

# SHIFTING THE POPULATION MOBILITY OF THE UKRAINE WESTERN REGION ON THE STRENGTH OF THE COVID-19 PANDEMIC

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## Abstract:

The Covid-19 pandemic has significantly affected the economic and social spheres of all countries. Restrictions introduced to reduce the risk of transmission have changed the structure of population movements. The impact of these restrictions on the characteristics of intercity travel is still an understudied problem. Based on the analysis of statistical data and the results of questionnaires, the article assesses the impact of pandemic restrictions on population mobility in the Western region of Ukraine and changes in the distribution of passenger flows between different modes (bus, rail, private transport, joint travel). In 2020, the volume of passenger traffic in the region decreased by an average of half compared to the previous year. The decline is sharper for rail passenger transport compared to the bus transport. For more developed railway networks, the impact of the pandemic on passenger traffic is more pronounced. Quarantine restrictions have also increased the share of own car travel. According to research, the distribution of intercity trips between modes is influenced by the age and sex of the traveler. During the pandemic, users of transport services who travel with children under the age of 14 choose private transport to travel more often than those who travel alone. The degree of influence of the above factors on the distribution of modes depends on the length of the trip. The application part of the work presents the results of modeling passenger flows of the studied region in the software environment PTV Visum. It was found that at the beginning of the quarantine restrictions the number of intercity trips decreases sharply. As the duration of restrictions increases, the rate of decline in mobility decreases. These data can be further taken into account when planning the work of transport enterprises and meeting the population's demand for travel. The practical application of the study results is that the identification of trends in the mobility of residents of the studying region depending on the impact of pandemic restrictions allows you to predict the mode and type of vehicles used. Based on these data, you can determine marketing strategies for the development of certain modes and directions of transportation.

**Keywords:** Intercity mobility, transport modelling, Covid-19 pandemic, mode choice, passenger flows

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## 1. Introduction

The Covid-19 pandemic, announced by the WHO in March 2020, has had a significant impact on the economic and social spheres of countries around the world. Governments in many countries have imposed restrictions to reduce the intensity of the virus. In particular, restrictions on population mobility (to reduce the number of social interactions). Mass passenger transport has become one of the main risk areas for virus transmission (Tirachini & Cats, 2020). One of the main consequences of the Covid-19 pandemic outbreak and related restrictions has been a sharp decline in travel and, as a result, reduced passenger traffic on urban and suburban routes. This reduction affects the financial condition of transport operators and their ability to provide quality services against the background of declining demand (Hörcher, Singh & Graham, 2020). Sustainable development of the region as a set of economic, social, and environmental parameters is impossible without the functioning of the transport industry.

The western region of Ukraine has a favorable geographical location, bordering four EU countries: Poland, Romania, Hungary, and Slovakia, as well as Moldova. Location and good recreational and tourist opportunities are the key vectors for the prospects of its sustainable development. An important parameter of this process is the transport system. Accordingly, it is important to study the factors influencing the change in intercity mobility in the region under the influence of Covid-19, and trends in this change. This study will anticipate changes in users' preferences for travel regimes and frequencies of trips and propose specific measures to reorganize and work resume transport operators after the pandemic.

The structural and logical scheme of the study is presented in Fig. 1. Analysis of literature sources reveals insufficiently open questions about the impact of the pandemic on intercity mobility. We analyzed statistical data for 2010 - 2020 on the volume and distribution of passenger traffic in the Western region of Ukraine in the pre-pandemic and pandemic periods. We also conducted a survey of transport service users. We have identified the main trends in the volume of passenger traffic under the influence of the pandemic. Then we formed the utility functions of the choice of passengers' mode of intercity travel. As a result of modeling in the software environment PTV Visum, we obtained the forecast volumes of passenger traffic in the study region.

## 2. Theoretical background

### 2.1. Intercity mobility research

The combination of socio-demographic factors, indicators of transport services, and characteristics of cities affect intercity mobility. Studies conducted by many authors confirm that the volume of intercity travel depends on the characteristics of households and individual users of transport services (age, gender, education, income, car availability), transport availability, size, and economic characteristics of the city (Arbués et al., 2016; Davidich et al., 2019; Davidich et al., 2020).

The authors Breyer, Gundlegård and Rydergren (Breyer et al., 2021) consider the possibility of using cellular network data to distribute intercity traffic between modes. The paper analyzes the movement between two pairs of Swedish cities to determine the share of road and rail travel. The authors compare the effectiveness of using different methods of calculating the cellular path and comparing it with the existing roadway or railway:

- geometry-based classification methods (Route/Antenna method, Route/Centroid method and Unique cells method);
- supervised mode classification methods (Likelihood method, k-nearest neighbor method and PCA/LDA method).

According to research results, in the case of nearby locations of highway and railway supervised mode classification methods give a more accurate result. In general, the analysis of the distribution of trips by mode based on data from the cellular network allows you to analyze the mode choice at different times of the day, different days of the week, and so on. The disadvantage is the difficulty of obtaining this data. In general, more and more research based on big data analysis has emerged in recent years. Based on the information of cellular operators, conducted an analysis of the distribution of traffic between air and surface transport between the two cities of Canada (Hui et al., 2017), estimated the volume of intercity traffic in France (Janzen et al., 2018), determined the structure of traffic between cities of China (Zhang et al., 2021) and Finland (Kiashemshaki et al., 2022). However, as the authors note in (Aultman-Hall & Ullman, 2020), analysts should supplement cellular data to analyze long-distance travel with survey data rather than relying solely on big data. The results of surveys just allow to link the characteristics of the trip with the socio-economic characteristics of users

of transport services and to determine the hidden demand for such movements.

