Journal of Geology, Geography and Geoecology

Journal home page: geology-dnu.dp.ua

ISSN 2617-2909 (print)
ISSN 2617-2119 (online)

Journ. Geol. Geograph. Geology,
33(1), 044-053
doi:10.15421/112405

Topological analysis of roadway and railway networks of the Ukrainian-Polish borderlands (on the example of Lviv Oblast and Subcarpathian Voivodeship)

Yurii Borsuk

Lviv Ivan Franko National University, Lviv, Ukraine, Yurii.Borsuk@lnu.edu.ua

Received 30.04.2023;
Received in revised form 16.05.2023;
Accepted 14.11.2023

Abstract. The paper presents an analysis of functioning of roadway and railway networks in the context of logistics flows. The interaction of road vehicles and railroad cars within the given territories was characterized. The provided spatiotemporal modelling allows comparing the configuration of roadways and railways from the peripheral settlements to the regional capitals. The points that form transport links with the administrative centres of each studied territory were identified. A comparative topological analysis of the given lines of roadway and railway transport within the Ukrainian-Polish borderland employed quantitative (distance, time) and qualitative (curvature, travel speed) modelling parameters, characterizing the relationship of the borderland territories in two neighbouring countries of Eastern Europe. Relative indicators, which include curvature and speed, were estimated. A database of settlements based on accessibility to the city by road and rail transport was created, taking into account the top-10 centres of territorial communities, or hromadas, in Lviv Oblast and Subcarpathian Voivodeship. Alternative modes of transport for travelling from a centre of territorial community to the regional centre in Ukraine and Poland were highlighted. The study compared the settlements with low transport accessibility to the regional capital (oblast, voivodeship), taking into account the functioning of the roadway and railway networks. Social-geographical problems of the given territories were identified based on the analysis of topological indicators of each transport connections. I found that the network system of transport infrastructure in Subcarpathian Voivodeship is low-dense, especially in mountainous areas. Also, there was analyzed high accessibility of suburban settlements to the city of Rzeszów. In Lviv, connection between the suburbs and the city centre can be called problematic. Within the studied borderland areas, there were also found cases of disuse of the existing railway stations for passenger traffic. Variants that would promote the development of public transport in the Lviv Oblast have been proposed, based on the example of the transport model in Subcarpathian Voivodeship. Applied developments include the need to build the Opillia-Roztocze highway, assignement of high-speed electric trains from remote areas to the regional capital.

Keywords: road network, railway network, transport accessibility, topological analysis, Ukrainian-Polish borderland, modelling.

Топологічний аналіз автомобільної та залізничної мережі українсько-польського прикордоння (на прикладі Львівської області та Підкарпатського воєводства)

Юрій Борсук

Львівський національний університет імені Івана Франка, Львів, Україна, Yurii.Borsuk@lnu.edu.ua

Анотація. Розглянуто функціонування автомобільних і залізничних мереж у контексті логістичних потоків. Охарактеризовано взаємодію автомобільного і залізничного транспорту в межах заданої території. Наведено просторово-часове моделювання, що дозволяє порівняти конфігурацію автошляхів і залізниць від периферійного до регіонального міста. Визначено точки, які формують транспортні зв'язки з адміністративним центром кожної досліджуваної території. Проведено порівняльний топологічний аналіз наведених ліній автомобільного й залізничного транспорту в межах українського-польського прикордоння. Використано кількісні (відстань, час) і якісні (кривизна, швидкість руху) параметри моделювання, що характеризують співвідношення прикордонних територій у двох суміжних країнах Східної Європи. Розраховано відносні показники, до яких віднесено кривизну і швидкість. Сформовано базу даних поселень за доступністю до міста автомобільним і залізничним транспортом, взято до уваги топ-10 центрів територіальних громад у Львівській області та Підкарпатському воєводстві. Виділено альтернативні види транспорту під час переміщення від центру територіальної громади до регіонального центру в Україні й Польщі. Проведено порівняння поселень із низькою транспортною доступністю до центрального (обласного, воєводського)

міста з урахуванням функціонування автомобільної і залізничної мереж. Виявлено суспільно-географічні проблеми наведених територій, отримані з аналізу топологічних показників кожного транспортного поєднання. З'ясовано, що в Підкарпатському воєводстві мережева система транспортної інфраструктури має низьку щільність, особливо в гірській місцевості. Також досліджено високу доступність окремих поселень у приміській зоні міста Жешув. У Львові проблемним можна назвати сполучення околиць із середмістям. У межах досліджених прикордонних територій існують випадки невикористання діючих залізничних станцій для пасажирського руху. Запропоновано варіанти, що можуть сприяти розвитку пасажирських перевезень у Львівській області за прикладом транспортної моделі в Підкарпатському воєводстві. До прикладних напрацювань варто віднести необхідність будівництва опільсько-розтоцької автомобільної магістралі, призначення прискорених електропоїздів із віддалених територій до регіонального міста.

Ключові слова: автомобільна мережа, залізнична мережа, транспортна доступність, топологічний аналіз, українсько-польське прикордоння, моделювання.

Introduction

Nowadays, transport networks are the main means that provide people with mobility. They provide the population with economic activities, for example deliveries of supplies for production purposes. In a socially-oriented country, functioning of transport networks guarantees an effective performance of public transport as one of the most necessary public services. Currently, administrative territorial units of local and regional levels vary in transport accessibility and mobility, which is related to unequal development of transport-logistic infrastructure in their population-spread systems.

Analysis of a network system of transport infrastructure can reveal a complex characterization of interactions between roadway and railway transport within a certain territory. This allows identifying points with alternative means of transporting passengers to an administrative centre. Utilizing mathematical modeling in the transport sphere distinguishes complex indicators characterizing roadway and railway networks in a region.

