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The possibilities of using regional rail for intra-urban commuting in post-socialist cities in Central and Eastern Europe

Wojciech Jurkowski[1, CDFMR], Maciej Kruszyna[2, CDFMR]

[1]*University of Wroclaw,* Faculty of Earth Sciences and Environmental Management, Department of Spatial Management, Institute of Geography and Regional Development, Wrocław, Poland, e-mail: wojciech.jurkowski@uwr.edu.pl (*corresponding author*), https://orcid.org/0000-0002-8926-3004 ; [2]*Wroclaw University of Science and Technology*, Faculty of Civil Engineering, Wrocław, Poland, e-mail: maciej.kruszyna@pwr.edu.pl, https://orcid.org/0000-0001-8876-6307

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Abstract. The main objective of this study is to explore the potential of using regional rail for intra-urban commuting in post-socialist cities of Central and Eastern Europe. The purpose of this study can be approached from cognitive and methodological perspectives. The cognitive objective is focused on the role of geographical and political conditions, while the methodological objective aims to propose and test a research procedure to assess to what extent existing regional train services can support urban rail transit. The study was conducted using examples from four cities in Central and Eastern Europe: Lviv, Riga, Wrocław, and Zagreb, as well as one from Western Europe (Leipzig), serving as a reference point for the analysis of research results. The main empirical part was conducted using nine indicators categorized into three groups: infrastructural, organizational, and developmental.

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1. Introduction

A shift in modal share from private cars to public transport in daily commuting is a fundamental goal of sustainable urban mobility (Banister, 2008). Achieving this goal is particularly challenging in many cities across the post-socialist countries of Central and Eastern Europe (CEE). These regions have undergone significant changes in both the functioning of the transport sector and spatial development patterns following the socio-economic transformation of the 1990s, which has led to a growing dependence on private car dependence (Pucher & Buehler, 2005).

These changes primarily involve a rapid increase in private car ownership, a decline in public transport use, and the expansion of built-up areas in both suburban zones and peripheral parts of cities (Spórna & Krzysztofik, 2020; Jurkowski et al., 2024). These processes have been largely driven by socio-psychological factors, including the perception of the car as a symbol of independence, prestige, and comfort, while homeownership reflected the unfulfilled aspirations of the socialist era. (Pucher, 1999; Pojani et al., 2018; Jurkowski, 2025).

As a result, the dominance of the private car as the primary mode of transport has been further reinforced, which has directly translated into investment priorities. The majority of financial resources have been allocated to the development of road infrastructure, while urban public transport systems in many cities have often been neglected and are now inefficient, requiring substantial modernization. This has led to a range of negative consequences, including traffic congestion, air pollution, road accidents, and the inefficient use of urban space for parking.

While these problems are not unique to CEE, infrastructural shortcomings and a deeply rooted car dependency in the socio-psychological context can pose particularly strong barriers to the implementation of sustainable urban mobility in this region. Therefore, transport policy must be aimed not only at ensuring accessibility but also at making public transport a competitive alternative to private cars.

The most efficient and competitive component of a city's public transport system is urban rail transit (URT), which includes all forms of rail-based transport operating primarily within a city's administrative boundaries (Vogiatzis & Kouroussis, 2017; Guo et al., 2025). The advantage of URT stems primarily from its ability to operate fully or partially independently of road traffic and from its provision of high capacity and reliability, made possible by the use of dedicated infrastructure (Zhang et al., 2025).

URT in post-socialist countries in CEE is relatively well-developed only in the largest cities with populations exceeding one million, such as Warsaw, Prague, or Bucharest, where it relies on efficient metro systems. These systems are further complemented by suburban trains such as the WKD (*Warszawska Kolej Dojazdowa*) in Warsaw or the HEV (*Helyiérdekű Vasút*) in Budapest. In cities with fewer than one million residents, URT — where it exists — is typically limited to tram networks, sometimes supplemented by light rail systems such as the Krivyi Rih Metrotram or the rapid tram in Poznań (PST line). While such systems can serve as effective solutions for mid-sized cities (Kołoś & Taczanowski, 2016; Gadziński & Radzimski, 2021), they often prove insufficient in larger cities exceeding 500,000 residents. Trams are generally capable of providing efficient service within central urban areas, but they are less effective in connecting the city center with peripheral parts of these cities (Seidenglanz et al., 2016). This becomes a particular challenge in the context of population growth and the rapid spatial expansion occurring in the outskirts of some of these cities, which increases transport demand and the average distance traveled to the city center (Goetz, 2019).

At the same time, most cities in CEE already possess relatively well-developed heavy rail infrastructure, primarily used by traditional train services for intercity, regional, and freight operations. Among these, regional rail — which often serves multiple stops within city boundaries — offers considerable potential to enhance URT. This approach is widely implemented in Western European countries, where regional rail systems are strongly integrated into urban transit networks, as exemplified by the S-Bahn in Germany, the RER in Paris or Trenord in Milan.

It is worth noting that the existing spatial layout of traditional rail networks in cities has been shaped by historical factors. The majority of rail lines constructed in recent decades have not significantly altered the original layout inherited from the 19th and early 20th centuries. Difficulties in building new railway lines within urbanized areas mean that increasing the number of access points to the existing network is usually the only way to expand the system. Therefore, the integration of regional rail into URT can be understood as adapting train timetables or developing the areas surrounding existing stations to improve accessibility. This approach is attracting growing interest in many CEE cities, as evidenced by initiatives like the introduction of integrated ticketing systems and promotional campaigns encouraging intra-city train travel. However, the lack of theoretical frameworks and established analytical methodologies continues to limit more systematic investigation of the issue (Ďurček & Horňák, 2016).

2. Aims and scope

The main objective of this study is to explore the potential of using regional rail for intra-urban commuting in post-socialist cities of Central and Eastern Europe (CEE). Regional rail refers to conventional train services operating on heavy rail infrastructure, typically stopping at most stations along a given line and linking outlying towns and cities with the regional core (Blainey & Preston, 2021). The term 'post-socialist' describes countries that, between 1945 and 1989, were part of the Eastern Bloc and later transitioned from centrally planned to market-based economies. The geographic scope of CEE region in this study follows the delineations proposed by Hamilton et al. (2005), which can be further divided into four subregions: Central, Eastern, Baltic, and the Balkans (Cottey, 2000; Ostergren, 2011) (Fig. 1).

This study is guided by two key research questions:

- RQ1 – How do geographic and political conditions influence the level of development of rail systems within city administrative boundaries?
- RQ2 – How can the overall potential of using regional rail for intra-urban commuting be effectively evaluated?

These questions reflect the two core aspects of this study. The first focuses on investigating the extent to which the integration of regional rail into URT system, as widely observed in Western Europe, is emerging in different parts of the CEE region. Geographic and political conditions refer primarily to spatial location, proximity to Western Europe, and integration into its sphere of influence, particularly through EU membership. In response to the second research question, the authors aim to propose a simple research procedure that enables a preliminary assessment of the development level of regional rail systems in the studied context.