Based on the analysis of surveys conducted in Xi'an (China), an assessment was made of the influence of 12 factors on passengers' mode choice of travel (air, high-speed rail, traditional passenger train, and express bus) (Li et al., 2020). The choice of passengers is influenced by travel distance, travel cost, travel time per 100 kilometers, quality of service, accessibility of transportation hubs, and ticketing methods. These studies are extended to paper (Xiaowei et al., 2021).

## 2.2. Impact of the Covid-19 pandemic on mobility

The Covid-19 pandemic has significantly changed the structure and volume of trips. The world is facing

this challenge for the first time and the lack of previous research has significantly limited the ability to predict the impact of the pandemic on various spheres of society, and mobility in particular. However, now we can talk about some developments in this direction.

Authors Wielechowski, Czech and Grzęda (Wielechowski et al., 2020) analyzes the results of the Covid-19 pandemic on the conditions of public transport in Poland. In particular, the authors investigated the correlation between strict government restrictions on coronavirus control and changes in mobility on public transport in different regions of Poland (correlation coefficient ranges from -0.72 to -0.86).

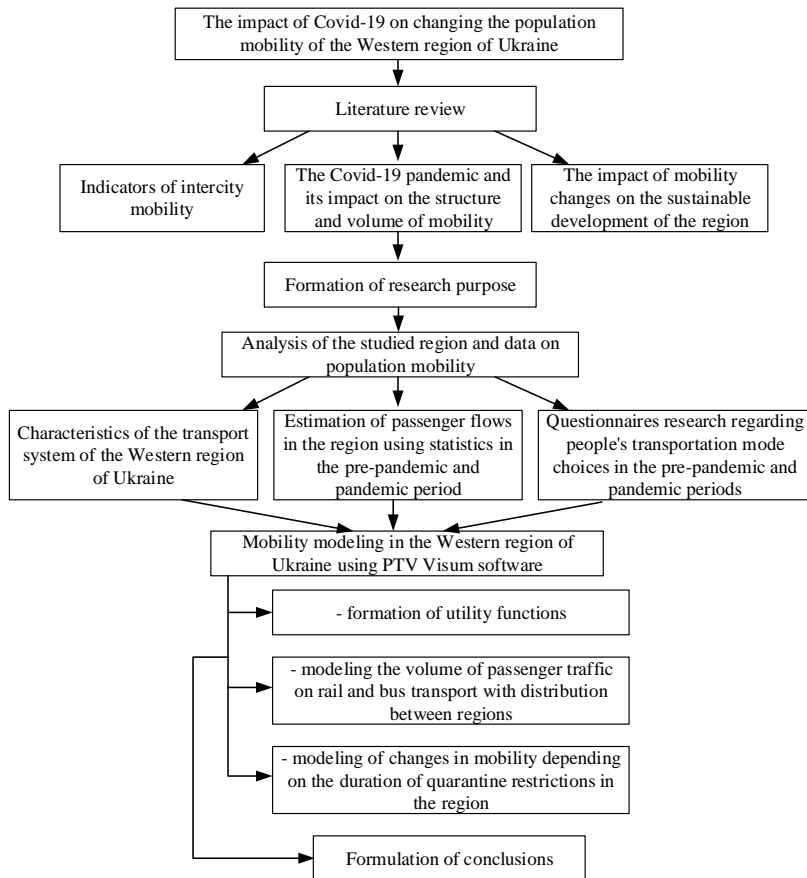


Fig. 1. Structural and logical scheme of the research

Studies conducted in Italy have been published by the (Carteni et al., 2021). The results of these studies confirm a strong correlation (up to 0.87) between Covid-19 and the count of public transport trips. The authors also note that the pandemic has changed access to mobility and affected social justice regarding mobility. People with a higher income who had an alternative (their vehicles) gained an advantage in mobility. Accordingly, the reluctance to use public transport has increased its negative impact on the environment due to the increasing use of private cars. A study of the impact of the pandemic and related restrictions on mobility and the distribution between modes was also carried out in Rome (Aletta et al., 2020).

Similar studies have been conducted in Sweden (Jenelius & Cebebauer, 2020), Australia (Beck, Hensher & Nelson, 2021), the Netherlands (de Haas, Faber & Hamersma, 2020), Spain (Aloi et al., 2020), China (emphasis on long-distance travel) (Li et al., 2021).

A study of the impact of the Covid-19 pandemic on mobility based on survey data from ten countries is presented in (Barbieri et al., 2021). These studies confirm the reduction in total passenger flow and the particularly negative impact of the pandemic on air transport and urban public transport.

There are also attempts to analyze possible ways to restore transport after a pandemic. According to them, airlines and railways have suffered the most from the pandemic (Christidis et al., 2021). The simulation results predict an increase in the share of private transport users in the European Union, which may negatively affect the development of public transport and environmental parameters.

### **2.3. The impact of mobility on the sustainable development of the region**

Sustainable development of the region implies development that meets the modern needs of society but does not jeopardize the ability of future generations to meet their needs. Concerning transport, sustainable development involves a systematic (economic, social, and environmental) approach and the use of modern information technology.