Similar territories have been observed to have various configurations of the roadway and railway networks. When characterizing the infrastructure, some Ukrainian researchers (Hrytsevych, Senkiv) used the curvature index. Curvature coefficient allows determining the curvature level in numerical parameters.

However, curvature is employed in case of characterizing the network proper (roads, railroads), i.e. immobile part of the infrastructure. As with transport performance, there emerge problems of logical flows. Qualitatively, they can be researched by analyzing time and speed of transportation.

Taking into account development of most key factors in a logistic strategy requires – in one way or another – a multi-criteria optimization. There are a number of scientific methodologies and models that estimate duration of multi-modal transportations, for example, network models, and additive and multiplicative models. However, those models consider time on the level of domestic market and one subject (organization). All of this comes down to micrologistics. Spanish researchers (Bensassi, Marquez-Ramos, Martinez-Zarroso, Suarex-Bourguet) identified the geographic factors and transport infrastructure as the main determinants of the global trade, proposing a model of exporting goods from regions of Spain to various destinations. The geographic and trade structure of transport-logistic infrastructure was studied by Azimov (Azimov, 2017). Researchers Mukhtarova, Ospanov, Sharapiyeva, and Antoni conducted a correlation analysis in order to determine factors affecting the efficiency of transport infrastructure the most.

In our study, we compared the transport and logistical parameters in the context of two types of land transportation – roadways and railroads. Such an analysis determined a possible distribution of passenger traffic at certain distances from administrative centres. This is a necessary factor in modeling passenger transfers, since it is essential for high-quality competitiveness between transporters.

The objectives of the study were the roadway and railroad infrastructures, taking into consideration quantitative and qualitative characteristics in Ukraine and Poland.

Materials and methods

The study unpacks the alternative ways of using the roadway and railroad networks in two similar bordering regions of the neighbouring countries. The predicted spatiotemporal modeling allowed comparing configuration of roadways and railroads according to curvature and travel time from peripheral centres (of hromadas, or territorial communities, and gminas) to the regional (oblast, voivodeship) capitals. Improving transport accessibility of some settlements in the oblast or the voivodeship should be of great interest for the local authorities.

After a topological analysis, each local power should concentrate their efforts on development of roadway or railway infrastructures. A determining factor in provision of transport connection is still mobility, measured by time and speed. Competition

between roadway and railway transportation to a certain destination depends on performance of temporal parameters – quantitative (duration) and qualitative (speed) parameters. In this study, speed values were considered qualitative parameters, because in this way it is possible to determine the effectiveness level of [rides on] transport vehicles. This aspect is especially interesting to groups of transporters who have to compete on a certain route in travel time and speed. Qualitative advantage is a factor in passenger transportation services, and therefore it continues to affect incomes from transportation.

Spatiotemporal analysis of roadway and railway networks revealed the level of transport accessibility in the neighbouring regions of the countries. In this case, transport routes in the given bordering territories are distinct by class and nomenclature. In Lviv Oblast, roadways of state significance include international, national, regional, and territorial. All of them are marked by one letter and two numbers (territorial ones have four numbers in numeration). In Subcarpathian Voivodeship, roadways are divided into international, national, interregional, and inter-voivodeship. Such roadways also have various indications: international are marked with one letter and a number (A4), national inter-regional – with a one- or two-digit number (9 or 28), and inter-voivodeship – with a three-digit number (835). Figure 1 shows how the roadways have been classified according to the Polish system. Thus, international roads of Lviv Oblast were identified to international, while national and regional – to national inter-regional, and territorial to inter-oblast or inner-oblast as well.

Prior to the analysis, the following hypotheses were put forward:

– In the mountainous part of Subcarpathian Voivodeship, the curvature of roadways is higher than in Lviv Oblast;
– Roadways in Subcarpathian Voivodeship provide the settlements with a better access to the region capital than such in Lviv Oblast;
– Travel speed on road transport in suburban area of a large city will be lower compared with remote peripheral area in both Ukraine and Poland.

The literature analysis included researches by representatives of Lviv human-geographic school, in particular V. Hrytsevych's and M. Senkiv's «Curvature of Roadway Space as a Factor of Transport Logistics in Western-Ukraine Region», which illustrated the triangulation network for the Western region, revealed the curvature coefficient for every triangle, and also presented a geographical analysis of distribution of curvature of roadway space in the Western region of Ukraine (Senkiv, 2014). The study by M. Senkiv revealed that Lviv Oblast has a well-developed network of roadways. The curvature increases in the mountainous bordering part of Turka and Staryi Sambir (now Sambir) districts. Mean values of curvature were seen along the Eastern Beskyds range. Further, the roadway space continues to increase in the eastern part of Lviv Oblast in the area of the low-mountain structures of Opillia, Holohory, and Voroniaky. Increase in the curvature coefficient was also characteristic for territories of Yavoriv National Natural Park and the Roztocze Natural Reserve, in hilly, poorly developed area between the city of Peremyshliany and urban-type settlement Novi Strilyshcha.

The study «Topology and Metrics of Roadway Space as a Factor of Transport-Logistical Activity in the Western Region of Ukraine» by Docent V. Hrytsevych and Postgraduate M. Senkiv focused on roadway positioning in urban settlements in the Western region of Ukraine and their effects on the logistics flows. In the Western region of Ukraine, the most promising transport-logistical centre is the city of Lviv (degree in relation to international roads – 5, in relation to national – 4). Besides Lviv, opportunities for transport-logistic activity in the oblast were observed for the city of Stryi (degree in relation to international roadways – 2, national – 1). Mostly in urban-type settlements, roadway positioning needs improvement in relation to the population (Novi Strilyshcha, Stara Sil, Borynia) (Hrytsevych, 2014; Senkiv, 2014). Among the cities, we should note Uhniv in the western part of Chervonohrad District.