The study was conducted using four case studies of post-socialist cities in CEE: Lviv, Wrocław, Riga, and Zagreb (Fig. 1). These cities were selected from among urban areas with populations between 500,000 and 1 million, identified as particularly challenging for the development of URT systems. This is primarily

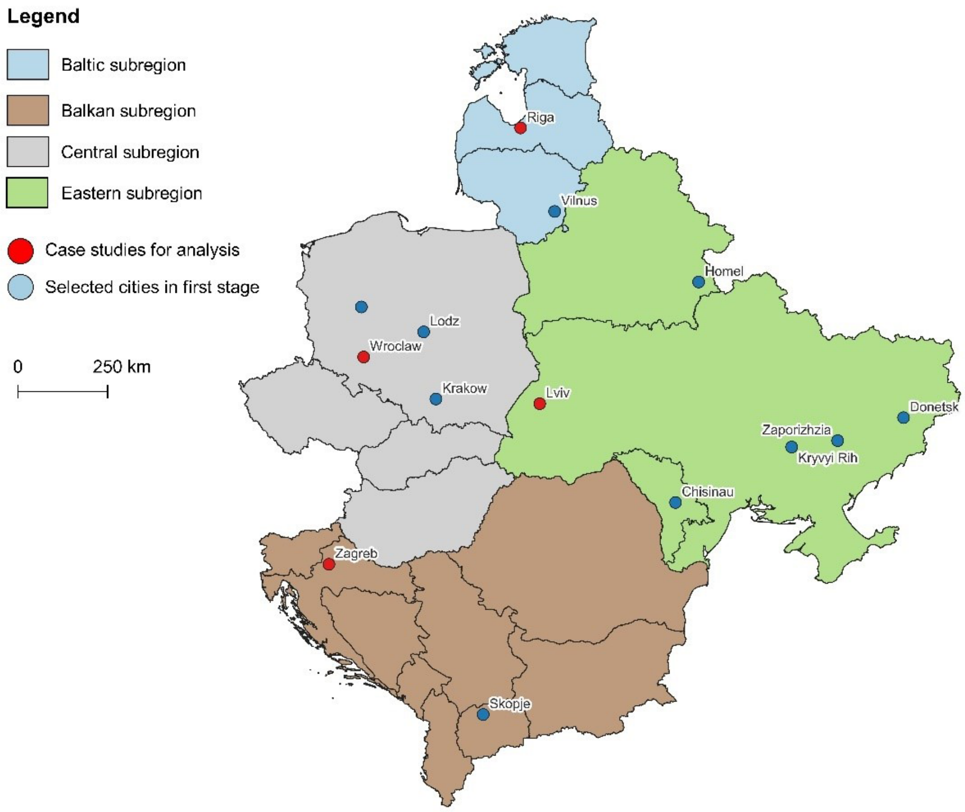

Fig 1. The spatial scope of analysis and selected case studies
Source: own elaboration based on Open Street Map

due to a combination of population growth, rapid spatial expansion in peripheral areas, and the absence of metro systems, which are often present in cities of comparable size in Western Europe. To ensure a representative selection, cities with the highest number of railway stations located within city administrative boundaries were chosen, representing each of the four major subregions of CEE.

A comparative approach to analysis should involve both internal comparisons among the selected cities and an external benchmark, the results of which can serve as a reference point. Ideally, this benchmark should be a Western European city with a well-developed regional rail system that also serves intra-urban areas. At the same time, it is important to select a city with contextual conditions similar to those in CEE, in order to ensure a meaningful and relevant comparison.

Leipzig was ultimately selected as the reference city, as it meets both criteria. It exemplifies the successful integration of regional rail into an URT system in line with Western European standards, while also sharing a socialist legacy with many post-socialist cities in CEE. Assuming that transport planning trends in Europe tend to spread from west to east, Leipzig offers a particularly valuable case for analysis. Once part of the Eastern Bloc, the city became integrated into Western Europe following German reunification in the 1990s. It therefore represents a transition from a centrally planned system to a more efficient and integrated model of urban transport.

Historically, Leipzig was the second city in Germany (after Nuremberg) to gain access to the railway system, with the Leipzig–Dresden line inaugurated between 1837 and 1839 (Schötz, 2018). However, following the destruction caused by World War II and decades of underinvestment during the German Democratic Republic era, Leipzig experienced significant infrastructural decline (Kirsche & Müller, 1988). Only after reunification — through substantial financial investment and modernization efforts — was a significant, though not complete, convergence in development levels between major cities in former East and West Germany achieved. In this context, Leipzig serves as a model case of how long-term infrastructural deficits can be overcome and how a public transport system can be successfully redeveloped.

3. Theoretical background

Rail transport plays a crucial role in urban public transport systems due to its fully or partially segregated infrastructure, independent from other traffic streams. This physical separation allows rail-based modes to achieve high competitiveness, reliability, and resistance to congestion. As a result, the development of rail transport in urban areas is essential not only for the implementation of sustainable urban mobility principles but also for improving the overall quality of life of city inhabitants.

There are many different forms of rail-based transport which, in the most general sense, can be divided into three main types: tram (streetcars), metro (subway), and train (conventional rail). However, various hybrid or intermediate forms exist between these categories, often grouped under the umbrella term light rail transit (LRT). This includes systems such as tram-train, metro-tram, or metro-train (Priemus & Konings, 2001; van der Bijl et al., 2018) The distinction between these forms remains ambiguous, as there is no universally accepted terminology in this regard (Vuchic, 2007). Therefore, in transport-related studies, a functional division is often applied, distinguishing between urban rail transit (URT) and long-distance rail, based primarily on the extent of their service area (Fig. 2).

The term URT refers to all rail-based transport modes that operate within the boundaries of a city or its immediate surroundings, typically using dedicated infrastructure (Pan et al., 2018; Wei et al., 2024). This category primarily includes tram and metro systems, often supplemented by various forms of light rail transit or suburban trains.

The term long-distance rail refers to various types of traditional train services operating at the regional, national, or sometimes international scale (Seidenglanz et al., 2021). In the literature, it is noted that this type of rail transport typically covers distances exceeding 100 km and involves trips that are not part of daily routines (Hall & Beissinger, 2017). Unlike the exclusive or semi-exclusive infrastructure typical of most URT systems, long-distance rail generally operates on shared mainline infrastructure, which is often also used by freight trains.

In the context of the proposed classification, the most debatable transport mode is regional rail, which—depending on the specific case—can be classified either as part of URT or as long-distance rail. On the one hand, its broader service area, often extending well beyond city boundaries, positions regional rail within the long-distance rail category. On the other hand, its dense stop spacing and frequent service in urban areas allow it to effectively support URT, particularly in cities lacking metro or suburban rail systems. Therefore, the main research task is to provide a theoretical foundation for the conditions under which regional rail can be effectively adapted into the URT system. This