Authors (Jachimowski et al., 2015) propose a simulation model (planned to be implemented in the software environment PTV Visum for Poland), which can be used to assess the impact of various factors

on sustainability parameters, including the distribution of traffic between modes of transport and environmental impact. The proposed model of the transport system includes the model of the transport network and the model of demand for passenger and freight transport. Transport is divided into groups depending on the type and level of harmful emissions into the environment. The model can be used to predict changes in the attractiveness of different modes of transport for users under the influence, for example, changes in the parameters of the transport network. The impact of such decisions on the parameters of the environment and the sustainable development of the region as a whole can also be assessed. The authors (Jacyna-Gołda, Zak & Gołębiowski, 2015) consider three scenarios for the development of transport infrastructure (for example, Poland), taking into account environmental constraints and increasing passenger traffic, and predict the impact of these changes on the distribution of movements between types (rail, bus transport, and private car). The approach proposed in the paper confirms the validity of taking into account the requirements of sustainability when assessing the possibility of achieving social, environmental, and economic goals of the transport system. These studies were further developed in (Vakulenko et al., 2019).

### **2.4. Research statement**

Although there are many studies examining the parameters of population mobility, assessing the impact of a pandemic on transport is a new challenge for scientists. The purpose of this paper is to determine trends in the distribution of passenger traffic in the Western region of Ukraine under the influence of Covid-19. To achieve this goal it is necessary to solve the following tasks: - to analyze statistical data on railway and road passenger traffic in the region and their change during the pandemic; to analyze the data of questionnaires on suburban trips during a pandemic; - to model passenger flows in the Western region of Ukraine and determine their volumes, distribution, and trend. Solving the formulated problems requires the use of the following research methods: method of scientific identification and analysis (when studying literature sources and statistical information), questionnaires (to collect data on trips characteristics), probability theory, and mathematical statistics (to assess the reliability of modeling re-

sults), system analysis (to form a list of factors influencing users' mode choice of travel), analytical modeling and regression analysis (to calculate utility coefficients), simulation using PTV Visum software (to calculate correspondence matrices considering distribution modes)).

### 3. Research results

#### 3.1. General characteristics of the Western region of Ukraine

The modern borders of Western Ukraine cover the territory of eight regions: Lviv, Ternopil, Ivano-Frankivsk, Volyn, Rivne, Chernivtsi, Zakarpattia, and Khmelnytsky. The total area of the region is 131.3 thousand km<sup>2</sup>, which is 21.8% of the total area of Ukraine. As of the beginning of 2021, the population of the region is 22.15% of the total population

in Ukraine, the distribution of the population between the regions themselves is shown in Fig. 2.

The transport infrastructure of passenger transport in the Western region includes the road network (roads and railways), transport service facilities (stations, stops), rolling stock, and transport companies. The railway network of the Western region is one of the densest, which is largely due to the border location of regions: in Lviv region the density of railways is 62 km / 1000 km<sup>2</sup> in Chernivtsi and Zakarpattia regions - more than 50 km / 1000 km<sup>2</sup> (average density in Ukraine 37 km / 1000 km<sup>2</sup>). Regarding the network of paved roads, the best situation is in Rivne and Ternopil regions, and only in the Zakarpattia region, about 80% of which is occupied by mountains, the density of roads is lower than the average Ukrainian value of 269 km / 1000 km<sup>2</sup> (Table 1).

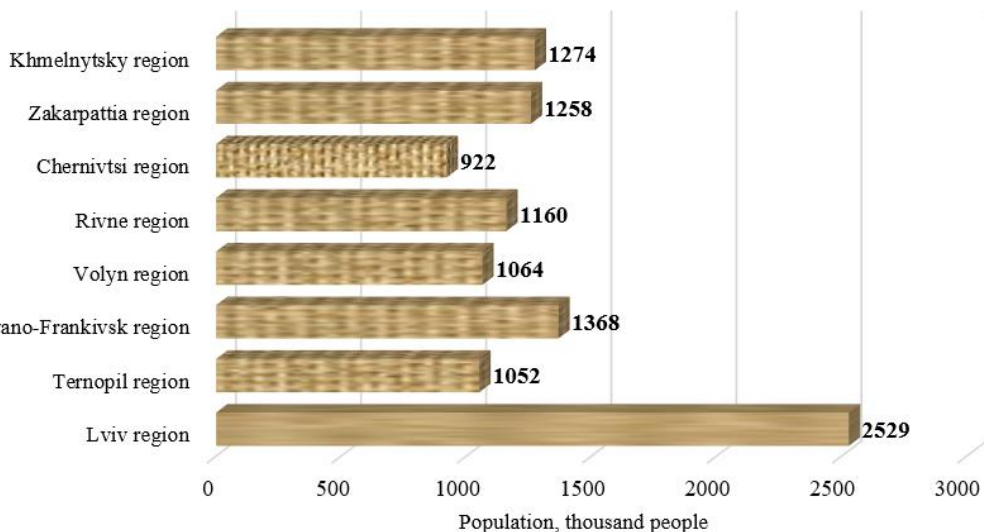


Fig. 2. Population distribution of the Western region

Table 1. Characteristics of the Western Ukraine regions

Administrative unit	Area, km <sup>2</sup>	Population density, person/km <sup>2</sup>	Density of railways, km/1000 km <sup>2</sup>	Density of roads, km/1000 km <sup>2</sup>
Lviv region	21832	116	59,9	339
Ternopil region	13823	76	45,9	369
Ivano-Frankivsk region	13928	98	34,5	299
Volyn region	20143	53	29,5	278
Rivne region	20047	58	29,3	376
Chernivtsi region	8100	114	51,0	355
Zakarpattia region	12777	98	45,4	214
Khmelnytsky region	20629	62	35,5	348

**3.2. Characteristics of passenger traffic modes within the Western region of Ukraine**

The main modes of passengers' transportation within the Western region are road and rail. There is information on the number of non-stop bus and train routes between the regional centers of the Western region in fig. 3, and in table. 2 - traveled distances by bus and rail.