In the study, I used my own model of connection between the central (oblast, voivodeship) cities and peripheral points of the territories in the two administrative objects of the neighbouring countries. The quantitative parameters were obtained through cartographic measurements of distances of the connections between 74 centres of hromadas and the oblast capital (Lviv Oblast) and between 147 centres of municipalities or gminas and the voivodeship capital (Subcarpathian Voivodeship). In total, 221 settlements were analyzed, identifying the curvatures of the roadways and railroad lines, as well as the speed of travel to the large cities.

Operation period is determined based on rates of investments into development of infrastructure. If no routes with lower curvature are designed, the speed of transportation will remain at the current level for another couple of years, and the study will thus be relevant later. However, in railway transport, graphs of train movement are developed every year, which

account for positive as well as negative speed parameters. Analysis of railway transportations requires monitoring travel time in the schedule, because the speed of train over a year can vary, depending on condition of the infrastructure and channel capacity.

The following materials were utilized for the study:

a) list of administrative formations (hromada of Lviv Oblast and gminas of Subcarpathian Voivodeship);
b) Google Maps platform to measure the shortest distance;
c) schedule of passenger trains from point A (centre of community) to point B (large city).

Curvature is a relative indicator, because it is calculated by the formula where the shortest roadway or railway is divided by a connective straight line between the two points. Such an indicator has no measurement units, but characterizes the ratio of a determined route to the perfect straight line. The curvature coefficient that equals 1 indicates absence of curved areas. Such a part of the road is the most straight. Curvature value cannot be below 1, because a perfect straight cannot be greater than the shortest straightforward road.

Speed is determined by ratio of distance to time. It depends on qualitative parameters on a way. When a road surface or railway track is in good condition, travel time decreases and speed increases. In this case, by moving with high speed, one can overcome the distance that is longer than the ideal. A straight road is not always a feature of a well developed transport infrastructure. In addition to a low curvature coefficient, paths should also be designed to facilitate efficient and fast movement. Sometimes, roads can be straight, but run through settlements with speed limits. This increases travel time, affecting the accessibility of the end point.

The study revealed that curvature coefficient and speed can be interrelated. Some centres of the communities showed a low level of curvature, which did not increase the mean travel speed. Other local centres are connected with the large city by a highway with high curvature, but the travel speed was observed to be quite high. To equalize the communities in the ratings of accessibility to the oblast of voivodeship capital, a quantitative parameter was used, obtained by the product of multiplying curvature by speed.

Identification of topological characteristics of a settlement within any territory requires a data base of several parameters. The primary parameters include the shortest distance and time of driving a vehicle from a centre of hromada (or gmina) to the large city, established using Google Maps. Then, distance between the points is measured and incorporated into the data base. After identifying the initial parameters, curvature and speed are estimated.

Curvature is determined using the formula:

$$C = \frac{S}{S_0}, \quad (1)$$

where C is the curvature coefficient; S – the shortest roadway distance; S_0 – topological distance.

The speed is estimated as follows:

$$V = \frac{S}{T}, \quad (2)$$

where V – speed; S – distance; T – time of travel.

The values of curvature and speed are also incorporated into the table. To characterize local settlements in relation to the administrative centre, the obtained values were organized into a rating list. As mentioned above, some points were found more accessible because of low curvature, while others because of high speed of movement on highways. Rating of settlements by curvature and speed varied, and therefore the values were arranged in an integral rating structure according to transport-logistical access of local points to the central city. Transport-logistical accessibility is an integrated quantitative parameter that reflects the interrelations between settlements of various ranks in the context of development of a transport-logistical infrastructure. The accessibility of the city from the settlements that are in its gravitation zone is estimated through multiplying curvature coefficient by speed value:

$$I_a = C \cdot V, \quad (1)$$

where I_a – index of settlements access to a city; C – curvature coefficient; V – speed of movement.

Zone of gravitation towards the large city accounted for the territory of 20 km radius. The most remote gravitation zone was from 40 to 60 km away. This territory is considered peripheral because compared to all other lateral zones it is located compactly close to the border and administrative boundaries of the oblast. The 40-60 km radius of the concentric circle outlines the boundaries of Lviv District – the oblast's most urbanized area. Also, distances in the range of 0 to 40 km were used to designate the Lviv agglomeration. Using the same approach, there were developed zones of gravitation towards the city of Rzeszów in Subcarpathian Voivodeship.

Results and analysis

According to the accessibility of the cities for the settlements, the local points (hromadas, gminas) were

rated in relation to the administrative centres (oblast or voivodeship capitals), from the lowest to the highest value. For example, there are demonstrated the top-10 settlements in the list of hromadas (Lviv Oblast) and gminas (Subcarpathian Voivodeship) with the best parameters of transport-logistical accessibility. The data for the settlements with best access to the regional capitals according to the transport-geographic locations in Lviv Oblast and Subcarpathian Voivodeship are given in Table 1.

Therefore, among 10 points with best access, the mean values in Lviv Oblast and Subcarpathian Voivodeship varied (45.5 and 54.5, respectively). This indicates that the accessibility of the city for local centres is better by 9 units in Lviv Oblast than in Subcarpathian Voivodeship. The accessibility parameter in certain points of the oblast (Murovane, Sokilnyky, Pidberiztsi, Davydiv) had demonstrated better results compared with the voivodeship. The Tyczyn village of Subcarpathian Voivodeship was found to be close to Zymna Voda of Lviv Oblast according to this parameter.

Using the aforementioned method of measuring curvature and speed, one can form a data base of settlements according to the accessibility to the city on railway transport. Of the ten points with the best road-vehicle access, the railway connection was observed to be the alternative in the four points of Lviv Oblast (Davydiv, Zymna Voda, Obroshyne, Kulykiv) and the Subcarpathian Voivodeship (Boguchwała, Świlcza, Czudec, and Łańcut).