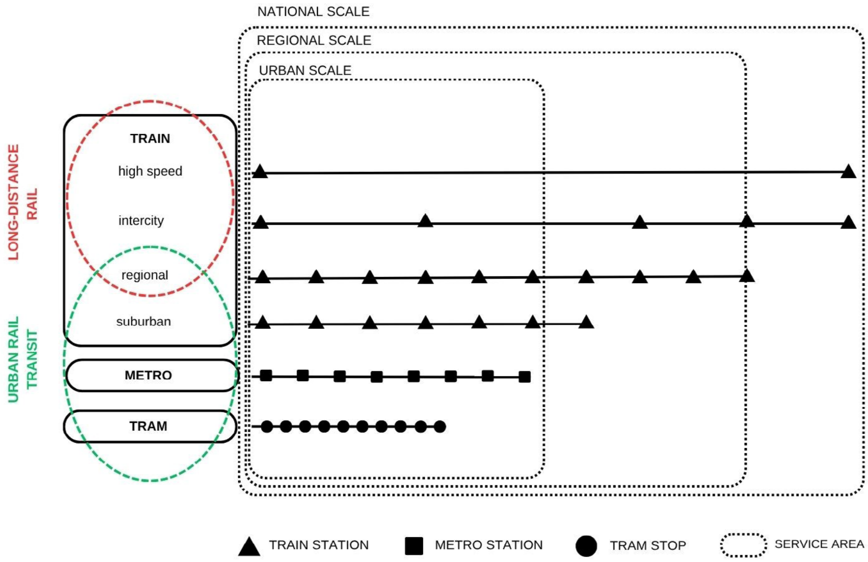

Fig 2. Schematic examples of different rail line types, illustrating characteristic stop distribution and the extent of their service areas
Source: own elaboration

includes not only transport-related characteristics, but also organizational and spatial dimensions.

The need for "convenient transport service" across different types of URT is frequently emphasized in the literature (e.g., Bell, 2019; Lin et al., 2022; Chang-Fu & Yuan, 2011). However, this concept is rarely clearly parameterized, and there is a lack of clearly defined, standardized indicators suitable for quantitative analysis. As a result, the evaluation of rail service quality remains underdeveloped and methodologically fragmented.

A review of existing studies shows that many analyses either focus on the entire urban public transport system or apply a limited and often inconsistent set of parameters. In the context of railway systems and station infrastructure, a subset of studies addresses evaluation methodologies more directly. For instance, Sperka et al. (2023) apply the Analytic Hierarchy Process (AHP) to assess the quality of transport hubs, while Liang et al. (2021) evaluate the spatial use of large railway hub station areas in Beijing in the context of integrated station-city development. Olaru et al. (2019) offer a classification of railway stops and stations based on surrounding land-use structures.

A particularly relevant stream of research deals with railway nodes and their broader functional role. From Bell (2019), who discussed intermodal mobility hubs and user expectations, to Olaru et al. (2019), who revisited the "place versus node" planning paradigm, to more recent work by Kruszyna and Makuch (2023), who propose mobility nodes as an evolution of traditional transfer nodes, there is growing interest in integrating railway infrastructure into wider urban systems. Other notable contributions include the greenway potential of Çankiri's railway corridor (Pekin et al., 2021), topological analysis of network complexity and node importance (Meng et al., 2022), and the role of railway nodes as potential sites for the integration of public transport services (Soczówka & Żochowska, 2020).

Despite the growing body of literature, comprehensive evaluation frameworks tailored to the specific types of rail transport within URT systems remain scarce. This gap is particularly significant given the emerging role of regional rail systems as substitutes or complements to metro or suburban rail services—especially in cities that lack dedicated rail infrastructure for intra-urban commuting.

4. Methods and sources

4.1. Procedure of assessment

In the main empirical part of this study, quantitative methods were applied, encompassing a broad range of statistical and spatial analysis methods using GIS software tools (QGIS). The assessment of a specific regional rail system was conducted using nine indicators, categorized into three groups: infrastructural (I1-I3), organizational (O1-O2), and developmental (D1-D4) (see Table 1). It is important to note, in the context of interpreting the results, that Indicator I3 and Indicator O2 are inversely related to performance — that is, higher values of these indicators reflect poorer system performance.

Infrastructural indicators (I) provide valuable insights into the overall accessibility and density of the regional rail network in specific urban areas. Indicator I1 focuses on the total length of the railway line, while Indicator I2 complements this by normalizing the values based on population size, enabling comparisons across different cities. Indicator I3 addresses the distribution of point elements of railway infrastructure (stations and stops). Ideally, these should be frequent and evenly distributed throughout the city to maximize accessibility for commuters.

Organizational indicators (O) assess two crucial aspects of intra-urban travel: the frequency of connections and the regularity of departures. These factors are key components of travel-time reliability (van Loon et al., 2011), which is typically considered the most important factor influencing transit ridership. Reliability forms the foundation of the customer requirements pyramid, where factors such as speed and comfort are considered only after it is ensured (van Hagen, 2011; van der Bijl et al., 2018). Travel time was omitted as an analyzed factor, as rail transport is generally assumed to be more competitive than other public transport modes in congested urban areas. From a methodological perspective, small differences in travel time could also result from varying network densities, making this indicator difficult to interpret reliably. The first organizational indicator (O1) evaluates the overall transport offer provided by the station, while the second (O2) assesses the regularity of regional rail departures, focusing on the intervals between consecutive trains in one direction (toward the city center).

Developmental indicators (D) provide insight into the broader built environment, land use, and walkability and cyclability around stations. The authors adopted the core principles of the widely recognized concept of Transit-Oriented Development (TOD), focusing on density, diversity, and design (the “3Ds”) (Cervero & Kockelman, 1997). Accordingly, the selected indicators reflect: built-up area (D1), related to density; the density of pedestrian and cycling infrastructure (D2, D3), related to design; and the number of services, indicating multifunctional development, related to diversity (D4). In line with the main objective of this study, the authors aimed to capture the general potential for interaction around railway stations, rather than to precisely measure the attractiveness of specific origins and destinations. Therefore, in the case of Indicator D4, no attempt was made to differentiate between more or less significant types of services, as such classification would exceed the scope of a straightforward spatial analysis. Instead, all categories of activity available in the OpenStreetMap (OSM) database were taken into account. The immediate surroundings were consistently defined as a buffer area of 500 meters (or 1000 meters in the case of Indicator D3) from the station. This corresponds to values commonly cited in the literature as the range of greatest transportation impact, typically between 400 and 800 meters.

4.2. Data source

This study required the collection of data on the distribution and characteristics of infrastructure, buildings, and services in order to calculate the selected indicators. The primary source of information was the OpenStreetMap (OSM) database, retrieved on February 20, 2024. While certain limitations of OSM are acknowledged in peripheral or rural areas, its accuracy and completeness in urban contexts—particularly with regard to infrastructural data—are considered high (Da Costa et al., 2016). Studies assessing the representativeness of OSM have shown that its quality is often comparable to that of official datasets (Haklay, 2010; Girres & Touya, 2010). The relevant data were downloaded in the form of a shapefile and subsequently processed using appropriate tools within a GIS environment (QGIS) to meet the requirements of the study (see Table 2).

The second data source used in this study consisted of rail timetables obtained from the official websites of railway operators active in the study area (see Table 3). These timetables were used to analyze transport services—such as frequency and intervals between departures—offered at the surveyed railway stations, which were necessary for calculating the organizational indicators. Since the timetables were available in various formats, different tools had to be employed to extract the relevant information, including journey planners and departure boards.