All regional centers are connected by at least one bus route. The most number of routes is between Rivne and Lutsk (center of the Volyn region), as well as between Khmelnytsky and Ternopil, in general, most bus routes depart from Khmelnytsky (107),

Lviv and Ternopil (104 each), the least - from Uzhgorod, the center of the Zakarpattia region (17). There is no direct rail passenger service between 12 of the 28 pairs of regional centers. The most number of rail routes depart from Lviv (43), the smallest - from Rivne and Lutsk (2 and 3, respectively). As for the distance for the bus trip and rail trip, the most different distance between Ternopil and Ivano-Frankivsk, Ternopil and Chernivtsi and Khmelnytsky - for these connections the distance traveled by rail is more than twice as long as the distance traveled by bus.

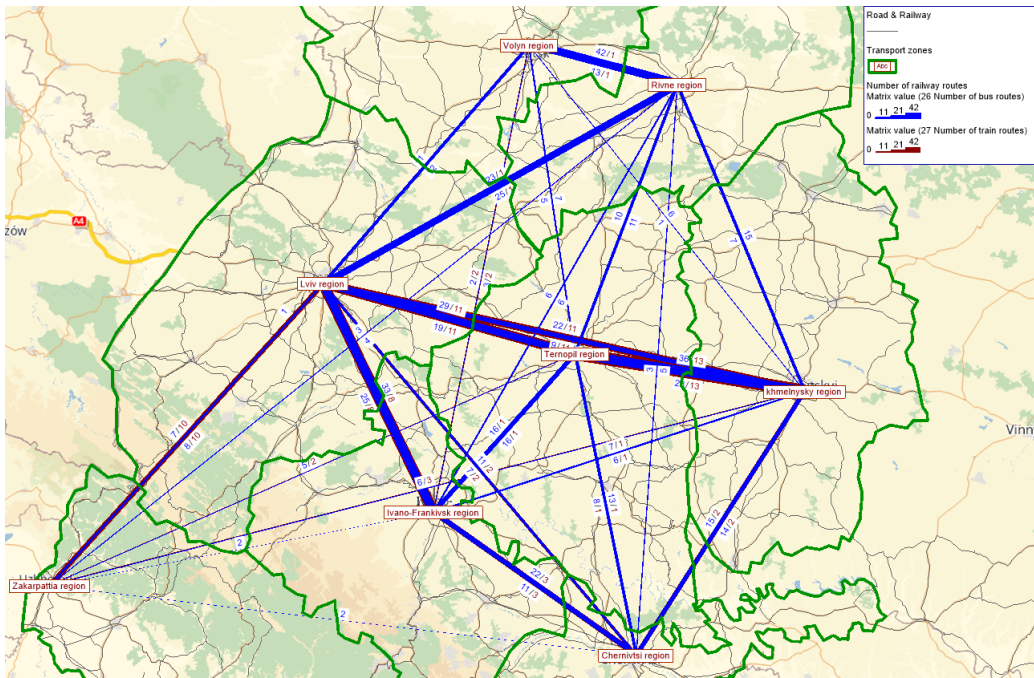


Fig. 3. Number of non-stop routes between regional centers of the Western region

Table 2. Distances between regional centers of the Western region of Ukraine, bus routes / railway routes

Administrative unit	L	T	IF	V	R	Ch	Zak	Kh
Lviv region (L)	-	135/140	125/140	169/-	225/207	300/267	282/288	260/260
Ternopil region (T)	135/140	-	144/282	180/-	175/-	182/408	340/429	196/119
Ivano-Frankivsk region (IF)	125/140	144/282	-	328/317	319/-	159/126	336/-	248/401
Volyn region (V)	169/-	180/-	328/317	-	74/78	335/-	447/-	280/-
Rivne region (R)	225/207	175/-	319/-	74/78	-	357/-	476/-	210/-
Chernivtsi region (Ch)	300/267	182/408	159/126	335/-	357/-	-	452/-	201/527
Zakarpattia region (Zak)	282/288	340/429	336/-	447/-	476/-	452/-	-	530/548
Khmelnytsky region (Kh)	260/260	196/119	248/401	280/-	210/-	201/527	530/548	-

The analysis of the volume of passenger road and rail intercity traffic was conducted based on data from the State Statistics Service of Ukraine during 2013 - to 2020 years (<http://www.ukrstat.gov.ua/>). The main results of the analysis are as follows:

- the total number of transported passengers by road and rail in the Western region in 2020 was 36533.6 thousand people, the distribution by region is shown in Fig. 4. Passenger traffic in the Western region is on average 18% of the all-Ukrainian. Lviv, Ternopil, and Volyn regions have the highest population mobility, while the Chernivtsi region has the lowest mobility (1.41 trips/year). The all-Ukrainian indicator of suburban transport mobility in 2020 was 2.93 trips/year;
- during the period under review, the trend in all regions is similar to the all-Ukrainian trend: a decrease in the share of rail passenger traffic after 2016 (Fig. 5). In general, the share of passengers transported by rail in the western regions is lower than in Ukraine as a whole. Chernivtsi and Volyn regions have the least railway traffic in the structure of passenger traffic in Western Ukraine, Zakarpattia region has the most;
- quarantine restrictions on transport significantly affected the volume of passenger traffic

in the region (Fig. 6). In 2020, there was a slump in passenger traffic compared to the previous year: from 43.2% for Ternopil region to 64.3% - for Rivne region. That is, the mobility of the population has halved on average.

