apart from utilising the EU funding for upgrading the railway infrastructure, all analysed countries are also eligible for investments under the BRI project and the associated 17+1 forum. The use of this funding source is most evident in the case of Hungary (Völgyi, Lukács 2021). However, it is not necessary to receive Chinese investment funds to be an important part of Eurasian transport routes because almost all analysed countries' are located at the EU external border, which means that they naturally play the role of entry and exit points to the EU in the context of transporting goods from and to Asia. This role enables them to retain 25% of collected customs duties (EC 2021) and develop their logistics and warehousing industries to accommodate the demand for rail transport capacity.

Figure 1 shows the essential infrastructure components relevant to Eurasian rail freight transport in the group of analysed countries. The map depicts linear and nodal facilities of key importance to the freight transport system, including the route of freight lines proposed by the EC in the 2021 revision of the TEN-T guidelines and border crossings, terminals and seaports. It is important to acknowledge the influence of recent global events (such as the ongoing war in Ukraine and sanctions against Russia or the COVID-19 pandemic) on the Eurasian transport system. The priority routes and nodes are subject to frequent change caused by such factors as blockades of railway tracks, increased transport risk, rising fuel prices, container shortages or temporary shutdowns of Chinese terminals and seaports. The slight reduction in the volume of goods transported by rail from the Far East is already evident in the statistics (Raimondi 2022); however, the whole Eurasian transport system is evolving to accommodate the current circumstances.

The transport systems in the Baltic States and the Visegrád Group countries represent an important and interesting scientific research object considering the circumstances affecting their development. A literature review determined that in the wide range of studies on transportation systems, authors most often separate the 2 groups of countries, i.e., the Baltic States (Schürmann 2013) and the Visegrád Group countries (Tóth 2018), or examine individual cases (Stawicki 2018). Examples of other research compiling and comparing all 7 countries in other areas, such as economics (Bobenič Hintošová *et al.* 2020) or information technologies (Samoilenko, Osei-Bryson 2015), suggest that adopting such a defined territorial study scope can yield interesting results. Therefore, this article provides an investigation into the Baltic States and the Visegrád Group countries rail freight transport systems considering the concept of transport accessibility.

2.3. Transport accessibility

Among the wide range of studies on transport issues, the transport accessibility concept is among the frequently investigated notions. One of the 1st and most widely used definitions of accessibility is provided by Hansen (1959) as the "potential of opportunities for interaction". Dalvi & Martin (1976) approached this concept from a more applied standpoint, defining accessibility as "the ease with which any land-use activity can be reached from a location using a particular transport system". On the other hand, Ben-Akiva & Lerman (1979) emphasised the output, stating that accessibility may be understood through the benefits provided by a land-use system. According to Komornicki *et al.* (2010), there are 2 important components of accessibility: transport, focusing on the structure of the

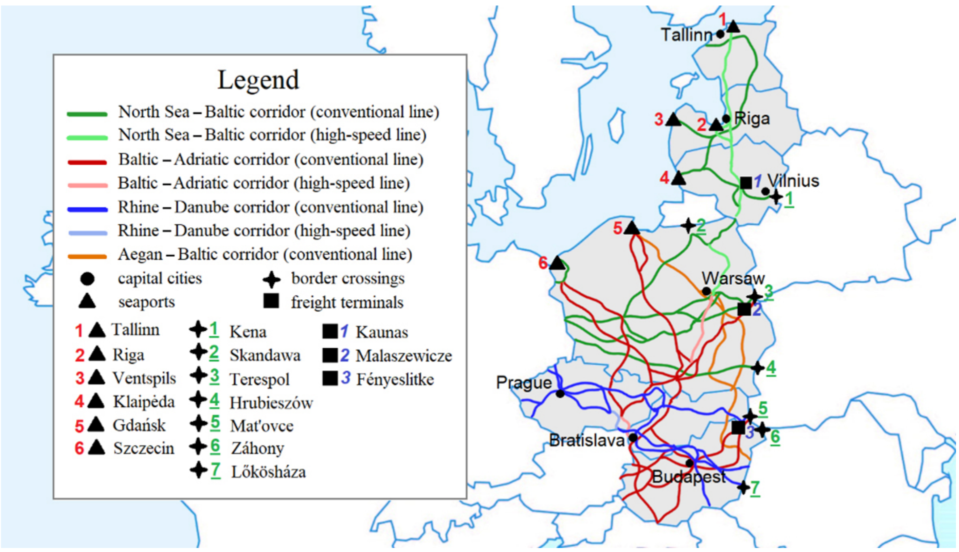

Figure 1. Important rail freight transport infrastructure in the Visegrád Group countries and the Baltic States (source: elaborated by the author using the GIMP software (*https://www.gimp.org*) based on the EC (2024), Wiśniewska & Jakóbowski (2021), Van Leijen (2022))

transport system, and land-use, focusing on the spatial distribution of demand and supply for transport services. Some authors also add temporal and individual components (Geurs, Van Wee 2004) that can be considered separately or as a facet of the 2 main components mentioned above.

