

SPATIAL FEATURES OF THE ROAD NETWORK IN WESTERN UKRAINE**¹Sergii PUHACH, ²Oksana YAROMENKO, ²Nina MYRONETS***¹Lesya Ukrainka Volyn National University, Lutsk, Ukraine**²Academician Stepan Demianchuk International University of Economics and Humanities, Rivne, Ukraine**¹puhachserhiy@gmail.com*

Abstract: The road network is an important part of the transport system that ensures the operation of all industries, agriculture and social sphere. Road maintenance costs can be from 5 to 10% of the state budget per year. On the other hand, it should be noted that vehicle owners make significant contributions to the state budget of Ukraine through direct and indirect taxes. The road network has a lot of problems in terms of efficient functioning. One of the main problems is insufficient financing of road repair works. The aim of the study is to determine the spatial features of the road network of Western Ukraine, and the main task - to analyze, based on open data OpenStreetMap, the accessibility of the road network in the context of regions, districts and cities of regional subordination of Western Ukraine using as the indicators the transport network density and the Engel's coefficient. Due to the difficulty of accessing official statistics at the local level, both official statistics and open data from the OpenStreetMap mapping service were used. As a result of the research it was revealed: relatively even distribution over the territory, lack of sharp fluctuations in the availability level (the maximum and minimum value of the Engel's coefficient differs only by 5.7 times); the most important roads (primary and secondary) connect regional centers and the largest cities with each other and with the state border; the largest road hub in Western Ukraine is the city of Lviv; among the districts, the highest accessibility of roads is observed in the western part of Volyn oblast, western and central parts of Chernivtsi oblast and southern part of Rivne oblast; increased concentration of roads in Precarpathian (an area of old industrial development); reduced concentration in the Ukrainian Carpathians and in the northeast of the region (north of Rivne region). In general, at the local level (districts, cities of regional subordination) the same patterns can be observed as at the regional level (regions).

Key words: road, road network, transport network density, Engel's coefficient, Western Ukraine.

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ПРОСТОРОВІ ОСОБЛИВОСТІ ФУНКЦІОНУВАННЯ МЕРЕЖІ АВТОМОБІЛЬНИХ ДОРІГ У ЗАХІДНІЙ УКРАЇНІ**¹Сергій ПУГАЧ, ²Оксана ЯРОМЕНКО, ²Ніна МИРОНЕЦЬ***Волинський національний університет імені Лесі Українки, Луцьк, Україна**Міжнародний економіко-гуманітарний університет імені академіка Степана Дем'янука, Рівне, Україна**¹puhachserhiy@gmail.com*

Анотація: Мережа автомобільних доріг є невід'ємною частиною єдиної транспортної системи, що забезпечує роботу всіх галузей промисловості, сільського господарства та соціальний розвиток суспільства. Значимість автомобільних доріг відображає той факт, що витрати на їх утримання кожного року можуть поглинати від 5 до 10% державного бюджету. З іншого боку, слід зазначити, що власники транспортних засобів через прями та непрямі податки роблять значні внески до державного бюджету України. Мережа автомобільних доріг має ряд проблем щодо ефективного функціонування. Однією з головних проблем є недостатнє фінансування дорожньо-ремонтних робіт.

Метою дослідження є визначення просторових особливостей функціонування мережі автомобільних доріг у Західній Україні, а основним завданням – на основі відкритих даних OpenStreetMap, проаналізувати забезпеченість мережею автомобільних доріг у розрізі областей, районів та міст обласного підпорядкування Західної України за допомогою показників щільності транспортної мережі та коефіцієнт Енгеля. У зв'язку з труднощами доступу до офіційної статистичної інформації на локальному рівні, використовувалися як офіційні статистичні дані, так і відкриті дані картографічного сервісу OpenStreetMap.