A comparison of intercity bus and rail mobility of residents of the studied regions (Table 3) for 2019 and 2020 (quarantine period) shows the impact of the pandemic on the distribution of movement between modes.

For all regions in 2020, the difference between the mobility of the population by rail and the mobility of the population by bus has increased. The most significant is the difference for the Lviv region, the most stable in terms of the mode choice is Volyn and Rivne regions. In the study of factors that may affect the magnitude of the difference between bus and rail mobility before and during quarantine restrictions on transport, it was found that there is a clear exponential relationship between the number of rail departures from the regional center and the difference between bus and rail mobility before and during quarantine (Fig. 7).

The bigger capacity of the railway station in the regional center, the more the negative impact has the Covid-19 pandemic and related quarantine restrictions on transport on its passenger traffic.

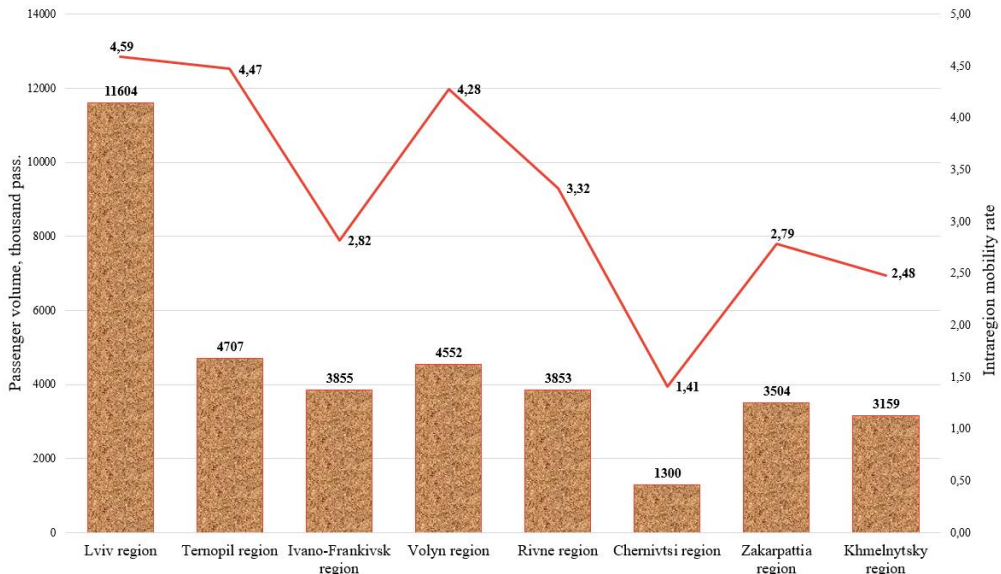


Fig. 4. The number of passengers carried during 2020 and the annual mobility of the population in the regions

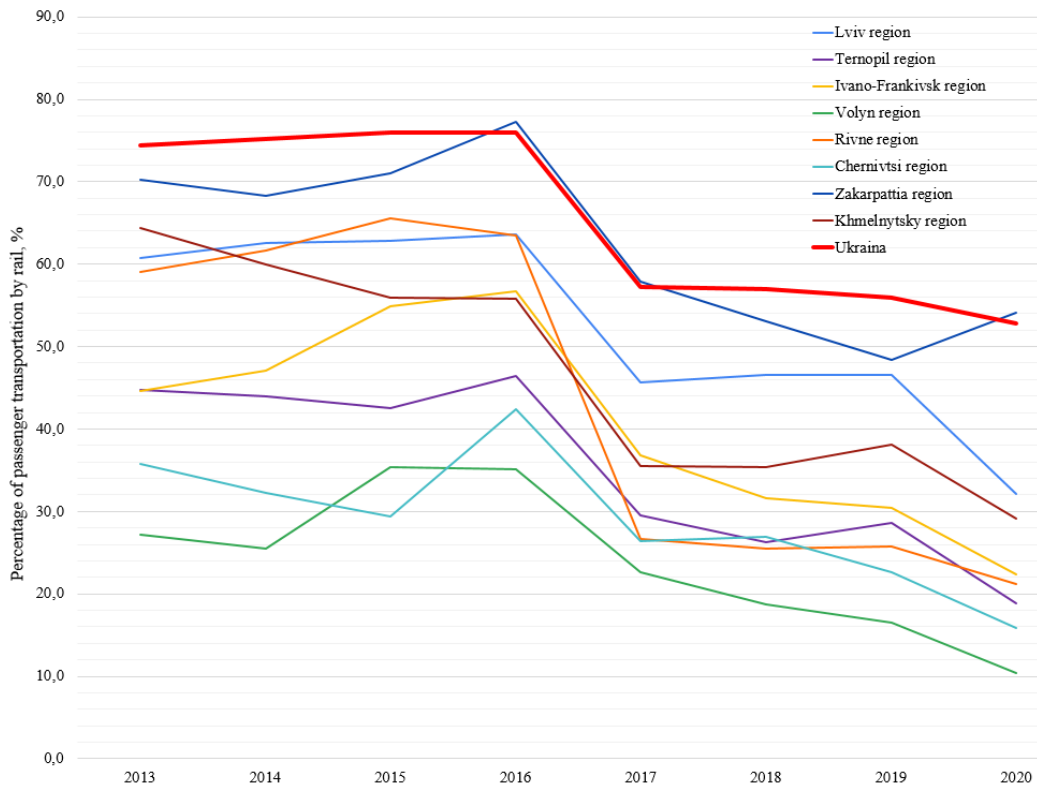


Fig. 5. Change in the number of transported passengers in the Western Ukraine region for the period 2010 – 2020