The variety of approaches to understanding accessibility also enables scholars to analyse it in multiple ways. The review of available literature allowed concluding that different authors distinguish between 3 (Spiekermann, Neubauer 2002) and as many as 11 (Bruinsma, Rietveld 1998) separate perspectives (or types) of accessibility. An example of the classification of accessibility types by Geurs & Ritsema Van Eck (2001) distinguishes between 3 perspectives:

- infrastructure-based, focused on the transport system (its quality, capacity, etc.);
- activity-based (further split into 2 sub-types: geographical and temporal), focused on assessing the range of opportunities within specific restraints;
- utility-based, focused on analysing the benefits of the transport system users.

Table 1 presents the 3 perspectives with the example measures that can be included in the analysis covering the specific accessibility perspective.

Types of accessibility mentioned in Table 1 are valid for measuring both passenger and freight accessibility (Geurs, Ritsema Van Eck 2001), although in a vast array of accessibility studies, it is the passenger component that leads in the number of publications. It seems to be confirmed by a review of related literature and the analyses of applicable freight accessibility models on a European (Spiekermann, Neubauer 2002) or corridor-wide (Africani *et al.* 2016) scale.

The choice of the accessibility type to lead the study depends on the aim, the context and the scope of the study and determines the selection of numerical data (accessibility indicators) and the data processing method. Table 2 presents a non-exhaustive list of example limits of the freight accessibility studies.

This study analysed the aspect of rail freight transport accessibility in a group of European countries: Estonia, Latvia, Lithuania, Poland, Czechia, Slovakia and Hungary, in the context of their presence in the Eurasian rail freight transport system. Among the accessibility types in Table 1, the study covered the infrastructure-based perspective with an additional utility measure (i.e., the cost factor). The study was descriptive in nature and investigated the relationship between rail freight accessibility and the rail freight performance of a country using the TOPSIS method.

3. Research methodology

To achieve the study's aim and enable the verification of the research hypothesis, a multi-stage research methodology was designed, as depicted in Figure 2.

Table 1. Types and measures of transport accessibility (source: elaborated by the author based on Geurs & Ritsema Van Eck (2001), Rosik (2012) and Górniak (2014))

Accessibility type		Example measures of accessibility
Infrastructure-based		length and density of road/rail network; quantity and quality of nodal infrastructure points; average speed on the road/rail network
Activity-based	geographical	number of perceived opportunities within a certain distance; distribution of perceived opportunities within a distance
	temporal	average travel time to reach several specific destinations; number of transport opportunities in a specific period
Utility-based		average cost of transport; attractiveness of available connections

Table 2. Examples of different approaches to accessibility

Coverage of the study	Example studies
Aim	descriptive (Jarocka, Glińska 2017)
	prescriptive (Wenner, Thierstein 2020)
Context	labour market analysis (Van den Heuvel *et al.* 2014)
	regional productivity (Jubiz-Diaz *et al.* 2021)
	emergency management (Borghetti, Malavasi 2016)
Scope	national (Freiria *et al.* 2022; Górniak 2014)
	regional (Jarocka, Glińska 2017; Jubiz-Diaz *et al.* 2021)
	corridor-wide (Chu *et al.* 2019, 2022)
Method	classical formulas (Páez *et al.* 2012; Cartenì 2014)
	universal techniques: data envelopment analysis (Freiria *et al.* 2022), principal component analysis (Martín, Reggiani 2007), TOPSIS (Khalili *et al.* 2020; Hawas *et al.* 2016)