I will attempt to demonstrate the top-10 settlements according to the access to the large cities (Lviv, Rzeszów) particularly on railroad cars (Table 2). The analysis included only hromadas and gminas with the central settlements that have operating stations and stops.

Therefore, the accessibility to the central city on trains in Lviv Oblast was found to be better than in Subcarpathian Voivodeship. It has to be noted that the settlements in the suburban zone of Lviv (Zymna Voda, Davydiv, Kulykiv, Obroshyne) were seen to better access via railroad cars than by roadway. In Subcarpathian Voivodeship, such a settlement is the Boguchwała village.

Table 1. Top-10 local settlements according to the level of access to the central city (of oblast and voivodeship) via road vehicles

№	Settlement	Accessibility	№	Settlement	Accessibility
Lviv Oblast			Subcarpathian Voivodeship		
1.	Murovane	31.25	1.	Tyczyn	47.73
2.	Sokilnyky	35.91	2.	Krasne	49.21
3.	Pidberiztsi	41.92	3.	Iwierzyce	52.00
4.	Davydiv	45.72	4.	Boguchwała	53.75
5.	Zymna Voda	48.30	5.	Świlcza	55.37
6.	Obroshyne	48.38	6.	Chmielnik	55.66
7.	Ivano-Frankove	50.16	7.	Czudec	56.70
8.	Solonka	50.40	8.	Łańcut	57.24
9.	Kulykiv	50.84	9.	Markowa	57.77
10.	Bibrka	51.70	10.	Trzebownisko	59.80
Mean		45.46	Mean		54.52

The initial data were developed by the author.

Table 2. Top-10 local settlements by access to the central city (of oblast or voivodeship) via railways

№	Settlement	Accessibility	№	Settlement	Accessibility
Lviv Oblast			Subcarpathian Voivodeship		
1.	Zymna Voda	31.97	1.	Boguchwała	50.21
2.	Davydiv	33.02	2.	Głogów Małopolski	52.81
3.	Kulykiv	35.67	3.	Czudec	58.82
4.	Novoiavorivsk	37.26	4.	Horyniec-Zdrój	63.05
5.	Obroshyne	37.50	5.	Lubaczów	64.28
6.	Rava-Ruska	37.96	6.	Cmolas	65.45
7.	Radekhiv	39.77	7.	Oleszyce	66.01
8.	Zhovkva	40.21	8.	Wiśniowa	66.15
9.	Dobrosyn	40.61	9.	Świlcza	66.67
10.	Shehyni	41.48	10.	Majdan Królewski	67.14
Mean		37.55	Mean		62.06

The initial data were developed by the author.

Also, it is practical to identify the points with the lowest access to the large cities in Lviv Oblast and Subcarpathian Voivodeship. Tables 3 and 4 present a list of settlements with the lowest accessibility parameters (over 80) according to the roadway and railway networks.

As shown, there are five settlements (Pidkamin, Novyi Rozdil, Maheriv, Borynia, Turka) with low parameter of roadway accessibility in Lviv Oblast and 53 in Subcarpathian Voivodeship. The highest values of low roadway accessibility were observed in the southwest outskirt of Subcarpathian Voivode-

Table 4. Settlements with low access to the central city (of oblast, voivodeship) via railways

Settlements	Number of settlements	Settlements	Number of settlements
Lviv Oblast		Subcarpathian Voivodeship	
Accessibility (141 – 150)			
	0	Nisko, Rudnik nad Sanem, Nowa Sarzyna	3
Accessibility (131 – 140)			
	0	Leżajsk	1
Accessibility (121 – 130)			
	0	Sędziszów Małopolski, Dębica	2
Accessibility (111 – 120)			
Drohobych	1	Sanok	1
Accessibility (101 – 110)			
	0	Stalowa Wola, Przemyśl, Nowa Dęba, Ropczyce, Kolbuszowa	5
Accessibility (91 – 100)			
Brody, Stryi	2	Jarosław, Łańcut, Zarszyn, Jasło, Besko, Przeworsk, Krosno	7
Accessibility (81 – 90)			
Skole, Slavske, Truskavets	3	Radymno	1

The initial data were developed by the author.

Table 3. Settlements with low access to the central city (of oblast, voivodeship) via roadways

Settlements	Number of settlements	Settlements	Number of settlements
Lviv Oblast		Subcarpathian Voivodeship	
Accessibility (131 – 140)			
	0	Roźwienica, Orły, Medyka	3
Accessibility (121 – 130)			
	0	Radymno, Wiązownica	2
Accessibility (111 – 120)			
	0	Pawłowa, Wielkie Oczy, Żyraków, Chłopice, Przeworsk	5
Accessibility (101 – 110)			
	0	Tryńcza, Sieniawa, Adamówka, Jarosław, Niwiska, Stubno, Cieszanów, Oleszyce, Czarna	9
Accessibility (91 – 100)			
	0	Stalowa Wola, Narol, Pilzno, Wojaszówka, Lubaczów, Padew Narodowa, Horyniec-Zdrój, Leżajsk, Kuryłówka, Laszki	10
Accessibility (81 – 90)			
Pidkamin, Novyi Rozdil, Maheriv, Borynia, Turka	5	Przecław, Jedlicze, Gawłuszowice, Krzeszów, Borowa, Kamień, Brzyska, Radomyśl Wielki, Rakszawa, Stary Dzików, Baligród, Wiśniowa, Fredropol, Skołyszyn, Nowa Sarzyna, Cisna, Dębowiec, Lesko, Wadowice Górne, Kołaczyce, Osiek Jasielski, Sanok, Solina, Pysznica	24

The initial data were developed by the author.

ship (Roźwienica, Orły, Medyka). This category can also include other gmina centres, especially near the Polish-Ukrainian border (Radymno, Wiązownica, Pawłowa, Wielkie Oczy).