Table 3. Study of population mobility with distribution by modes of movement

Indicator	Lviv region	Ternopil region	Ivano-Frankivsk region	Volyn region	Rivne region	Chernivtsi region	Zakarpattia region	Khmelnysky region
Rail mobility rate in 2019	4,33	2,25	1,67	1,79	2,39	0,86	2,88	1,89
Bus mobility rate in 2019	4,95	5,63	3,83	9,00	6,92	2,93	3,08	3,07
Difference1, %	12,7	60,0	56,3	80,2	65,4	70,8	6,4	38,5
Rail mobility rate in 2020	1,48	0,85	0,63	0,44	0,71	0,22	1,51	0,72
Bus mobility rate in 2020	3,11	3,63	2,19	3,84	2,62	1,19	1,28	1,76
Difference2, %	52,6	76,7	71,2	88,5	73,0	81,1	17,7	58,9
Difference2- Difference1, %	39,9	16,7	14,9	8,3	7,7	10,3	11,3	20,4



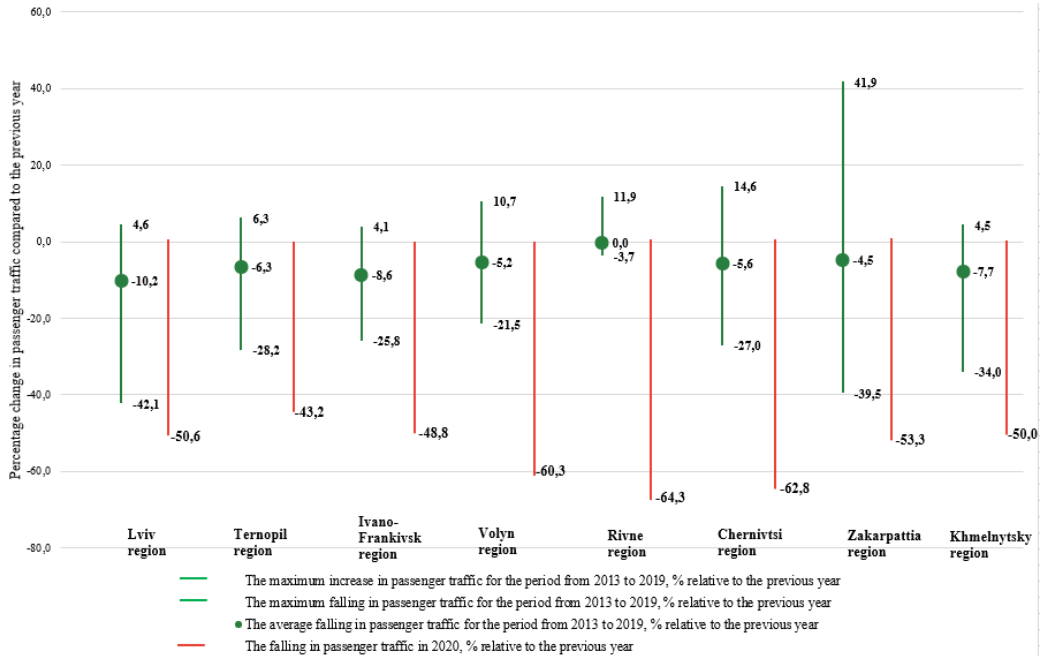


Fig. 6. Change in passenger traffic in the first year of the pandemic

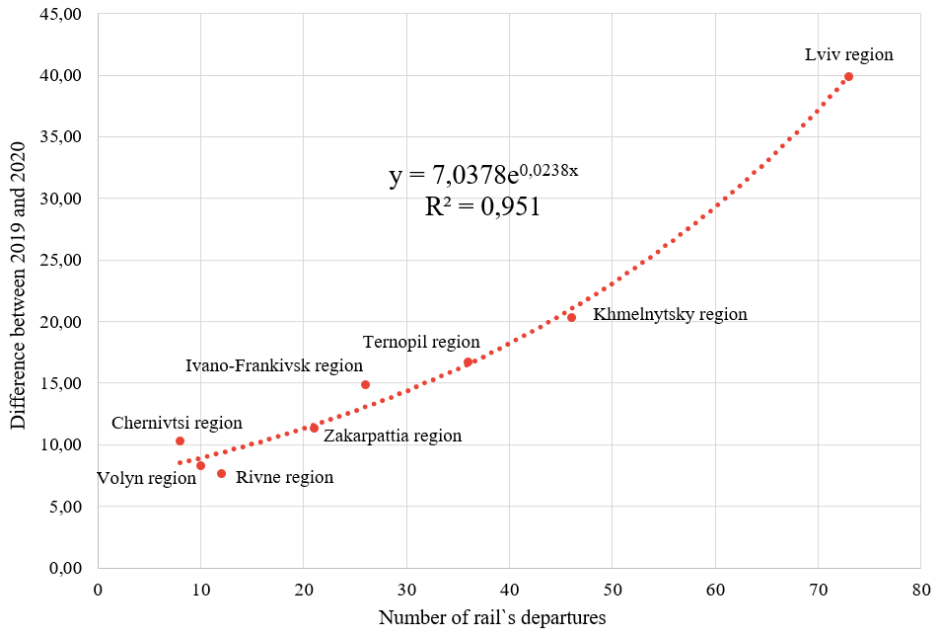


Fig. 7. The relationship between the number of departures from the railway station and the difference between the number of rail and bus trips before and during the pandemic