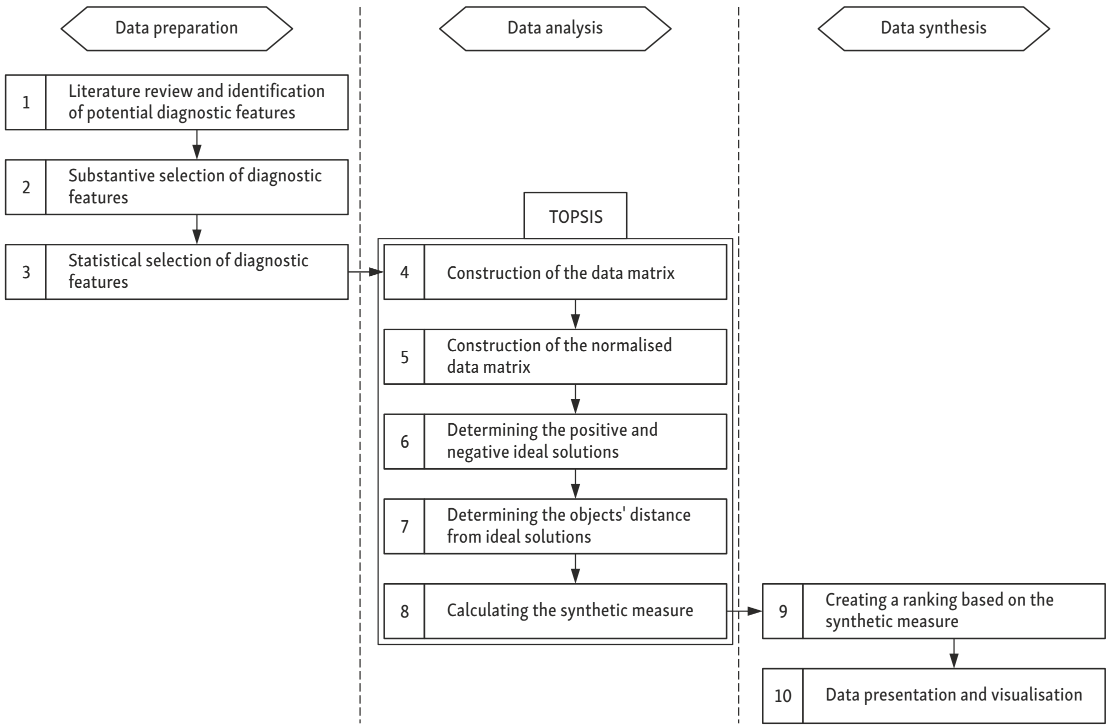

Figure 2. Schematic representation of the proposed research workflow (source: elaborated by the author using *draw.io* (*https://app.diagrams.net*) software)

The proposed methodology consists of 3 consecutive stages: (1) data preparation, (2) data analysis and (3) data synthesis. The 1st stage (steps 1–3) included the data collection and initial processing based on literature resources and statistical analysis methods. The end result of this stage was a selected list of diagnostic features eligible for further analysis during the 2nd stage of the study. The 2nd stage (steps 4–8) was based on the TOPSIS method and allowed for calculating final results presenting the levels of rail freight accessibility and rail freight performance of particular countries. The last stage (steps 9 and 10) included the arrangement of the obtained results in the form of 2 rankings, as well as the presentation of the results in visual form. It is important to emphasise that the same procedure had to be repeated twice to develop 2 separate rankings, including both infrastructure-based rail freight accessibility (Ranking #1) and rail freight performance (Ranking #2), and to analyse and compare the results.

The step 1 included conceptualising and writing the list of possible diagnostic features to be included in the study based on the literature review results. The initial list of 15 potential diagnostic features was created to examine the rail freight accessibility and performance of analysed countries. Since it had been decided that the study would include infrastructure-based accessibility (Ranking #1), a list of 4 infrastructural accessibility measures was created and then supplemented with one utility-based measure to expand the scope of the analysis. A list of ten performance measures was created to analyse the country's rail freight performance (Ranking #2).

Then, the substantive selection of diagnostic features was performed (step 2) since the quality of the set of characteristics describing the analysed objects determines the reliability of the results (Jarocka 2013). Indicators were selected according to specific formal criteria, such as measurability and comparability (the indicator can be expressed numerically), accuracy (the indicator is within the scope of the study) and relevance (the indicator's information value is valid to the study).

Another aspect of data selection was its statistical screening (step 3), which allowed for the selection of variables characterised by a high level of diagnostic potential, i.e., a relatively high COV level (10% and above) and a low level of correlation (between –0.7 and 0.7). When analysing correlation, an important factor is the information load provided by the variables since, in the case of 2 variables reflecting different information, the high level of correlation between them does not automatically call for one's exclusion (Kukuła 2000).

The data analysis stage was conceptualised using the TOPSIS method (Hwang, Yoon 1981). This method belongs to the linear ordering methods, which are included within the taxonomic methods and (in a narrower sense) within multi-criteria decision-making methods (Keshavarz-Ghorabaee *et al.* 2022). It can be applied to problems involving a wide range of alternatives and criteria, and it allows for assessing and ranking the alternatives according to their proximity to positive and negative ideal solutions (Çelikbilek, Tüysüz 2020). The TOPSIS method enables the description of a complex phenomenon that cannot be directly measured, as the level of the studied phenomenon is expressed using the aggregated indicator called a synthetic measure. This method has been utilised in a variety of scientific areas, including socioeconomics (Rollnik-Sadowska, Jarocka 2021), urban development (Hajduk 2021) or technology assessment (Halicka 2020). It has also been used to assess accessibility (Khalili *et al.* 2020; Hawas *et al.* 2016) and transport performance (Zhang *et al.* 2018); however, during the literature review, no such study emerged, including both of these 2 aspects.

Figure 3 presents the visualisation of consecutive steps realised within the data analysis stage based on the TOPSIS method. The initial part of the TOPSIS analysis was the construction of the data matrix (step 4). Due to the different ranges of data, the next step was data normalisation (step 5), using the vector normalisation formula (Jarocka 2015). Based on the normalised data matrix, the positive and negative ideal solutions had to be determined (step 6). Then, the separate measures of distance from the positive and negative ideal solutions (step 7) were to be calculated. The last step of the data analysis phase involved calculating the value of the synthetic measure (step 8).

The data analysis performed in this way allowed to rank the analysed countries by the value of the synthetic indicator R_i (step 9) and categorise them into 4 groups:

- group I, when $R_i \geq \bar{R} + s$;
- group II, when $\bar{R} \leq R_i < \bar{R} + s$;
- group III, when $\bar{R} - s \leq R_i < \bar{R}$;
- group IV, when $R_i < \bar{R} - s$,

where $\bar{R}$ is the arithmetic mean of the synthetic indicator and s is the standard deviation.