У результаті дослідження виявлено такі просторові особливості: відносно рівномірний розподіл по території, відсутність різних коливань рівня забезпеченості (максимальне та мінімальне значення коефіцієнта Енгеля відрізняється лише у 5,7 разів); найважливіші дороги (міжнародні, національні) з'єднують між собою обласні центри та найбільші міста з державним кордоном й між собою; найбільшим автомобільним вузлом регіону є м. Львів; серед районів найбільша забезпеченість автошляхами спостерігається у західній частині Волинської, західній та центральній частинах Чернівецької, південній частині Рівненської областей; підвищена концентрація автошляхів у Передкарпатті (район давнього промислового освоєння); понижена концентрація в Українських Карпатах та на північному сході регіону (північ Рівненської області). Загалом, на локальному рівні (райони, міста обласного підпорядкування) можна спостерігати ті ж патерни, що й на регіональному рівні (області).

Ключові слова: автомобільна дорога, мережа автомобільних доріг, щільність транспортної мережі, коефіцієнт Енгеля, Західна Україна.

Introduction. Transport networks, as well as their characteristics and possibilities for the transportation of passengers and cargo, have always been a determining factor in the socio-economic development of settlements, regions and entire countries in general.

The road network is an important part of the transport system that ensures the operation of all industries, agriculture and social sphere. In addition, roads provide uniform access to different places of communities, districts, regions, countries. They also ensure the safe and reliable movement of people and goods. Motor roads are one of the subsystems of the country's economic system, a public product and have a great importance. The state of highways determines the transportation costs of goods and passengers, the prices level, to some extent the employment of the population, the rate of development of the regional and national economy. In turn, the condition of roads depends on economic opportunities and the level of road construction financing.

Road maintenance costs can be from 5 to 10% of the state budget per year. On the other hand, it should be noted that vehicle owners make significant contributions to the state budget of Ukraine through direct and indirect taxes.

The road network has a lot of problems in terms of efficient functioning. One of the main problems is insufficient financing of road repair works. Writing programs and projects of socio-economic growth is impossible without an analysis of the current state and prospects for the development of road transport, a study of the mutual influence of the motor transport network and the entire socio-economic system in general. That is why we consider the research topic is relevant and one that requires further research.

Purpose of the study. The purpose of the study is to determine the spatial features of the road network in Western Ukraine, and the main task is to analyze the availability of the road network in the context of oblasts, districts and cities of regional subordination of Western Ukraine, based on OpenStreetMap open data using the indicators the transport network density and the Engel's coefficient.

Literature review. The study of transport networks has long traditions dating back to the 19th century. Among the first researchers of communication routes were such scientists as J. Kohl, L. Lalanne, E. Engel, L. Henkel (Tarhov, 2006). In those years, L. Lalanne formulated the first laws for the development of transport networks on the example of railways (Lalanne, 1863). There are a large number of publications on the functioning of road transport and its networks in the English scientific literature (Docherty & Shaw, 2008; Jamroz, 2012; Rodrigue, 2020; Wang et al., 2020; etc.).

Such scientists as Z. Gerasymchuk, V. Hrytsevych, L. Makovetska, O. Pikulyk, S. Puhach, H. Senchuk, M. Senkiv, G. Smirnov and others dealt with issues of the functioning and development of the road transport network in Western Ukraine. In particular, V. Hrytsevych and H. Senchuk studied the motor vehicle network in the

context of European integration (Hrytsevych & Senchuk, 2010), the curvature of the motor vehicle space (Hrytsevych & Senchuk, 2009; Hrytsevych & Senchuk, 2011b), polytransport (a combination of road and rail transport in a certain areas) highways of the Carpathian region of Ukraine (Hrytsevych & Senchuk, 2011a). O. Pikulyk analyzed the spatial aspects of transport infrastructural support of the socio-economic development of the Western region of Ukraine (Pikulyk, 2009). M. Senkiv made a geologicistic description of the Western region of Ukraine (Hrytsevych & Senkiv, 2015; Senkiv, 2016; Senkiv, 2017), in particular, she analyzed road and railway networks using graph theory and cartographic GIS modeling. V. Hrytsevych and M. Senkiv studied the topology and metrics of the motor vehicle space in the Western region of Ukraine (Hrytsevych & Senkiv, 2014).