**3.3. Description of the results of questionnaires**

For studying of the factors influencing the passenger's intercity mode choice during the Covid-19 pandemic, a survey of transport service users was conducted using an online questionnaire, available at the link: <https://forms.gle/LfEhW4LJ3F8J4bmJ6>. The questionnaire we developed consists of two parts: data on the respondent (age, gender, place of residence, the presence of children under 14, and the presence of their car in the family) and data on the characteristics of intercity trips of the respondents (Fig.8).

The sample covers the working population aged 17 to 60 years. The general characteristics of the sample are given in the table. 4.

The pandemic affects the mode choice of users of transport services in intercity travel. Building a diagram in Fig. 9a uses the data collected by Pivtorak (Pivtorak, 2021) (these surveys were conducted in 2019) and building a diagram in Fig. 9b - the results of the above online questionnaire.

According to surveys, the pandemic has significantly increased the number of travelers who choose to travel by own car. For long trips (over 200 km) the share of travel by own transport has increased from 4% to 38%. It is due to the impact of quarantine restrictions on public transport (from the need to comply with sanitary requirements to the complete cessation of long-distance passenger traffic) and the desire of people to protect themselves from the risk of disease. The significant decrease in the share of rail transport for short trips (up to 4% for distances up to 50 km and 7% for distances from 50 to 100 km) can be explained by the fact that this connection is most often used by electric train with a common

carriage, where the risk of contracting Covid-19 is very high.

The distribution of trips by mode depends on the sex of the user (Fig. 10). Men, unlike women, do not use the railway for travel up to 100 km (3% and 18% respectively). For long-distance travel (more than 200 km), the percentage of rail use does not depend on the sex of the user, but women avoid bus travel, preferring their car or joint travel.

The choice of the mode of trip of users is also influenced by age (Fig. 11).

Users over the age of 30 are more likely to use their car for intercity travel, regardless of distance. However, travelers under the age of 30 are much more likely to choose a joint trip.

The distribution of trips by modes for users depending on the presence of children under 14 years is presented in Fig. 12. Travelers with young children do not use the services of joint trips (possibly due to the reluctance of drivers). They also try not to travel long distances by bus (the reason may be that for children such trips are very tiring, especially in compliance with sanitary requirements).

The analysis of the sample of users with children under 14 years of age for their trips with children presents the following results:

- among users who have their car, 91% use it for intercity trips with children;
- among users who do not have a car, 45% use the bus for trips up to 100 km, and 55% - the railway. For trips longer than 100 km the share of railway users increases to 80%.

It should be clarified once again that the diagrams in Fig. 10 - 12 are based on user surveys of their intercity trips conducted in 2020-2021, so they reflect their choices during the pandemic.

Який Вид переміщення ви зазвичай використовуєте для ваших самостійних зовнішніх поїздок (за межі населеного пункту)? \*

	до 50 км	Від 50 км до 100 км	Від 100 км до 200 км	більше 200 км
власне авто	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
переміщення автобусом	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
переміщення залізницею	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
спільна поїздка (з друзями, BlaBlaCar тощо)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Який вид переміщення Ви зазвичай використовуєте для ваших зовнішніх поїздок при поїздах з дітьми? \*

	до 50 км	Від 50 км до 100 км	Від 100 км до 200 км	більше 200 км
власне авто	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
переміщення автобусом	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
переміщення залізницею	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
спільна поїздка (з друзями, BlaBlaCar тощо)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Fig. 8. Fragment of the questionnaire of users of transport services (in Ukrainian)

Table 4. General characteristics of the sample of respondents

Characteristic	Value, %	Characteristic	Value, %
Number of men	52	The presence of children under 14 years	31
Number of women	48	The presence of own car in the family	66

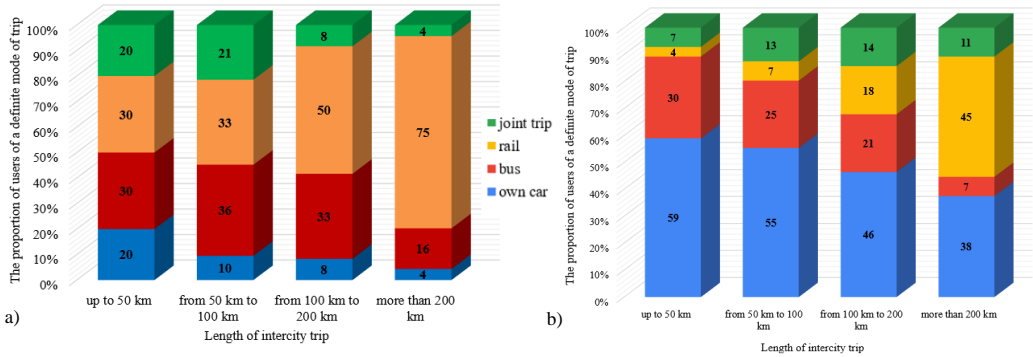


Fig. 9. Distribution of users by modes of the trip: a) before the pandemic; b) during a pandemic