Based on the developed rankings and categories, it was possible to present and visualise the final results (step 10).

4. Data

To assess the rail freight accessibility and the rail freight performance of the analysed group of countries, the initial list of 15 diagnostic features was created. Table 3 presents the list of indicators.

The list was conceptualised and drawn based on the literature review (Table 1) and a thorough search query through available databases, such as *Eurostat* or yearly *EU*

Step 4. Construction of the data matrix:

$$X = [x_{ij}], \tag{1}$$

where: x_{ij} is the value of the j-th indicator for the i-th object.

Step 5. Construction of the normalised data matrix (vector normalization):

$$v_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \tag{2}$$

where: v_{ij} is the normalized value of the j-th indicator for the i-th object; $i = 1, ..., m$; $j = 1, ..., n$.

Step 6. Determining the positive ideal solution:

$$A^+ = \left\{v_1^+, v_2^+, ..., v_n^+\right\} = \left(\left(\max v_{ij} | j \in S\right), \left(\min v_{ij} | j \in D\right)\right) \tag{3}$$

and negative ideal solution:

$$A^- = \left\{v_1^-, v_2^-, ..., v_n^-\right\} = \left(\left(\min v_{ij} | j \in S\right), \left(\max v_{ij} | j \in D\right)\right), \tag{4}$$

where: $i = 1, ..., m$; $j = 1, ..., n$; S is associated with benefit criteria (more is better); D is associated with the cost criteria (less is better).

Step 7. Determining the objects' distance from the positive ideal solution:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_i^+)^2} \tag{5}$$

and negative ideal solution:

$$d_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_i^-)^2}, \tag{6}$$

where: $i = 1, ..., m$.

Step 8. Calculating the value of the synthetic measure:

$$R_i = \frac{d_i^-}{d_i^- + d_i^+}, \tag{7}$$

where: $0 \leq R_i \leq 1$; $i = 1, ..., m$.

Figure 3. Visual representation of the data analysis stage steps (source: elaborated by the author based on Hwang & Yoon (1981), Roszkowska (2009))

Transport in Figures: *Statistical Pocketbooks* published by the EC (2009–2023), and other reports and datasets, such as the annual reports of IRG Rail or *RailFreight.com* datasets. The measurement units were expressed in relation to the country's area or population to ensure comparability despite countries' varying sizes. All data is from 2020, except the value of the X5 indicator for Estonia, for which data is from 2019. Table 4 presents the numerical data matrix.

In the case of X1 to X5 indicators, which allowed for determining countries' rail freight accessibility, an example of indicators included information about the country's linear infrastructure, or the number of transport means. The variety of 4 infrastructural indicators was additionally supplemented by one utility indicator depicting the transport cost since it was decided that it would enhance and improve the analysis scope. Y1 to Y10 indicators were selected as measures of the countries' rail freight per-

Table 3. Indicators of rail freight accessibility and rail freight performance

Indicator	Unit	Type
Ranking #1 – infrastructure-based rail freight accessibility		
X1. Total route length	km/10000 km^2	(s)
X2. Electrified route length	km/10000 km^2	(s)
X3. Number of intermodal terminals	number/10000 km^2	(s)
X4. Number of goods transport wagons	number/10000 km^2	(s)
X5. Level of track access charges for freight services	euro/train-km/100000 population	(d)
Ranking #2 – rail freight performance		
Y1. Rail transport share of freight modal split	%	(s)
Y2. Rail freight traffic	bln net tonne-km/100000 population	(s)
Y3. Freight traffic load	tonne-km/freight train-km/100000 population	(s)
Y4. Network usage intensity for freight services	trains/day/route-km/100000 population	(s)
Y5. Volume of containers transported	number/100000 population	(s)
Y6. Goods transported in intermodal transport units (containers + swap bodies)	thousand tonnes/100000 population	(s)
Y7. Number of rail freight undertakings	number/100000 population	(s)
Y8. Degree of freight market opening	%	(s)
Y9. Extra-EU trade volume transported by rail*	thousand tonnes/100000 population	(s)
Y10. Share of freight services in rail traffic	%	(s)

Notes: (s) – stimulant (i.e., more is better); (d) – destimulant (i.e., less is better); * – including trade (import and export) with Europe's 5 most important Eurasian partners: China, Russia, Japan, South Korea and India (Eurostat 2024b).