Data and methods. There are certain difficulties with access to official statistical information at the local level. In this regard, in our research we used both official statistical data (Petrenko, 2020; Verner, 2019) and open data from the OpenStreetMap mapping service (Geofabrik, 2020). Since different roads have different importance for the development of the territory, we have carried out the normalization procedure. During normalizing, the following weight coefficients were used for different classes of roads: trunk – 1.25, primary – 1.25, secondary – 1.0, tertiary – 0.75, unclassified – 0.75. The calculation of the total length of the road network was carried out in the GIS package QGIS Desktop 2.14.9.

The level of accessibility of the territory by roads was recognized using two indicators: transport network density and Engel's coefficient. The *transport network density* D_s , was calculated as the multiplication of the network length L and the area of the territory S . The *Engel's coefficient* D_e , was calculated as the division of the network length L by the square root of the product of the land area S by the population that living in it P (Dudnyk, 2016).

The territorial units of the second rank of the "old" administrative-territorial division of Ukraine, which existed until July 17, 2020, were chosen as the basic units of the study.

Main findings. The main mode of transport in Ukraine is road transport. Accordingly, the main communication network in Western Ukraine is the road network. It has a long history of formation and its development continues today. Some sections of roads fall into decay, while others are acquiring new impulses of development. The main factors influencing the development of transport networks, including the road network, are natural (primarily relief, hydrological network, hydrogeological conditions), settlement system (communication routes connect first of all places with population concentration), the level of socio-economic development (communications have a relatively high cost of construction and subsequent operation; therefore, more developed territories have better transport networks), administrative-territorial division (a connection can be found between the hierarchy (quality) of roads and the

rank of administrative centers which they connect), international division of labor and cross-border cooperation (international communications are the best in terms of quality), etc.

The total length of public roads in Western Ukraine is 35,200 km (Petrenko, 2020). This is 21.7% of Ukrainian roads, while the share of the Western Ukraine in the area of Ukraine is 18.3% (Verner, 2019). Lviv oblast has the longest road length (8,400 km). Volyn oblast takes the second place in the rank (6,200 km). The shortest lengths of roads are in Zakarpattia oblast (3,400 km) and Chernivtsi oblast (2,9 km) (Table 1).

However, the absolute indicators of the length of the road network are not very informative. It is quite expected that the longest length of roads is observed in the Lviv oblast (the largest area, the most developed region). The second place of the Volyn oblast is explained by its relatively large area in combination with powerful transit international highways. Zakarpattia and Chernivtsi oblasts have the shortest length of roads, as they are small in area. In addition, a significant part of the territory of Zakarpattia, Ivano-Frankivsk, and Chernivtsi oblasts is occupied by the mountain massifs of the Ukrainian Carpathian Mountains. The total length of roads in the mountains is much less than in the plains.

It is better to analyze the level of accessibility of the region to roads using the road network density indicator. In general, Western Ukraine is characterized by a higher density of roads compared to Ukraine (318.2 versus 268.2 km/1000 km²).

The highest density of roads was recorded in Lviv (384.8 km/1000 km²), Ternopil (361.7 km/1000 km²) and Chernivtsi (358.2 km/1000 km²) oblasts. Such high rates are a consequence of the large total length of road (Lviv oblast), as well as due to the small total area of the territory of the oblast (Ternopil, Chernivtsi oblasts). The lowest roads densities are in Zakarpattia (266.6 km/1000 km²) and Rivne (259.3 km/1000 km²) oblasts. These oblasts have lower indicators of the road network density than the average for Ukraine. The reason for this may be the lower development level of the territory (mountainous areas of Zakarpattia oblast, large areas of forests and swamps in the Rivne oblast).

In addition to the roads length and the land area, the level of accessibility to the road network is also affected by the population size. Regions with a larger population need a denser transport network. To calculate the accessibility availability of roads in the territory, we used E. Engel's formula. Volyn (1.360) and Ternopil (1.319) oblasts have the highest level of accessibility to the road network among the oblasts of Western Ukraine according to the Engel's coefficient. These oblasts have a relatively small population. The Lviv oblast (1.134) also has value higher than the average for Western Ukraine. The lowest values of the Engel's coefficient are typical characteristic for the densely populated Ivano-Frankivsk (0.939) and Zakarpattia (0.850) oblasts.