Low parameter of railway accessibility was observed for settlements of Subcarpathian Voivodeship. This was observed in the largest range (141-150), which included Nisko, Rudnik nad Sanem, and Nowa Sarzyna. In Lviv Oblast, there were observed six points with the poorest railway-network access (Drohobych, Brody, Stryi, Skole, Slavske, Truskavets), whereas the number of such settlements in Subcarpathian Voivodeship was found to be almost three times higher.

The roadway and railway networks in Lviv Oblast are more ramified, providing a high access to the region capital not only for the nearest but also remote settlements. For example, the Murovane village is 10 km roadway distance away from Lviv, while the town of Bibrka is 34 km away. Sometimes, the list of the points with best roadway access includes settlements in territories of other districts (urban-type settlements Ivano-Frankove, Yavoriv District). The ten points with lowest access included no settlements of the Drohobych and Chervonohrad districts. However, settlements of the Stryi (Novyi Rozdil, Zhuravno, Hnizdychiv) and Zolochiv (Pidkamin, Brody, Pomoriany) districts were characterized by low level of roadway access to Lviv. From the presented points, only Zhuravno and Hnizdychiv have railroad stations, though there is no direct connection between either of them and Lviv due to high curvature of the route. However, the railway accessibility for some settlement (Drohobych, Brody, Stryi, Skole, Slavske, Truskavets) was found to be notably lower than the roadway accessibility due to greater curvature and speed limits (Kuzyk, 2020; Borsuk, 2020). In general, there were found eight centres of territorial communities with operating stations that provide no direct connection with the Oblast capital (Belz, Biskovychi, Hnizdychiv, Dobromyl, Zhydachiv, Zhuravno, Ralivka, Khyriv) (see Fig. 2) (Ukrainska zaliznytsya, 2022).

In Subcarpathian Voivodeship, roadway and railroad networks are not highly dense, especially in mountainous areas. Most of the points with best ac-

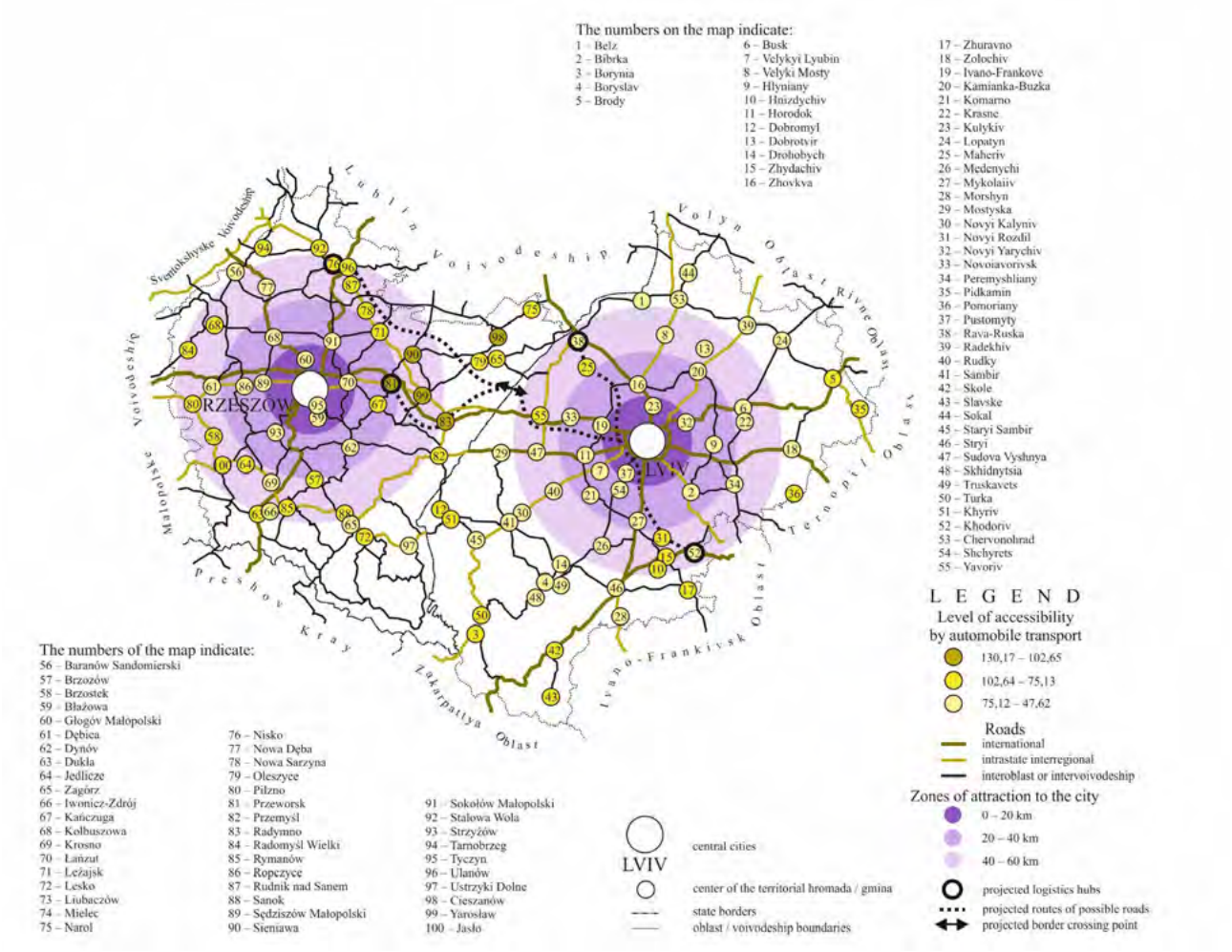

Fig. 1. Accessibility by roadways in the Lviv Oblast and Subcarpathian Voivodeship