Table 4. Numerical data for indicators of rail freight accessibility and rail freight performance

Indicator	Source	EST	LVA	LTU	POL	CZE	SVK	HUN
Ranking #1 – infrastructure-based rail freight accessibility								
X1	(a)	331.49	356.90	305.13	629.75	1236.80	754.37	842.32
X2	(a)	51.79	41.39	24.27	390.18	419.95	329.66	340.89
X3	(b)	0.00	0.16	0.80	1.18	1.94	1.87	0.77
X4	(c)	5257	983.60	1199.80	2711.30	3914.40	2697.00	946.80
X5	(a)	1.10*	0.69	0.72	0.01	0.01	0.03	0.02
Ranking #2 – rail freight performance								
Y1	(d)	0.39	0.55	0.64	0.21	0.22	0.24	0.22
Y2	(a)	0.11	0.42	0.58	0.14	0.14	0.15	0.12
Y3	(a)	101.43	90.67	60.03	1.78	4.01	10.70	6.53
Y4	(a)	0.15	0.32	0.51	0.03	0.09	0.20	0.07
Y5	(c)	3387.90	3464.70	5502.50	6207.00	15680.50	10610.00	3033.70
Y6	(c)	26.75	44.70	47.28	56.46	110.08	94.08	44.53
Y7	(a)	0.15	0.21	0.07	0.23	0.90	0.86	0.30
Y8	(d)	0.00	0.24	0.00	0.55	0.41	0.25	0.46
Y9	(c)	84.62	75.62	66.16	29.88	19.85	69.36	9.94
Y10	(a)	0.18	0.44	0.61	0.33	0.21	0.29	0.18

Notes: Source: (a) – IRG Rail, (b) – *RailFreight.com*, (c) – *Eurostat*, (d) – *EU Transport in Figures*: *Statistical Pocketbook*; * – 2019.

formance, including information about the country's rail freight capacity or the structure of the rail freight market. Ten indicators were intended to consider domestic, international and intercontinental transport of goods.

5. Research results

Once the list of possible indicators is complete, their individual analysis commences ensuring their measurability and comparability, accuracy and relevance (step 2). This process allowed the exclusion of several indicators. 1st, X2 was excluded based on the relevance criterion due to its significant similarity to indicator X1 in information value. It was observed that both of these indicators reflected nearly the same information (i.e., data about the linear rail infrastructure), but the scope of the information provided by X2 was narrower and entirely within the scope of indicator X1. Then, indicators Y8 and Y10 were excluded based on the accuracy criterion due to their low information value in the studied context. It was decided that although these data generally fell within the study range, they did not enhance the analysis or allow for positive or negative differentiation of the analysed countries. Finally, the relevance of indicators Y2, Y5 and Y6 was examined since a moderate similarity in information value had been noted (i.e., all 3 indicators related to the freight transport capacity). It was decided that all of them would be further analysed with the exclusion possibility during the statistical analysis.

Table 5 presents the statistical analysis of the indicators selected for Ranking #1 (step 3). The analysis results suggest that all indicators differentiate the countries under analysis since the COV have relatively high values (10% or above). The correlation analysis showed a relatively high correlation (more than 0.70 or less than –0.70) between the 3 pairs of indicators: X1 and X3, X1 and X5, and X3 and X5 (highlighted background in Table 5). However, as all of them reflect different and important information (thus, are valid to the study), it was deemed reasonable to retain them all.

Table 6 presents the statistical analysis of the indicators selected for Ranking #2. The analysis results suggest that all indicators differentiate the analysed countries since the COV have relatively high values (10% or above). The correlation analysis showed that a relatively high level of correlation occurred between 8 pairs of indicators: Y1 and Y2, Y1 and Y3, Y1 and Y4, Y2 and Y4, Y3 and Y9, Y5 and Y6, Y5 and Y7, and Y6 and Y7 (highlighted background in Table 6). Careful consideration led to the decision to keep Y1, Y3, Y4, Y7 and Y9 in the analysis despite considerably high levels of correlation with few other indicators due to their unique information value (i.e., unexpressed directly by any other variable). Among these indicators, Y1 and Y7 accurately depict the countries' rail freight markets, whereas Y3, Y4 and Y9 provide useful insights into the utilisation degree of their transport networks. In the case of Y2, Y5 and Y6, high levels of correlation with some of the other indicators were noted on top of the already questioned relevance during the previous step. It was decided that Y5 would be excluded due to its most limited extent of provided information, whereas Y2 and Y6 would be retained in the analysis as they convey similar but unidentical information.

Table 5. Statistical analysis of the indicators for Ranking #1

Variable	X1	X3	X4	X5
COV	54%	79%	65%	124%
Correlation matrix				
	X1	X3	X4	X5
X1	1.00	0.79	0.17	–0.80
X3	0.79	1.00	0.09	–0.81
X4	0.17	0.09	1.00	0.21
X5	–0.80	–0.81	0.21	1.00

Table 6. Statistical analysis of the indicators for Ranking #2

Variable	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y9
COV	51%	78%	111%	86%	69%	50%	88%	59%
Correlation matrix								
	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y9
Y1	1.00	0.92	0.77	0.92	–0.43	–0.49	–0.60	0.65
Y2	0.92	1.00	0.46	0.94	–0.25	–0.26	–0.46	0.41
Y3	0.77	0.46	1.00	0.54	–0.56	–0.66	–0.59	0.81
Y4	0.92	0.94	0.54	1.00	–0.21	–0.22	–0.36	0.60
Y5	–0.43	–0.25	–0.56	–0.21	1.00	0.96	0.89	–0.30
Y6	–0.49	–0.26	–0.66	–0.22	0.96	1.00	0.94	–0.35
Y7	–0.60	–0.46	–0.59	–0.36	0.89	0.94	1.00	–0.28
Y9	0.65	0.41	0.81	0.60	–0.30	–0.35	–0.28	1.00