5. Case studies characteristics

Leipzig, located in eastern Germany on relatively flat terrain, has a population of 625,341 and covers an area of approximately 297.6 km². As a representative Western European city, it serves as a reference point in this study. The city features a well-developed regional rail network, consisting of 9 outgoing

Table 1. Proposed set of indicators used in the empirical part of this study

Symbol	Group of indicator	Characteristic	Unit
I1	infrastructural	$I1 = \frac{L_{tr}}{A_{urb}} \times 100$ L_{tr} - length of lines served by passenger trains (km) A_{urb} – urban surface area (km^2)	km/100km^2
I2	infrastructural	$I2 = \frac{St}{P} \times 10000$ St – total number of railway stations in the city, P – city population	-
I3	infrastructural	$I3 = \frac{\sum_{i=1}^{n} d_i}{n}$ d_i – distance between adjacent stations i and i+1 on a specific rail line n – the number of interstation sections, i.e., the number of distances measured between adjacent stations on a given line.	km
O1	organizational	$O1 = \frac{\sum_{j=1}^{St} Dj}{St}$ Dj – daily number of departures from station j, St – total number of railway stations in the city	
O2	organizational	$O2 = \frac{\sum_{d=1}^{I} T_d}{I}$ I_{dp} – interval between adjacent departures i and i+1 on a specific rail line (towards city centre) I – the total number of intervals between daily train departures on a given rail line.	min
D1	development	$D1 = \frac{A_{bui;t}}{A_{b500}} \times 100$ A_{built} – built-up area within a 500 m radius of all stations (km^2), A_{b500} – total buffer area of 500 m radius around all stations (km^2)	%
D2	development	$D2 = \frac{L_{pd}}{A_{b500}}$ L_{pd} – length of pedestrian infrastructure within a 500 m radius of stations (km) A_{b500} – total buffer area of 500 m radius around all stations (km^2)	km/km^2
D3	development	$D3 = \frac{L_c}{A_{b500}}$ L_c - length of the cycle infrastructure network within a 1000 m radius of stations (km), A_{b1000} – total buffer area of 1000 m radius around all stations (km^2)	km/km^2
D4	development	$D4 = \frac{S}{A_{b500}}$ S - the number of services within a A_{b500} – total buffer area of 500 m radius around all stations (km^2)	points/km^2

Source: own elaboration

Table 2. The category of shapefile from OSM database used in this study.

Objects	Attributes utilizing in this study
buidings	all categories
main roads	Categories: primary, primary link, secondary, secondary link
pedestrian infrastructure	footway, living street, path, pedestrian, service, steps
cycle infrastructure	cycleway
services	arts centre, artwork, atm, attraction, bakery, bank, bar, beauty shop, beverages, bicycle rental, bicycle shop, biergarten, bookshop, butcher, café, camera surveillance, camp site, car dealership, car rental, car sharing, car wash, caravan site, castle, chalet, chemist, cinema, clinic, clothes, college, comms tower, community centre, computer shop, convenience, courthous, dentist, department store, doctors, dog park, drinking water, embassy, fast food, fire station, florist, food court, fort, furniture shop, garden cente, golf course, graveyard, greengrocer, guesthouse, hairdresser, hospital, hotel, ice rink, jeweller, kindergarten, kiosk, laundry, library, lighthouse, mall, market place, mobile phone shop, motel, museum, newsagent, nightclub, observation tower, optician, outdoor shop, pharmacy, picnic site, pitch, playground, police, post office, pub, restaurant, school, shoe shop, sports centre, sports shop, stadium, stationery, supermarket, swimming pool, theatre, theme park, toilet, tourist info, tower, town hall, toy shop, travel agent, university, vending machine, vending parking, veterinary, viewpoint, zoo.

Source: own elaboration based on Open Street Map (data accessed: February 20, 2024)

Table 3. List of sources of timetable information. for the analyzed cities

Cities	Source of timetable
Leipzig	https://www.bahnhof.de/en/search
Lviv	https://uz.gov.ua/en/passengers/timetable/
Riga	https://www.pv.lv/en/train-schedule/
Wroclaw	https://rozklad-pkp.pl/
Zagreb	https://www.hzpp.hr/

Source: own elaboration

lines and 39 stops, with Leipzig Hauptbahnhof functioning as the main station (see Fig. 3). The spatial layout of the network is characterized by bypasses around the central areas, with lines radiating outward toward the city's peripheral districts. A major investment that significantly enhanced the capacity and connectivity of Leipzig's railway system was the City Tunnel, opened in 2013. This underground link connects Leipzig Nord and Leipzig Bayerischer Bahnhof stations, enabling through-running services across the city and improving the integration of regional rail into the urban transport system.

Intra-urban railway stations in Leipzig are primarily served by S-Bahn Mitteldeutschland, a company that is part of the national railway group Deutsche Bahn. Stations located on lines not covered by the S-Bahn network—such as the line from Werkstättenstraße to Liebertwolkwitz—are operated by RegionalBahn (RB), while services at more significant stations are also supplemented by Regional-Express (RE) connections. However, these services are less frequent than those provided by the S-Bahn and are primarily intended to connect Leipzig with major towns and cities in Saxony, Saxony-Anhalt, and Thuringia.

Lviv, located in the western part of Ukraine, lies in a relatively hilly area within the Roztocze Upland. It is the only city in this analysis situated outside

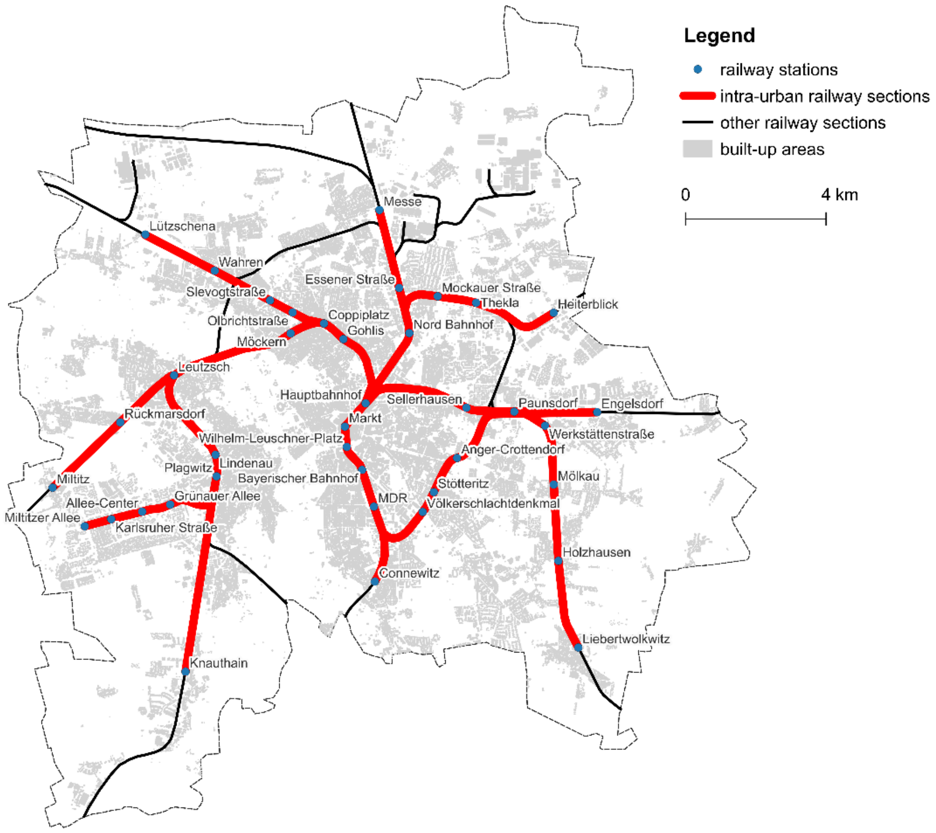

Fig 3. Regional rail network in urban areas in Leipzig
Source: own elaboration based on Open Street Map

the European Union, although Ukraine has held candidate status since 2022. Lviv covers an area of approximately 171.0 km² and has a population of around 717,803. Among the analyzed case studies, the regional rail network in Lviv is the least developed, consisting of 5 outgoing lines and 14 stops (see Fig. 4). The network is primarily oriented toward long-distance travel, with most rail lines bypassing the city center and exhibiting a peripheral layout. A notable feature is the sparse distribution of stations—particularly in the northeastern direction—where, despite the considerable distance from the city boundary, Pidzamche station is already the final stop within the city limits.