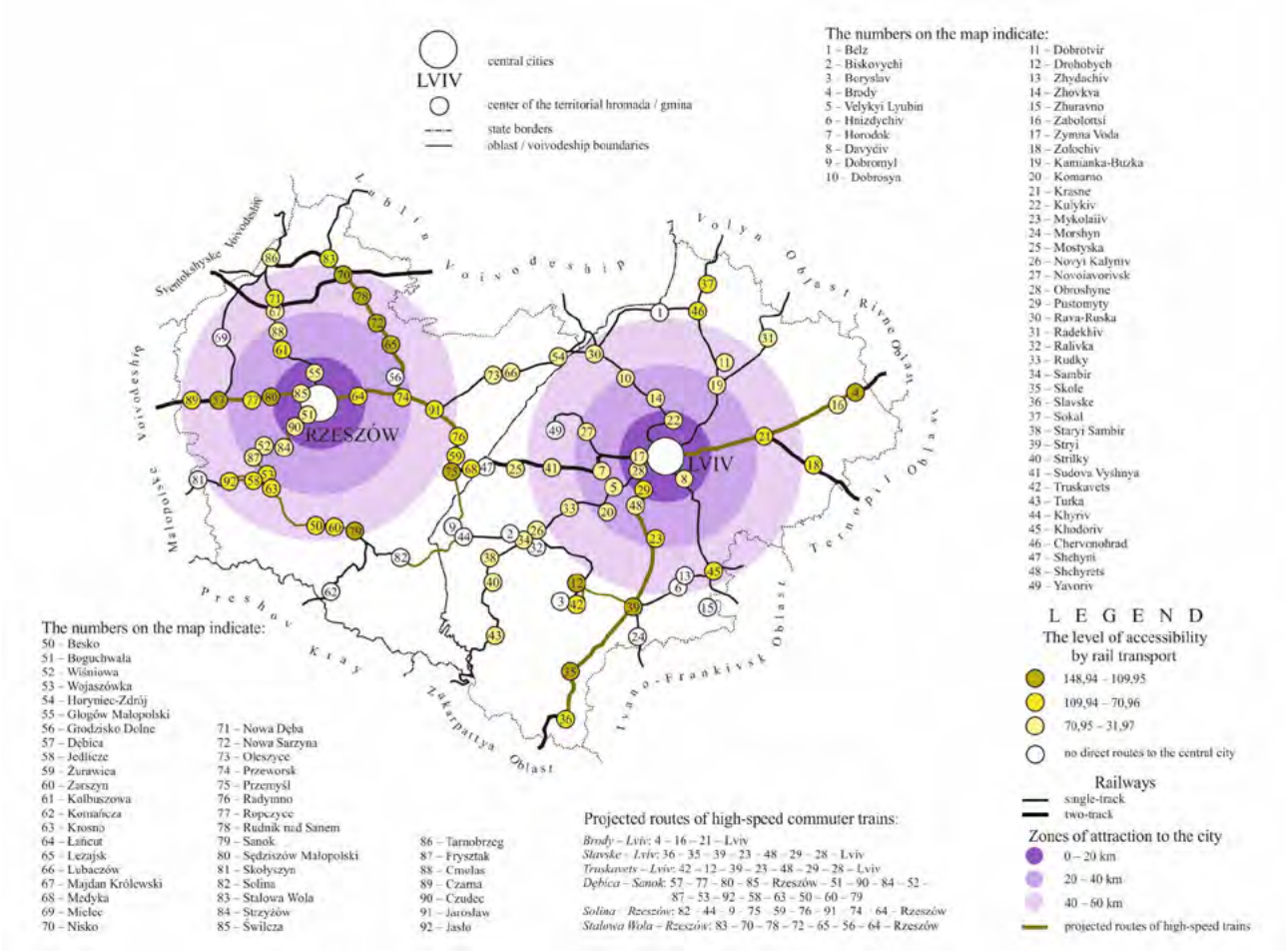

Fig. 2. Accessibility by railways in the Lviv Oblast and Subcarpathian Voivodeship (on the example of suburban transport)

cess are located near the city of Rzeszów (Tyczyn – 10 km, Łańcut – 17 km). Of the ten settlements with the poorest access to the voivodeship capital, there can be pointed out Radymno and Przeworsk, and the Medyka village. Low availability of the roadway network is compensated by functioning of the railway section Rzeszów – Przeworsk – Jarosław – Przemyśl – Medyka. Thanks to commercial contracts with local authorities, transportation is provided by commuter trains Rzeszów – Przemyśl (Medyka) – Rzeszów. Furthermore, state contracts for transport services also included transportation to destinations with a road access rating exceeding 80 (Jarosław, Oleszyce, Czarna, Wojaszówka, Lubaczów, Horyniec-Zdrój, Leżajsk, Jedlicze, Wiśniowa, Nowa Sarzyna, Sanok). Low level of railroad access to Rzeszów was observed for Nisko, Rudnik nad Sanem, Nowa Sarzyna, Leżajsk, Sędziszów Małopolski, Dębica, Sanok, Stalowa Wola, Przemyśl, Nowa Dęba, Ropczyce, Kolbuszowa, Jarosław, Łańcut, Zarszyn, Jasło, Besko, Przeworsk, and Radymno. Also, there could be named points with stations, but still with no public-transport connection (Grodzisko Dolne, Komańcza, Olszanica, Mielec, and Skołyszyn).