Table 7. Accessibility and performance rankings of analysed countries

Position	Ranking #1 – infrastructure-based rail freight accessibility			Ranking #2 – rail freight performance		
	Country	R_i	Group	Country	R_i	Group
1	Czechia	0.86902	I	Lithuania	0.60106	I
2	Slovakia	0.70372	II	Latvia	0.57641	II
3	Poland	0.62663	II	Slovakia	0.45126	II
4	Hungary	0.53852	II	Estonia	0.43573	II
5	Estonia	0.33977	III	Czechia	0.39295	II
6	Lithuania	0.27757	III	Poland	0.15012	III
7	Latvia	0.21582	IV	Hungary	0.13214	III

Based on the results of substantive and statistical analyses of the initial 15 indicators, it was decided that 4 indicators would be excluded from further analysis. The decision to exclude them, although made subjectively, was based on the determined inclusion criteria and careful consideration of each indicator. 4 indicators were selected for the assessment of the countries' rail freight accessibility, and 7 were selected for the assessment of the countries' rail freight performance.

Considering the adopted indicator sets, the countries' rail freight accessibility and rail freight performance were calculated using the TOPSIS method, which involved performing steps 4–8 (Figures 2 and 3) twice, using the *Microsoft Excel* software. The results of the TOPSIS analysis allowed the ranking of the countries in the order of their final results and their categorisation into 4 groups (step 9). Table 7 presents the final results of the data analysis.

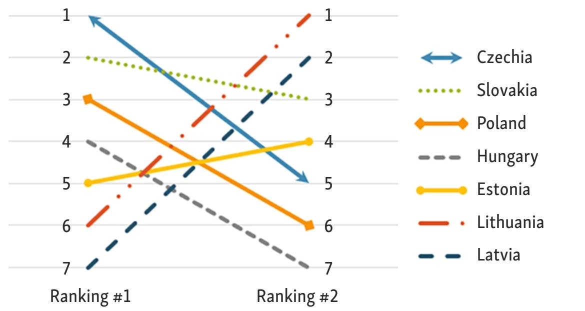

Figure 4. Graphic representation of the final results (source: elaborated by the author using the *Microsoft Excel* and *Gimp* software)

6. Discussion

Based on the indicators included in the analysis and corresponding data, Czechia is the leader in infrastructure-based accessibility, while Latvia closes the ranking with the lowest score. The leader in rail freight performance is Lithuania, while Hungary closes the ranking with the lowest score. Figure 4 presents the results in both rankings.

Further examination of the results revealed that the rail freight accessibility of Estonia, Lithuania and Latvia is of a relatively lower level than their rail freight performance. On the other hand, the results for Czechia, Slovakia, Poland and Hungary indicate the exact opposite situation. Interestingly enough, this interpretation allows for drawing the dividing line almost precisely between the 2 groups of countries: the Visegrád Group countries lead in rail freight accessibility, whereas the Baltic States (and Slovakia) lead in rail freight performance. The most prominent positive disparity between the ranks of the particular country can be observed in the example of Lithuania and Latvia, since these countries ranked, respectively, 2nd to last and the last in rail freight accessibility but were 1st and 2nd in the rail freight performance ranking, and advanced from groups III and IV to I. The most prominent negative disparity can be observed in the example of Czechia since the country ranked 1st in rail freight accessibility but took fifth place in the rail freight performance ranking and fell from group I to II.

The high disparity in the results achieved by particular countries in the 2 rankings prompted the author to conduct a statistical analysis of the results to determine the level of dependence between the results achieved by a country in the 2 rankings. The value of Pearson's correlation coefficient r_P was calculated using the synthetic measures R_i from both rankings for every country (Table 7) and amounted to –0.495, indicating a medium negative correlation, i.e., the higher the country's accessibility level, the lower its performance level. The value of Spearman's rank correlation coefficient r_S was calculated using the countries' positions in rankings and amounted to –0.536, indicating a strong negative correlation. However, for both the r_P and r_S coefficients, the probability values (respectively, p_P and p_S) indicated that the results of the correlation analysis were not statistically significant (since p_P = 0.26 and p_S = 0.22, and the threshold for statistical significance was set at $p < 0.05$). The obtained results of the correlation analysis did not allow to confirm that the country's level of rail freight accessibility affects its level of rail freight performance and vice versa. The final results for both rankings were nevertheless deemed eligible for further analysis, albeit separately.

Figure 5 presents the components of the overall score for every country in the form of normalised values of the indicators. In the case of the 1st ranking, it is important to note that while 3 of the indicators were stimulants, one of them (X5) was destimulant. To accurately present the values of that indicator on the chart and ensure its visual comparability with other indicators, the values of X5 were converted accordingly.