At the local level, we can see more clearly the features of the territorial differentiation of the transport network. Roads are part of a basic framework of the

Table 1

Main indicators of the road network in Western Ukraine*

| Indicator | Volyn oblast | Zakarpattia oblast | Ivano-Frankivsk oblast | Lviv oblast | Rivne oblast | Ternopil oblast | Chernivtsi oblast | Western Ukraine | Ukraine |
|---|--------------|--------------------|------------------------|-------------|--------------|-----------------|-------------------|-----------------|---------|
| Population (1.01.2020, thous. people) | 1032.2 | 1254.3 | 1368.8 | 2513.8 | 1153.7 | 1039.7 | 901.9 | 9264.4 | 41940.7 |
| Share in the population of Ukraine (%) | 2.5 | 3.0 | 3.3 | 6.0 | 2.8 | 2.5 | 2.2 | 22.1 | 100.0 |
| Total area (km ²) | 20144 | 12753 | 13927 | 21831 | 20051 | 13824 | 8096 | 110626 | 603549 |
| Share in the area of Ukraine (%) | 3.3 | 2.1 | 2.3 | 3.6 | 3.3 | 2.3 | 1.3 | 18.3 | 100.0 |
| Length of public roads (thous. km) | 6.2 | 3.4 | 4.1 | 8.4 | 5.2 | 5.0 | 2.9 | 35.2 | 161.9 |
| Length of public roads (%) | 3.8 | 2.1 | 2.5 | 5.2 | 3.2 | 3.1 | 1.8 | 21.7 | 100.0 |
| Road network density (km/1000 km ²) | 307.8 | 266.6 | 294.4 | 384.8 | 259.3 | 361.7 | 358.2 | 318.2 | 268.2 |
| Engel's coefficient | 1.360 | 0.850 | 0.939 | 1.134 | 1.081 | 1.319 | 1.073 | 1.100 | 1.018 |

* Compiled and calculated by the authors based on (Petrenko, 2020; Verner, 2019)

territory. These are the channels through which the majority of modern material communications between settlements are carried out. Motor roads are present in all territories without exception. Any modern settlement has car entrances to all objects, buildings and structures. Today, a popular statement asserts that “modern cities are made for cars, not for people”. That is why the current stage of human development is sometimes called the “automotive” stage.

The total (total) length of roads in Western Ukraine is 50,227.5 km (42,106.0 km after normalization). After normalization, the total length of roads decreased by

16.2%. This indicates that the basis of the road network consists of district and local roads. As a rule, these roads are of low quality. The longest length of roads (more than 600 km) is observed in the Storozhynets (Chernivtsi oblast), Rivne (Rivne oblast), Yavoriv (Lviv oblast), Kovel, Horokhiv (Volyn oblast) districts (Fig. 1). These are large administrative districts, adjacent to cities of regional subordination (except Horokhiv district), which have a dense settlement network and a high level of socio-economic development (Dzhaman, 2003; Pikulyk, 2009; Puhach, 2021; Semenov, 2008; etc.).