At Lviv's main railway station, two distinct operational sections can be identified. The first serves primarily long-distance traffic, while the second—established in 1997 and known as Lviv Suburban Rail—was intended for shorter-distance services. However, despite its name, this section predominantly supports regional routes rather than typical suburban connections. Intra-urban railway stations in Lviv are primarily operated by Lviv Railway, one of the six regional divisions of the national carrier Ukrainian Railways (*Ukrzaliznytsia*). The services provided are primarily regional in nature, connecting major towns within Lviv Oblast, such as Ternopil, Rava-Ruska, Khodoriv, and Mostyska. Notably, the railway system in Lviv is oriented more towards long-distance and regional transportation, rather than serving intra-urban mobility needs. Many of the intra-urban railway stations are in a state of neglect, with some facilities consisting of large, underutilized buildings dating back to the socialist era.

Riga, located in the central part of Latvia, lies on low-lying terrain near the Gulf of Riga, which acts as a natural barrier to spatial development in the northern direction. As the capital city, Riga plays a central role in the country's administrative and economic landscape. Although it was part of the Soviet Union until 1991, Latvia has been a member of the European Union since 2004. Riga is the smallest of the analyzed cities in terms of population, with 605,802 inhabitants, and covers an area of approximately 307.2 km². The regional rail network in Riga consists of 5 outgoing lines and 22 stops within the urban area (see Fig. 5).

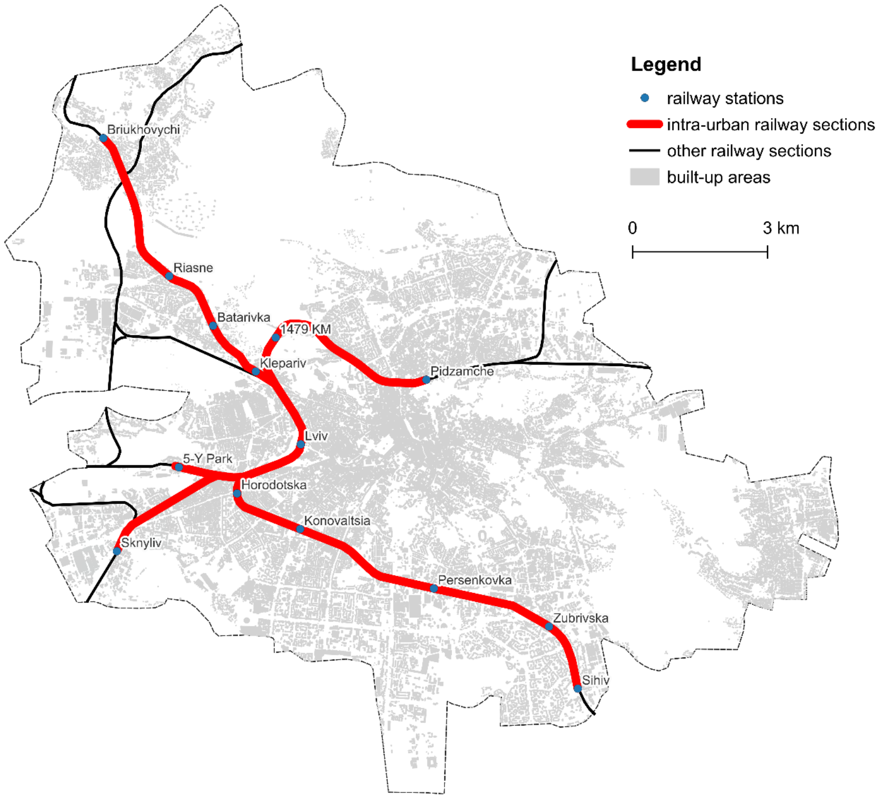

Fig 4. Regional rail network in urban areas in Lviv
Source: own elaboration based on Open Street Map.

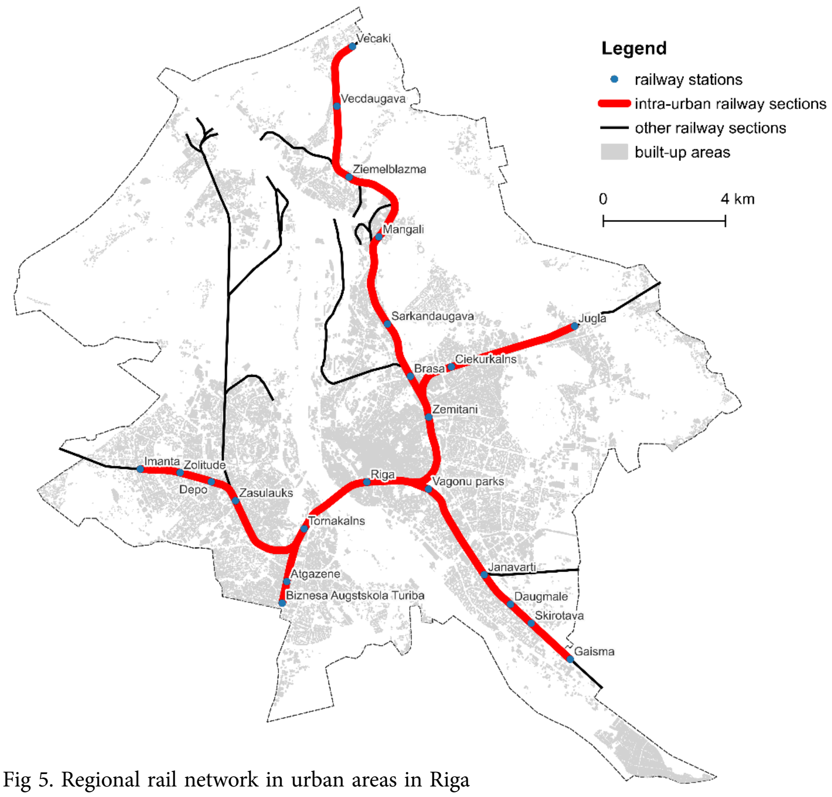

Fig 5. Regional rail network in urban areas in Riga
Source: own elaboration based on Open Street Map.