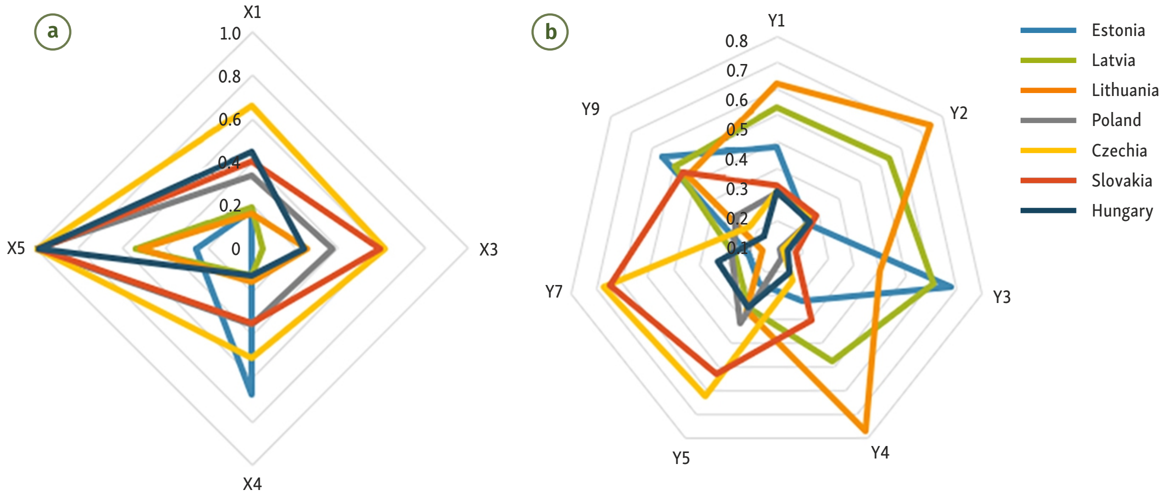

Figure 5. Components of the overall score for analysed countries (source: elaborated by the author using the *Microsoft Excel* software): (a) – Ranking #1; (b) – Ranking #2

Within the results of the infrastructure-based accessibility ranking, the domination of Czechia in the case of all but one indicator is somewhat visible. However, the results of other countries are close, especially for Slovakia, Poland and Hungary. The graphical representation of the results of all countries is similar, and consequently, the components of countries' overall scores are rather balanced. The only exception appeared to be Estonia, leading for indicator X4 – "Number of goods transport wagons". While further investigating this departure in results, it turned out that Estonia's stock of goods transport wagons increased rapidly between 2002 and 2003 (from 7000 to 17000 units) and continued to grow over the following years. One possible explanation for that result might be Estonia's important role in the EU's growing trade with Russia (Eurostat 2009). In the case of rail freight performance ranking, the results are much more irregular, with particular countries often being the sole leaders in terms of different indicators. The lead of Lithuania is rather visible, e.g., for indicators Y1, Y2 or Y4. However, other countries, such as Slovakia, are close runners-up. Despite ranking 4th out of 7, Estonia was the leader in 2 indicators: Y3 and Y9. In the case of indicators Y6 and Y7, and Slovakia achieved the highest results. Interestingly, Poland and Hungary achieved relatively low overall results.

When taking an overall look at the accessibility ranking results, the domination of the Visegrád Group countries is evident. This may be in part due to their geographical location in the centre of Europe. This factor, along with their relatively large logistics markets, may enable their role as transit countries for different freight flows. This includes both the North–South connections between European seas (i.e., Baltic, Adriatic and Black) and the East–West connections that can reach the Asian part of the Eurasian transport system and EU's main trade partners: China, Russia, Japan, South Korea or India (Eurostat 2024b). This arrangement speaks for the fact that 4 of the TEN-T corridors run through the territory of Visegrád Group countries compared to one corridor in the Baltic States. However, although the relatively more peripheral location of the Baltic States does not entitle them to be the focal point of the Eurasian transport network, it still allows them to achieve high results in the performance ranking. This may be in part due to these countries' location enabling them to be a part of the intermodal transport network through access to the Baltic Sea.

According to OECD (2024), EUR 900 bln was invested in railways in the EU countries and the UK, Norway and Switzerland in 2000–2020. Among the countries analysed in this study, the largest sum was invested in Czechia, both in absolute terms (EUR 12 bln) and as a percent of GDP (average 0.4% of GDP in 2000–2020) (OECD 2023), which is in a way reflected by the 1st place taken by Czechia in the study's ranking of infrastructure-based accessibility. However, when analysing the value of investments, it is critical to note the upcoming gradual increase in the importance of railroads for freight transport, both in the European context – as indicated by the plans to increase the rail transport's share of freight modal split to 30% in 2030 (CoEU 2024a), and in the wider Eurasian setting – as indicated by the year-on-year growth of the volume of goods transported by rail via the BRI corridors (Wiśniewska, Jakóbowski 2021). The provision of rail transport infrastructure in sufficient quantity and quality is among the conditions for the success of both these endeavours. However, the plans for a shift to rail are a rather recent development, preceded by years of prioritisation of road transport in Europe (as evidenced, inter alia, by the fact that road investments have received nearly EUR 500 bln more than rail projects in Europe in 2000–2020) and maritime transport in the Eurasian freight. As rail transport has remained only the 2nd option after road or sea for years, as a result, the development of Europe's rail infrastructure has stagnated. This means that for Europe to proceed successfully with the modal shift, the rail network's accessibility must be upgraded accordingly. In this context, the scope of this study allows concluding that Czechia's results in accessibility ranking can act as a benchmark for the Baltic and the Visegrád Group countries.