Among the settlements closest to Lviv, Novyi Rozdil and Maheriv were found to be the least connected to it. This problem stems from their locations in peripheral zones away from highways and lack of branching of the local roadways. A solution would be laying a Novyi Rozdil – Maheriv highway along the Opillia-Roztocze Hills. In this case, the southern part of the Lviv agglomeration would be connected to the northern one through the hromadas of Stryi, Lviv, and Yavoriv districts. Further, the Novyi Rozdil – Maheriv highway should be connected to other international highways: from Novyi Rozdil to M30 in the city of Khodoriv and from Maheriv to M09 in the city of Rava-Ruska. Thus, the two cities would be connected to each other in the outskirts, opening other logistical opportunities (we should note that Khodoriv and Rava-Ruska are conjunctions in the railroad network) (Shabliy, 2021; Borsuk, 2021).

A similar concept can be realized in Subcarpathian Voivodeship from Wielkie Oczy, with a ramification in two directions – northern (to Nisko) and southern (to Przeworsk). The northern direction Wielkie Oczy – Nisko would be laid through Lubaczów, Oleszyce, Stary Dzików, Adamówka, Kuryłówka, Krzeszów, Rudnik nad Sanem, with a junction with S19. The advantage of the Nisko conjunction is the presence of a 1,520 mm-track-wide railroad in the direction of Volyn Oblast, to the Izov Station (Fig. 2). The southern direction should be designed from the Wielkie Oczy village to the city of Przeworsk through Laszki, Radymno, Chłopice, and Roźwienica. At the same time, Wielkie Oczy can be made into a checkpoint on the Ukrainian side. Therefore, in Lviv Oblast, a border checkpoint could be organized in the Bozha Volia village of Yavoriv District.

Connection of some centres would be best improved with a railway infrastructure. This is relevant for pre-mountain settlements of the both territories. In Lviv Oblast, from the city of Drohobych to the oblast centre, transportation is carried out by long-distance and commuter trains. A problem is the long travel time of the Truskavets – Lviv commuter trains (the shortest travel time is 2 h, 3 min). This is due to high curvature of the route, and also the need to make stops in most of the settlements. The travel time could be decreased by making fewer stops on the route. For example, there could be commuter daytime trains, stopping in settlements with over 2 thou population and a station and settlements with over 1 thou population and an existing station. In our case, high-speed trains Truskavets – Lviv would make stop at the determined points: stations Stebnyk, Drohobych, Verhni Haii (Drohobych hromada); station Stryi (Stryi); stations Bilche-Volytsia, Pisochna (Mykolaiv); stations Mykolaiv-Dnistrovskyi (Rozvadiv); station Shchyrets-1, station Shchyrets-2 (Shchyrets); and station Sknyliv (Lviv hromada). Train traffic on such routes should be financed from the budget of the territorial communities. If some administrative-territorial authorities refuse to sign agreements to pay for services, it is recommended not to establish train stops in those settlements.

In a similar way, in Subcarpathian Voivodeship, there has been established a commuter connection between the cities of Stalowa Wola and Rzeszów. High curvature of the railway forms an interline-transfer scheme for commuter trains in Przeworsk. Traffic of projected electric multiple units Stalowa Wola – Rzeszów can be sped up, making stops at Nisko, Rudnik nad Sanem, Nowa Sarzyna, Jelna, Leżajsk, Wierzawice, Grodzisko Dolne, Gniewczyna, Przeworsk, Grzęska, Kosina, Łańcut, Krzemienica, and Strażów. Logically, this route should be further continued to the city of Dębica. In the similar way, it would be necessary to connect Dębica and Sanok via Rzeszów. Then, it would be practical to establish a transborder train route Solina – Rzeszów through the Ukrainian territory (Khyriv, Dobromyl).

Conclusions

The objective of this study was determining topological (spatiotemporal) roadway and railway accessibilities from a local centre (of a hromada or gmina) to the administrative capitals (of the oblast or voivodeship) in two countries – Ukraine and Poland. To achieve the objective, distances between cartographic objects were measured, along with travel time, curvature, and travel speed. Analysis of the results confirmed that the roadway curvature in mountainous areas of Subcarpathian Voivodeship is higher than in Lviv Oblast, thus refuting the hypotheses that the roadway network in Subcarpathian Voivodeship provides a better accessibility. Actually, the mobility of the population is provided by the commuter trains, which are commissioned by local authorities from a railway transporter. Also, there was revealed that the central part of Rzeszów is easier to reach from its suburban zone than the downtown of Lviv from its outskirts.

Taking the aforesaid into account, we need to consider some possible solutions to the problems in the roadway and railway networks in Lviv Oblast. For the settlements with the lowest roadway access to Lviv (Pidkamin, Novyi Rozdil, Maheriv), there should be laid new roadways with lower curvature and faster travel speed. In the same way, there should be developed a project of the Novyi Rozdil – Lviv – Maheriv – Rava-Ruska roadway as an Opillia-Roztocze border highway with a connection to a border checkpoint. In the mountainous area, the lowest level of roadway accessibility was observed for the Turka and Borynia hromadas. This problem can be solved by high-speed trains from those communities to Lviv. Also, there should be assigning of commuter trains with high comfort in the connections Truskavets – Lviv, Brody – Lviv, Slavske – Lviv, Nisko – Dębica, and Dębica – Sanok. All costs for passenger transportation should be paid by the local authorities, i.e. territorial communities on the train routes.

References

Azimov, P. (2017). The State of the World Transport and Logistics Infrastructure and Transport and Logistics Services Market. Journal of new economy, 6 (74), 52–63.

Bensassi, S., Marquez-Ramos, L., Martinez-Zarzoso, I., Suarez-Burguet, C. (2015). Relationship between logistics infrastructure and trade: Evidence from Spanish regional exports. Transportation Research Part A: Policy and Practice, 72, 47–61, https://doi.org/10.1016/j.tra.2014.11.007.