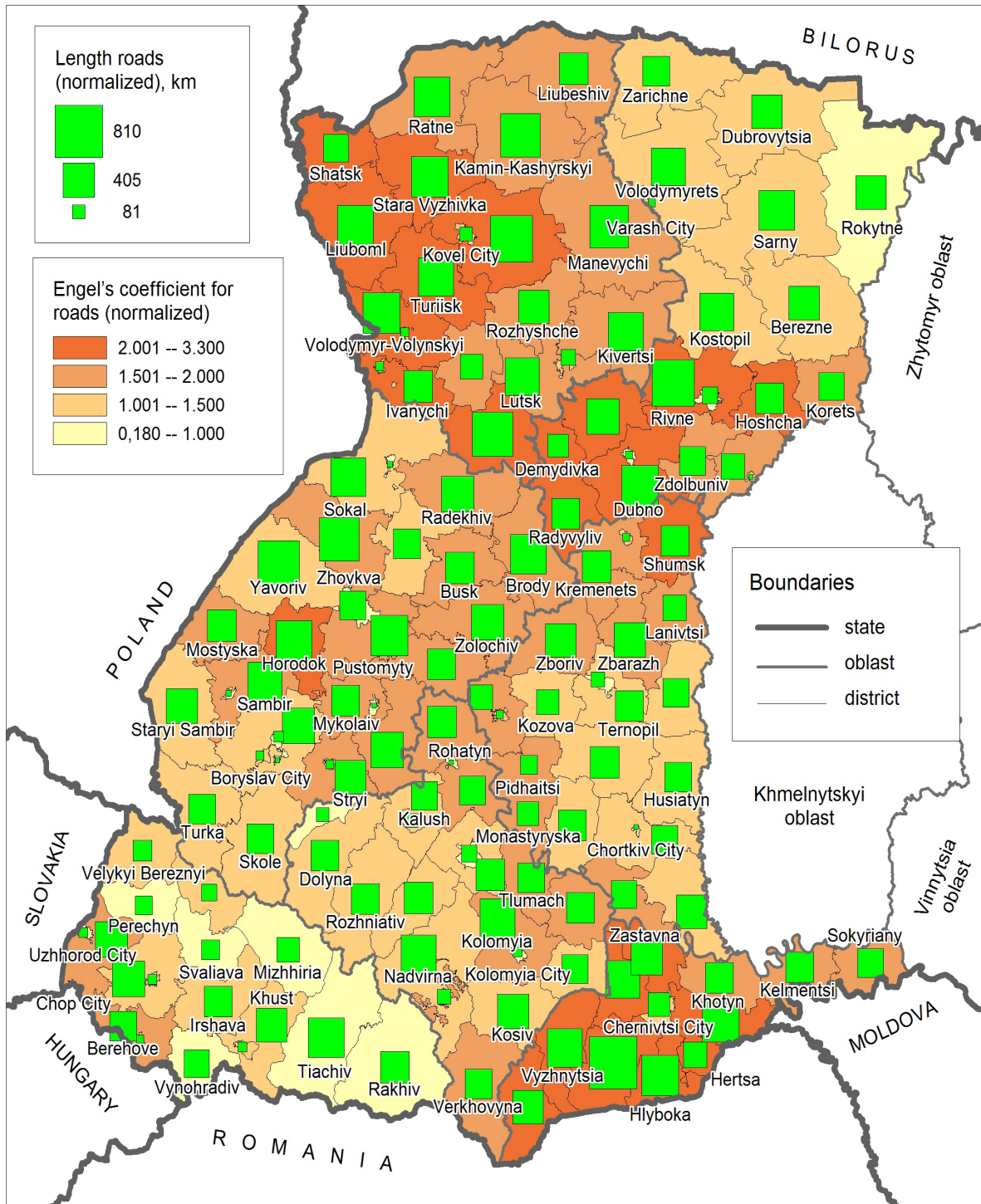


Fig. 1. Road network in Western Ukraine

In Western Ukraine, 15 administrative districts have the length of roads from 500 to 600 km (Fig. 1). Six of them are located in the Volyn oblast (Kamin-Kashyrskiy, Manevychi, Stara Vyzhivka, Volodymyr-Volynskiy, Liuboml, Ratne districts), four are in the Lviv oblast (Zhovkva, Pustomyty, Horodok, Brody districts), two are in the Rivne oblast (Dubno, Sarny districts) and two are in the Chernivtsi oblast (Hlyboka, Novoselytsia districts). Ivano-Frankivsk, Ternopil and Zakarpattia oblasts do not have administrative districts with long roads. This can be explained by the presence of mountainous areas where road construction is difficult (Ivano-Frankivsk and Zakarpattia oblasts) and the small areas of the most administrative districts (Ternopil oblast).

20 districts have a total length of roads within 400-500 km; 39 administrative units - from 300 to 400 km; 24 districts - within 200-300 km, 38 administrative-territorial units have less than 200 km of roads. On average, in Western Ukraine, one administrative-territorial unit of the second level (district or city of regional subordination) has 356.2 km (298.6 km of normalized) motor roads.