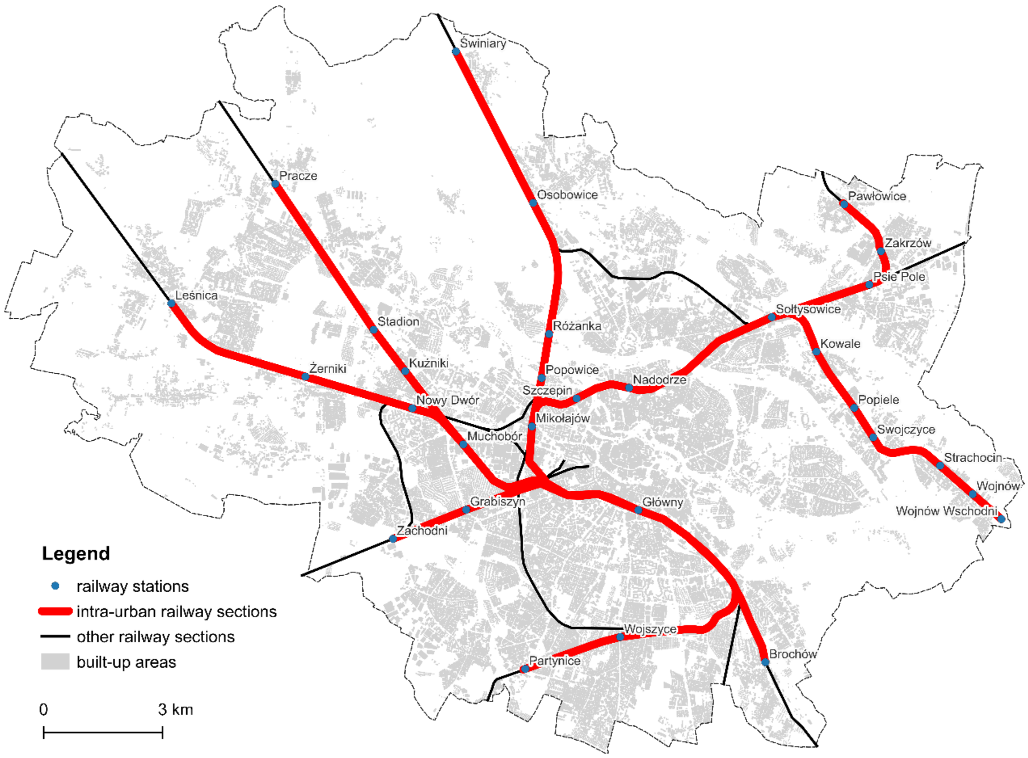

Fig 6. Regional rail network in urban areas in Wroclaw
Source: own elaboration based on Open Street Map

Intra-urban railway stations in Riga are primarily operated by the national carrier ViVi (formerly Pasažieru vilciens). In recent years, ViVi has received significant investment in rolling stock. The trains are modern and well-maintained, equipped with amenities such as air conditioning and Wi-Fi, aligning with Western European standards. Despite these improvements, many intra-urban railway stations still require modernization and often appear impractical or poorly adapted to current mobility needs, which limits their potential to function effectively as local transfer hubs.

Wrocław, located in the southwestern part of Poland, lies in a lowland area that offers highly favorable conditions for the development of rail transport. The city is one of Poland's key regional growth centers, with a population of 674,132 and covering an area of approximately 292.8 km². The regional rail network in Wrocław consists of 9 outgoing lines and 30 stops within the administrative boundaries of the city (see Fig. 6). This relatively dense and well-distributed network is largely the result of favorable historical circumstances. During the formative period of railway expansion in Europe, Wrocław was part of the Kingdom of Prussia, which strongly prioritized railway development.

The city's main railway station, Wrocław Główny, serves both long-distance and regional services. The overall layout of the rail network is relatively balanced in all directions, although a minor limitation is the lack of direct connections from the main station toward the northeastern part of the city.

Intra-urban railway stations in Wrocław are primarily served by two operators: *Koleje Dolnośląskie* and Polregio (formerly *Przewozy Regionalne*), both of which are publicly owned regional carriers. The majority of services provided from these stations are regional in nature, connecting Wrocław with towns and cities across Lower Silesia and beyond. Some routes extend into neighboring voivodeships, and in certain cases even cross international borders—for example, the connection to Lichkov in the Czech Republic.

Zagreb, located in the northern part of Croatia and bordered to the north by a mountain range that forms a distinct geographical barrier, is the capital of the country. Croatia was part of Yugoslavia until 1991 and has been a member of the European Union since 2013. The city has a population of 767,131

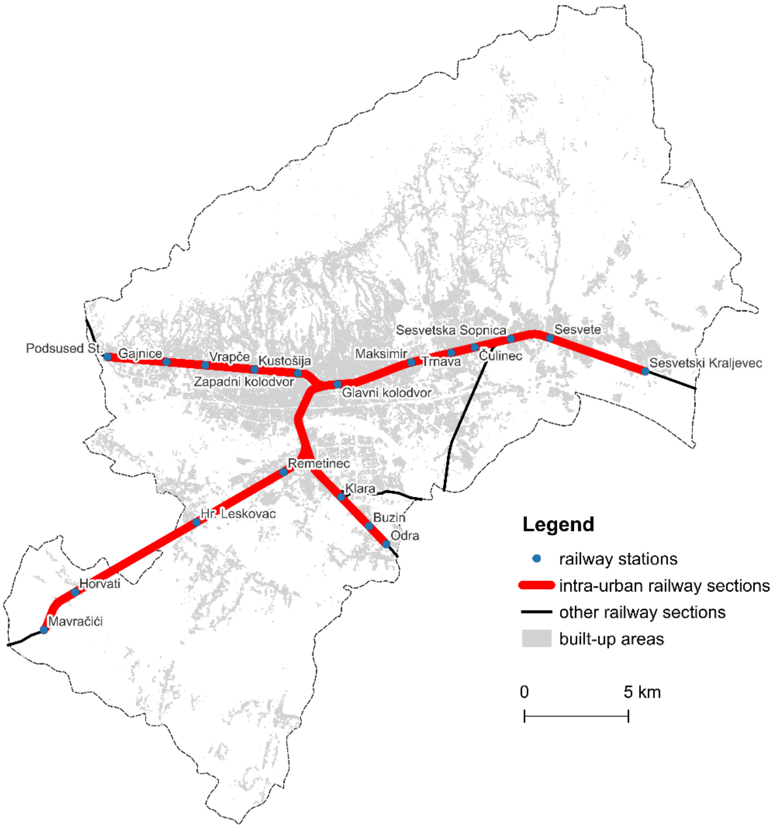

Fig 7. Regional rail network in urban areas in Zagreb
Source: own elaboration based on Open Street Map.

and covers an area of approximately 641.0 km². The layout of Zagreb's urban railway network follows a cross-shaped pattern, with four outgoing directions and 19 railway stops (see Fig. 7). The main axis of the intra-urban railway network runs in a north–south direction, from the Sevetski Kraljevec station to Podsused Stajalište. Zagreb Glavni Kolodvor, located near the city center, serves as the main railway station from which all railway connections originate.