The rail freight performance ranking considered a variety of factors describing the functioning and performance of the country's rail freight market, including both internal factors (such as indicators Y7, "Number of rail freight undertakings", or Y1, "Rail transport share of freight modal split", describing the countries' rail freight markets), and external outcomes of country's presence in the Eurasian rail freight system (such as indicator Y3, "Freight traffic load", or Y9, "Extra-EU trade volume transported by rail"). Lithuania's performance results proved to be relatively best among the analysed countries. The country's highest results for indicators Y1, "Rail transport share of freight modal split", Y2, "Rail freight traffic", or Y4, "Network usage intensity for freight services", seem to prove the actual prioritisation of rail freight transport in Lithuania. Other Baltic countries' performance has also been assessed positively, with Estonia leading in 2 indicators and Latvia being a close runner-up in the case of 4 others. One possible methodological explanation behind the high results of the Baltic States and relatively poor performance of the Visegrád Group countries might be that the unit of measure related to countries' population favouring the smaller Baltic States over the more densely populated Visegrád Group countries.

Even though the study did not allow to confirm that the countries' results in both rankings can be linked (i.e., a country's rail freight accessibility affects its rail freight performance and vice versa), it seems safe to assume that both of these parameters will be crucial in the context of the incoming modal shift to rail freight in Europe and whole Eurasia. In this context, to improve the rail freight performance of the analysed countries and streamline the freight transport process, some corrective measures can be taken, e.g., improving the information flow between the members of the supply chain, refining the coordination of consecutive stages of transport process or clarifying the regulations of the transport process.

7. Conclusions

The research allowed examining the freight rail transport systems of selected European countries in the context of their presence in the Eurasian rail freight transport system, albeit in a fragmentary way. By considering 2 separate aspects of a country's rail freight system, i.e., rail freight accessibility and rail freight performance, a fairly broad perspective was considered. The link between these 2 aspects could not have been confirmed based on the obtained results, which means that the research hypothesis could not have been proven. However, the study's main aim (i.e., determining the levels of countries' rail freight accessibility and rail freight performance and examining the relationship between these 2 levels) has been successfully achieved. The use of the TOPSIS method provided the results in a clear and comparable ranking form within the expected constraints. In the author's opinion, the TOPSIS method can be a helpful tool for diagnosing the strengths and weaknesses of transport systems, including exploring the different aspects of transport accessibility.

Despite successfully fulfilling the research objective, the study is certainly not free of limitations. 1st, the general scope of the study (including, for example, its geographical scope or selected mode of transport), although logically related to the aim of the study, may be treated as a limitation. 2nd, there are some limitations related to the chosen perspective of accessibility. While the study included the transport component of accessibility, it did not address the land-use component, which allows only for a partially comprehensive analysis of the network. 3rd, the way of application of the research method can be subject to certain limitations. One of the drawbacks of the linear ordering methods is that the rankings are based on an ideal solution determined by data for a certain group of objects. It means that the results allow only for the assessment and cross-comparison within this selected part of the transport network, i.e., Czechia's or Lithuania's 1st place can only be interpreted relatively and within this particular study rather than universally. The decision on the optional prioritisation of indicators, i.e., whether to assign weights to the indicators or omit this step entirely, is also subject to limitations due to the researcher's subjective view. In this study, the decision was made for the indicators not to be weighted, which does not detract from the merits of the study, although it somewhat limits its rigour.

Considering the growing expectations towards the transport systems, such as increased resilience, agility or sustainability, it can be assumed that this development will further open up the field of research on the functioning of the whole Eurasian transport system. The development of common transport initiatives, such as BRI or TEN-T, was addressed in this research context in the form of an exploration of the countries' accessibility and performance, which seems to be a well-founded scientific endeavour. Both the designed research process and the obtained results offer some rationale for conducting further research. In the case of the former, the subsequent research could address the identified limitations, i.e., provide an investigation into the accessibility of the Eurasian transport system considering the wider coverage (e.g., geographical, temporal) and scope (e.g., mode of transport, perspective and components of accessibility) of the research. Whereas in the case of the latter, additional research could focus on further exploring the dependencies between accessibility and performance of the countries, for example, considering the extended range of the indicators.

Funding

This research has been developed within the framework of the Project No WI/WIZ-INZ/8/2022 of the Bialystok University of Technology and financed from the subsidy granted by the Minister of Education and Science of the Poland.

Disclosure statement

The author declares that there is no conflict of interest.

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