According to the indicator of road network density (km/1000 km²), the highest values were recorded in the cities of regional subordination. Indicators vary from 942.5 (Khust) to 2433.9 (Luts'k) km/1000 km². The small area of the cities, combined with the concentration of socio-economic activity, requires intensive development of roads.

The highest indicators of the road network density (500-800 km/1000 km²) among administrative districts have seven districts of Chernivtsi oblast (Hlyboka, Hertsa, Kitsman, Novoselytsia, Storozhynets, Zastavna, Vyzhnytsia), three districts of Lviv oblast (Horodok, Pustomyty Mykolaiv), three districts of Volyn oblast (Horokhiv, Ivanychi, Volodymyr-Volynskiy), one district of Rivne oblast (Rivne), one district of Zakarpattia oblast (Uzhhorod). These are predominantly small territorial formations with a high level of socio-economic development and an advantageous transport-geographical location.

High road density (400-500 km/1000 km²) is observed in 36 districts; average indicators (300-400 km/1000 km²) are recorded in 34 administrative districts; the lowest indicators (less than 300 km/1000 km²) have 23 territorial units. All areas with a low roads density are located either in the Ukrainian Carpathians, or they are large peripheral districts with a low development level and a geographical disadvantage (Fig. 1). On average, a second-level administrative-territorial unit in Western Ukraine has a road density of 627.2 km/1000 km².

Compared to the road density, the Engel's coefficient shows a slightly different pattern. Its highest values (over 2.0) are observed in 24 districts, such as: Volodymyr-Volynskiy, Stara Vyzhivka, Turiisk, Horokhiv, Kovel, Ivanychi, Shatsk, Liuboml (Volyn oblast), Putyla, Hlyboka, Storozhynets, Hertsa, Zastavna,

Kitsman, Novoselytsia, Vyzhnytsia (Chernivtsi oblast), Demydivka, Mlyniv, Hoshcha, Rivne, Radyvyliv, Dubno (Rivne oblast), Dubno (Lviv oblast), Shumsk (Ternopil oblast). Geographically, these are mainly the areas of the western part of Volyn oblast, the western and central parts of Chernivtsi oblast and the southern part of Rivne oblast (Fig. 1).

Descending to the lower parameter values, 43 administrative-territorial units have relatively high values of the Engel's coefficient (1.50-2.00), and 48 territorial units of Western Ukraine have an indicator within 1.00-1.50. The lowest values (Engel's coefficient 0.50-1.00) have 26 territorial units (19 cities of regional subordination and 7 districts). These are the districts of the Zakarpattia oblast (Mizhhiria, Perechyn, Rakhiv, Velykyi Bereznyi, Svaliava, Tiachiv) with significant mountainous areas. This group also includes the peripheral Rokytne district of the Rivne region which has significant forestal areas and nature reserves.

The average value of the Engel's coefficient for road network of second-level administrative-territorial units in Western Ukraine is 1.507. It divides the data array into two almost equal parts 47.5% and 52.5%. There is a uniform distribution and the absence of sharp fluctuations in the index of the Engel's coefficient between administrative and territorial units.

Conclusions. The following spatial patterns are found in the distribution of road network in Western Ukraine (Fig. 1):

- 1) relatively even distribution over the territory, lack of sharp fluctuations in the availability level (the maximum and minimum value of the Engel's coefficient differs only by 5.7 times);
- 2) the most important roads (primary and secondary) connect regional centers and the largest cities with each other and with the state border;
- 3) the largest road hub in Western Ukraine is the city of Lviv;
- 4) among the districts, the highest accessibility of roads is observed in the western part of Volyn oblast, western and central parts of Chernivtsi oblast and southern part of Rivne oblast;
- 5) increased concentration of roads in Precarpathian (an area of old industrial development);
- 6) reduced concentration in the Ukrainian Carpathians and in the northeast of the region (north of Rivne region) due to the natural conditions.

Further research of the road networks should be directed to the study of its individual parts at the local and micro levels. This will make it possible to develop projects for optimizing the transportation of goods and passengers. An important aspect for further studies is also the quality of the road network and its reliability (the last is important from the point of view of contemporary Russian aggression). Modeling of passenger flows and cargo flows using graph theory is also promising.

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