Intra-urban stations in Zagreb are primarily served by the Zagreb Commuter Rail (*Zagrebačka prigradska željeznica*), a division of Croatian Railways (*Hrvatske željeznice*, HŽ). This system provides regular connections between the city and surrounding regional towns such as Velika Gorica, Zaprešić, Dugo Selo, Sesvete, and Samobor. Significant investments in rolling stock were made between 2015 and 2023, resulting in modern, comfortable trains equipped with numerous amenities. Most intra-urban railway stations have the potential to function as transfer hubs, although some would benefit from functional and design modernization.

6. Results

The basis for calculating indicators for the analyzed case studies was the initial data concerning the rail networks of the selected cities, presented in Table 4. Zagreb was the largest in terms of both population and area. Lviv had the smallest area, while Riga had the smallest population. Despite significant differences in area, it is worth noting the relatively similar population figures, confirm that the selected units are relatively comparable.

The main analysis of all five research units reveals a clear advantage for Leipzig compared to the other cities (see Table 5). In most cases, Leipzig achieved significantly higher values across the analyzed indicators. These values were several times higher, particularly in indicators related to the organizational aspects of rail transport. This was especially evident in metrics concerning the operational structure and management of the railway system.

However, it is important to note some exceptions—Leipzig did not achieve the highest values for three indicators (I1, D2, and D3). Wrocław outperformed Leipzig in I1 and D3, while Riga surpassed

Table 4. Summary of initial data for the cities considered.

City	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
Leipzig	297,6	625341	69,4	39	20	28,83	91,0	553,1	120,6	2352
Lviv	171,0	717803	29,5	14	15	10,69	39,1	178,7	26,1	351
Riga	307,2	605802	43,9	22	18	16,87	59,9	529,0	47,9	1019
Wroclaw	292,8	674132	73,7	30	19	23,12	80,0	474,0	126,8	958
Zagreb	641,0	767131	52,4	19	18	14,68	56,7	210,1	39,6	630

X1 - area [km^2], X2 - population, X3 - the length of lines used in urban traffic, X4- the number of stations withing city administrative border, X5 - round-trip period of train operation within a day (rounded) [h], X6 - total area of aggregated buffers (500m) [km^2], X7 - total area of aggregated buffers (1000m) [km^2], X8 - the length of pedestrian infrastructure in aggregated buffers (500m) [km], X9 - the length of cycle infrastructure in aggregated buffers (1000m) [km], X10 - the number of services in aggregated buffers

Source: own elaboration based on Open Street Map and Census Results shard on City Population Website

Table 5. The values of indicators potential of urban railway transport in analyzed cities
(the most favourable result is highlighted in bold)

Group of indicators	Symbol	Leipzig	Lviv	Riga	Wroclaw	Zagreb
Infrastructural	I1	23,3	17,2	14,3	**25,2**	8,2
	I2	**0,62**	0,20	0,36	0,45	0,25
	I3	**1,74**	2,64	2,21	2,77	2,94
Organisational	O1	**158**	9	64	63	71
	O2	**15**	398	35	40	31
Development	D1	**0,17**	0,13	0,12	0,11	0,12
	D2	19,20	16,70	**21,30**	20,50	14,30
	D3	1,33	0,67	0,80	**1,51**	0,70
	D4	**81,59**	32,83	60,41	41,43	42,92

Indicators Indicators I3 and O2 are considered destimulants, meaning that lower values indicate better performance
Source: own's elaboration

Leipzig in D2. It is worth noting that I1 may simply reflect the presence of more long-distance railway lines within the urban area that do not serve local traffic. Additionally, indicators D2 and D3 measure the density of active travel infrastructure in the vicinity of railway stations, and thus reflect the broader urban environment rather than the quality of the railway network sensu stricto. Nevertheless, these findings suggest that, in certain aspects, post-socialist cities in CEE demonstrate potential in utilizing rail transport for intra-urban commuting, comparable, in some cases, to Western European standards.

When comparing the cities of Riga, Wrocław, and Zagreb in CEE, it is difficult to unequivocally identify which one has the greatest potential for intra-urban commuting (see Table 4, Table 5). This reflects the similarity of the analyzed case studies in terms of the current level of development of railway transport within their administrative boundaries. Each city stood out slightly in one of the examined aspects of the railway system's functioning. Therefore, in the context of comparing CEE cities with cases from Western Europe, it is more appropriate to discuss potential within specific aspects rather than making broad generalizations about overall performance.

A different situation can be observed in the case of Lviv, whose results significantly underperformed in comparison to the other three cities. It recorded the lowest values in half of the analyzed indicators, in some cases substantially lagging behind the remaining cases.

In terms of the infrastructural aspect, the highest potential among CEE cities was observed in Wrocław. This was primarily due to a noticeable advantage in the values of indicators I1 and I2, resulting from a well-developed rail network and the presence of 30 railway stations within the city's administrative boundaries. This distinguishes Wrocław from other cities in CEE and brings it closer to Leipzig. Although the value of the third indicator (I3) in Wrocław is slightly less favorable than in Riga or Lviv, it is important to consider the even distribution of stations. Despite greater distances between individual stations compared to the other cities, their availability across the entire urban area is undoubtedly an advantage for Wrocław. Unlike Lviv, railway stations in Wrocław are also located in peripheral areas of the city, particularly in the eastern part. In terms of infrastructure, Zagreb performed the weakest, which can be partly attributed to the city's specific geographical conditions (see Chapter 3.1).

The results for the organizational aspect show that Zagreb has the greatest potential in this regard. Although the differences between Riga, Wrocław, and Zagreb are not substantial, the transport offer from individual stations in Zagreb appears to be the most consistent, with trains departing at regular intervals. Although Lviv has a dedicated suburban station, suggesting the existence of a high-frequency suburban railway, the actual frequency of service poses a fundamental barrier to integrating regional rail with urban transit in Lviv. The research results clearly show that railway transport in Lviv is strongly oriented toward long-distance travel, with relatively few regional connections. These connections are insufficient to significantly complement the public transportation network within the city limits.

The analysis of development indicators revealed that Riga exhibited the greatest potential in this area, even surpassing Leipzig in the D2 indicator. It was evident that railway stations in Riga are significant elements of the functional-spatial structure, being surrounded by dense development, a well-developed network of bicycle paths, and a concentration of service facilities. Particularly noteworthy were the results for service density, which indicate that both buildings and commercial entities tend to cluster near railway lines. This could facilitate the formation of multifunctional sub-centres near railway stations.

Interestingly, Lviv also performed reasonably well in the development aspect, suggesting that railway stations are important points in the urban space. However, an alternative explanation for Lviv's relatively high service density should be considered. It may be that the relatively small number of railway stations in Lviv are more likely to be located in urban centers or subcenters where commercial activity is concentrated, rather than in residential areas that typically serve as origins for commuter traffic. This spatial distribution would result in a higher average service density around Lviv's fewer stations. In contrast, other cities have a larger number of stations distributed across both commercial centers and residential neighborhoods, supporting a more extensive intra-urban commuting network. Consequently, although the networks in these cities may be more suitable for commuter traffic, the average service density indicator appears lower due to the inclusion of stations in residential areas with fewer surrounding services.

Additionally, it is important to note that the pedestrian and cycling infrastructure indicator does not fully capture the quality of these elements, making it difficult to assess the extent to which Lviv benefits from favorable conditions in this regard. The quality of such infrastructure in Lviv may vary significantly compared to similar facilities in other cities.