Borsuk, Y. (2019). Suspilno-heohrafichni problemy transportnoho spoluchennia u zoni tiazhinnia velykykh i serednikh mist (na prykladi Lvivskoi oblasti) [Social-geographical problems of transport connection in the zone of large and medium-sized cities (on the example of Lviv Oblast)]. Realities, problems and prospects of geography development in Ukraine: Proceedings of the XX All-Ukrainian Student Scientific Conference (Lviv, May 15–17, 2019), 67–71 (in Ukrainian).

Borsuk, Y. (2020). Ekonomiko-heohrafichna kharakterystyka prymiskoho zaliznychnoho transportu v umovakh zbytkovosti (na prykladi Lvivskoi oblasti) [Economic and geographical characteristics of suburban railway transport in the conditions of unprofitability (on the example of Lviv Oblast)]. Economic and social innovations as a factor in economic development: Coll. mater. II International. scientific-practical conf. (Zaporizhzhya, June 27, 2020), 34–40 (in Ukrainian).

Borsuk, Y. (2021). Suspilno-heohrafichni problemy transportnoho spoluchennia zakhidnoukrainskoho prykordonnia z krainamy-susidamy Yevropeiskoho Soiuzu v konteksti rozvytku mizhnarodnoho turyzmu [Social-geographical problems of the transport connection between the western Ukrainian borderland and the neighbouring countries of the European Union in the context of the international tourism development]. Scientific debates and prospective orientations of scientific development: collection of scientific papers «ΛΌΓΟΣ» with materials from the II International Scientific and Practical Conference (Vol. 2), Paris, October 1, 2021, 109–115, doi.org/10.36074/logos-01.10.2021.v2.34 (in Ukrainian).

Borsuk, Y. (2022). Suspilno-heohrafichni chynnyky transportnoi infrastruktury v konteksti rozvytku turyzmu pid chas voiennoho stanu v Ukraini [Social-geographic factors of transport infrastructure in the context of tourism development during martial law in Ukraine]. Interdisciplinary integration processes in the system of geographic, tourism, and environmental science: materials of the 3rd international scientific and practical conference dedicated to the 30th anniversary of the Department of Ukraine's Geography and Tourism at Ternopil National Pedagogical University named after Volodymyr Hnatyuk, October 4–5, 2022, 31–33 (in Ukrainian).

Detsentralizatsiia (2022). Hromady Lvivskoi oblasti [Territorial communities of the Lviv Oblast]. (in Ukrainian). Retrieved from https://decentralization.gov.ua/areas/0322/gromadu.

Hrytsevych, V. (2009). Kryvyzna avtotransportnoho prostoru Lvivskoi oblasti [Curvature of roadway space of Lviv Oblast]. Scientific notes of TNPU. Ser. Geography. 1, 50–55 (in Ukrainian).

Hrytsevych, V., Senkiv, M. (2014). Topolohiia i metryka avtotransportnoho prostoru yak chynnyk transportno-lohistychnoi diialnosti u Zakhidnomu rehioni Ukrainy [Topology and metrics of roadway space as a factor of transport and logistics activities in the Western region of Ukraine]. Geopolitics and ecogeodynamics of regions. 10, 2, 483–488 (in Ukrainian).

Kuzyk, S., Borsuk, Y. (2018). Praktychne vykorystannia heolohistyky v transportnii haluzi Zakhidnoho rehionu Ukrainy [Practical use of geologistic in the transport industry of the Western region of Ukraine]. Visnyk of the Lviv University. Series Geography, 52, 152–162, dx.doi.org/10.30970/vgg.2018.52.10181 (in Ukrainian).

Kuzyk, S., Borsuk, Y. (2020). Formuvannia prymiskykh zaliznychnykh perevezen u Zakhidnomu rehioni Ukrainy [Formation of suburban railway transportation in the Western region of Ukraine]. Scientific economic journal «Intellect XXI», 5, 51–55, doi.org/10.32782/2415-8801/2020-5.9 (in Ukrainian).

Mukhtarova, K., Ospanov, S., Sharapiyeva, M. Antoni, A. (2018). The Evaluation of the Efficiency of Transport and Logistics Infrastructure of Railway Transport. Scientific Journal of Maritime Research, 32, 88–101.

Senkiv, M., (2014). Kryvyzna avtotransportnoho prostoru yak chynnyk transportnoi lohistyky u Zakhidnomu rehioni Ukrainy [Curvature of roadway space as a factor of transport logistics in the Western region of Ukraine]. Ukraine and the world: social-geographical dimensions: collection of works of the Ukrainian scientific-practical conference of young scientists, graduate students and students, dedicated to the 200th anniversary of the birth of Taras Shevchenko (Lviv, February 26–28, 2014), 383–390 (in Ukrainian).

Shabliy, O. (2021). Suspilna heohrafiia. Kn. 5. Na vazheliakh doli [Human geography. Book 5. On the scales of fate], 666 (in Ukrainian).

Shabliy, O., Borsuk, Y. (2021). Heolohistychni aspekty zaliznychnykh pasazhyrskykh perevezen v Ukraini [Geologistic aspects of railway passenger transportation in Ukraine]. Journal of socio-economic geography. 31, 37–46, doi.org/10.26565/2076-1333-2021-31-03 (in Ukrainian).

Ukrainska zaliznytsia (2022). Rozklad rukhu prymiskykh poizdiv [Schedule of suburban trains] (in Ukrainian). Retrieved from https://www.uz.gov.ua/passengers/suburban_train_schedule/.

Wikipedia. Free encyclopedia (2022). Spysok mist Pidkarpatskoho voievodstva [List of cities of Subcarpathian Voivodeship] (in Ukrainian). Retrieved from https://uk.wikipedia.org/wiki/Список_міст_Підкарпатського_воєводства.