7. Discussion and conclusions

This study contributed to the ongoing discourse on improving urban public transport systems in CEE region within the broader context of the transition toward sustainable urban mobility (Buzási & Csete, 2015; Fitzová et al., 2018; Svirčić Gotovac & Kerbler, 2019; Mulíček & Seidenglanz, 2019). From a research perspective, it was essential to consider both the conditions necessary for new infrastructural investments and the potential for enhancing the efficiency of existing transport networks. This paper focused on the integration of existing regional rail infrastructure into URT systems as one of the measures that could be implemented relatively quickly and at a lower cost compared to large-scale new investments.

This study should be regarded as a preliminary investigation that provides a reference framework for future research, rather than a source of direct, application-oriented recommendations. The empirical analysis focused on general indicators which, while valuable for comparative insights at the macro scale, do not offer a sufficient basis for determining the extent to which regional rail can serve as a viable alternative for intra-urban commuting. Addressing this question would require access to detailed—and often difficult-to-obtain—demand-side data, such as passenger volumes and travel behavior.

The main contribution of this study lies in its multi-faceted comparative approach, including the geographical dimension. Particularly valuable was the comparison of the analyzed cities with Leipzig—a city that represents Western European standards despite having initial conditions similar to those of the post-socialist cities examined. Based on this comparison, it can be concluded that none of the analyzed cities currently possess fully adequate conditions for the effective integration of regional rail into URT systems. This does not mean, however, that these cities lack potential in this regard—especially when considering different aspects of rail transport functioning. It should be emphasized that, in the case of specific indicators within a given aspect, the analyzed cities approached—and in some individual cases even exceeded—the values recorded for Leipzig. Nevertheless, the greatest advantage of Leipzig over the CEE cities was observed in the organizational aspect, which seems to be a fundamental requirement for regional rail to function effectively as part of a URT system.

Equally valuable was the comparison of results among the analyzed cities themselves, although it remains difficult to unequivocally identify which city holds the greatest overall potential for integrating regional rail into urban transit. Nevertheless, the analysis clearly showed that Lviv exhibited the weakest conditions in this regard. These differences confirm findings from the literature: variations exist among these countries in terms of the trajectories of public transport market transformation after 1989 in CEE (Taczanowski, 2015; Król & Taczanowski, 2016).

This study also contributed to the ongoing discussion on the terminology used in the literature to describe rail-based transport modes within the framework of URT in CEE cities. In relation to traditional train services operating within city boundaries or suburban zones, terms such as agglomeration railway (Raczyńska-Buława, 2017; Puławska-Obiedowska et al., 2024) and metropolitan railway (Kotecki & Pasławski, 2025) were frequently used. This raised the question of whether such systems could genuinely be distinguished from regional rail, given that most of these services operated on standard regional lines and were not exclusively dedicated to agglomeration-scale travel.

In many cases, service to stations located within the metropolitan area was provided by regional connections. For example, a significant portion of so-called agglomeration services in Wrocław terminated in cities such as Jelenia Góra, Wałbrzych, or Kłodzko. Conversely, in cases where trains did not extend beyond the agglomeration area, this was often the result of infrastructural constraints rather than a clearly defined and dedicated function. These were typically short lines without continuation beyond the immediate urban zone—such as Wrocław–Trzebnica, Kraków–Wieliczka, or Riga–Skulte.

The authors advocated for the use of the term regional rail as a more precise and appropriate designation for the systems in cities analyzed in this study. In contrast, terms such as agglomeration railway, metropolitan railway, or the equivalent suburban rail were considered more suitable for systems like WKD and SKM in Warsaw or HÉV in Budapest, which exhibited dedicated operational characteristics and a clearly defined urban–suburban function. Indeed, regional rail constitutes a broader category within which certain subtypes of connections can be distinguished—as pointed out by Taczanowski and Kołoś (2020).

In response to RQ1, geographical and political conditions influenced the way rail services operated within urban areas only to a certain extent, thereby shaping—though not decisively—the potential for their integration into URT systems. Contrary to the authors' initial expectations, this influence was less pronounced and appeared to be limited to a single aspect. The impact was most evident when comparing cities such as Riga, Wrocław, and Zagreb—located within the sphere of Western European (European Union) influence—with Lviv, which lies outside of this sphere. The inclusion of these countries within the orbit of European transport policy allowed for a greater diffusion of trends in the organization of URT, following Western European models. The study did not provide sufficient evidence to determine how geographical conditions or spatial proximity influenced the results within the analyzed scope.

In the context of RQ2, the authors proposed a research procedure primarily aimed at identifying general features that could be easily interpreted and compared across different urban areas. The selected indicators referred to several fundamental elements reflecting various aspects relevant to the operation of railway transport within urban administrative boundaries. However, future research with a more detailed focus on specific systems should expand the scope of the examined features to gain a fuller understanding of the particularities of each case. The empirical analysis also prompted reflections on the limitations of the applied methods, providing a basis for further discussion and refinement of the research procedure in subsequent studies.

First and foremost, it should be emphasized that not all indicators necessarily carry equal importance in assessing the quality or usability of a specific form of rail transport, as much depends on the objective of the study and the intended interpretation of the results. Therefore, it may be worth considering the application of weighting to the proposed indicators to better reflect their relative significance. An additional value could also come from adopting a more synthetic approach that combines individual indicators into a broader analytical framework. For example, a complementary metric to I1, I2, and D1 could be the proportion of the city's built-up area located within a 500-meter radius of all railway stations. This would offer a more comprehensive insight of how much of the urban fabric is effectively served by the rail network.

In more detailed studies, certain indicators—particularly those related to the development aspect—would require further refinement, especially when the analysis focuses on a more quantitative assessment of origin and destination potential in those areas. Greater attention should also be paid to the selection and weighting of service-related points. It is worth questioning whether all listed facilities are equally relevant or comparable in terms of their influence on travel demand. For instance, a central shopping center or hospital is likely to generate significantly more trips than ATM. Moreover, it would be beneficial to incorporate indicators reflecting multimodal aspects of accessibility—particularly those related to integration with other modes of public transport, such as interchange quality or ease of transfers.

In summary, while strengthening regional rail for intra-urban commuting can bring measurable benefits, it should primarily be seen as an urgent optimization of existing resources rather than a justification for postponing or abandoning of new infrastructual investments. Indeed, numerous studies have shown that in cities such as Sarajevo (Mehanović, 2021) and Ljubljana (Brezina, 2008) can successfully improved their URT systems by transforming traditional tram networks into LRT. Similarly, Ďurček and Horňák (2016) argued that Bratislava does not necessarily require a full metro system, and that enhancing accessibility to the conventional rail network could be a viable alternative. Seidenglanz et al. (2016), in their analysis of Czech and Slovak cities, noted that the legacy of rapid tram systems—despite technical limitations—can be further developed as part of a modern rail network without the need for constructing a full-scale metro. However, it should be noted that these studies largely focused on mid-sized urban centers with populations below 500,000, where broadly defined light rail or regional rail solutions may be sufficient (Knowles and Ferbrache, 2016; Gadziński & Radzimski, 2021). In contrast, in larger cities experiencing rapid population and spatial growth, more substantial investments—such as in metro systems—may need to be seriously considered.

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