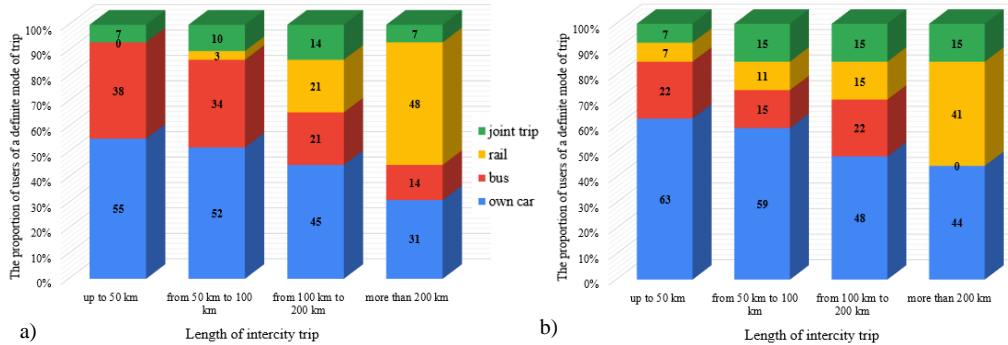


Fig. 10. Distribution of trips by mode depending on the length of the intercity trip with the distribution of users by sex: a) men; b) women

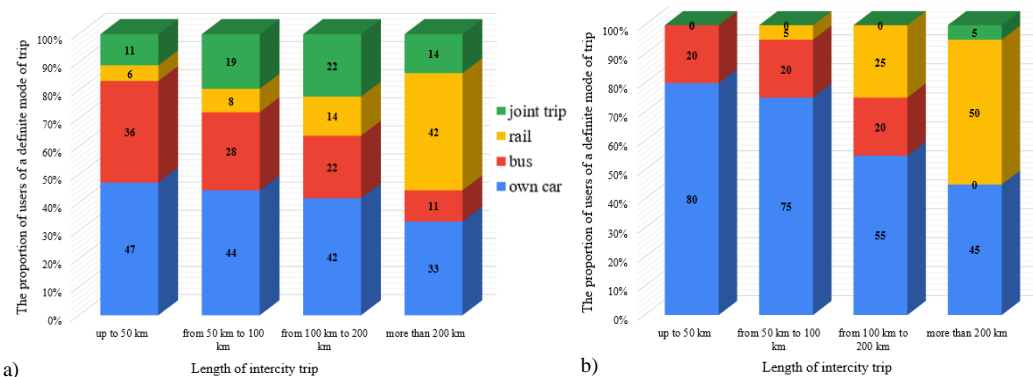


Fig. 11. Distribution of trips by mode depending on the length of the intercity trip with the distribution of users by age: a) up to 30 years; b) after 30 years

#### 4. Mobility modeling in the Western region of Ukraine

The PTV Visum software environment was used to simulate the number of trips between the regions of Western Ukraine and their distribution by mode.

The utility for each mode of the trip is calculated as a linear combination of the impedance parameters (Ortuzar & Willumsen, 2001):

$$U_{ijm} = \sum_g \beta_g \cdot c_{ijmg} \quad (1)$$

where:  $c_{ijmg}$  - specifies the impedance of cost type for the trip from zone  $i$  to zone  $j$  by mode  $m$ .

The logit function used in the distribution of trips by modes has the form:

$$p_{ijm} = \frac{e^{c \cdot U_{ijm}}}{\sum_k e^{c \cdot U_{ijk}}} \quad (2)$$

where:  $c$  - procedure parameter.

Number of trips made by mode  $m$ :

$$T_{ijm} = p_{ijm} \cdot T_{ij} \quad (3)$$

where:  $T_{ij}$  - the total number of trips in the relation  $i - j$ .

The number of non-stop bus and train routes between regional centers was chosen as parameters of the utility function in dividing the total number of trips between bus and rail connections in intercity services.

Utility of travel by bus and rail was obtained based on generalized data on the total number of departures from each regional center to other regional centers of the Western region and the volume of passen-

ger traffic (Table 5). The difference between the carrying capacity of the bus and the train is also taken into account. Approximation probability coefficient  $R^2 = 0.85$ :

– for railway movements:

$$U_{ij}^{rail} = 0.43 \cdot \eta_{rail} - 0.12 \cdot P_{rail} + 4.82 \quad (4)$$

– for bus movements :

$$U_{ij}^{bus} = 0.43 \cdot \eta_{rail} - 0.12 \cdot P_{rail} + 63,58 \quad (5)$$

Modeling volumes of trips between regional centers of the Western region and their distribution on railway and bus transportations are carried out taking into account matrices of distances and the received utility functions. The obtained results are presented in Fig. 13 and table 6.

In general, according to the simulation, 75% of passenger traffic is performed by buses and 25% - by rail. The diagram (Fig. 14) shows the distribution of the total passenger traffic by rail by region (separately departure and arrival).

The largest volumes of traffic, as expected, are from Lviv region, which has the largest population and the largest number of railway routes compared to other regions. The largest disparity between the population and the volume of rail passenger traffic is observed in Ternopil region (seventh in terms of population, but third in terms of volume sent and second in terms of received passenger traffic).

In general, the resulting passenger flows correlate with statistics data. This allows you to calibrate the model to predict changes in passenger traffic during the implementation of quarantine restrictions on transport.

Table 6. Results of modeling passenger flow in the Western region

Administrative unit	Passenger flow volume, thousands of people			Distribution of passenger flow volume, %	
	bus	rail	sum	bus	rail
Volyn region	7969,9	1697,5	9667,4	82,44	17,56
Rivne region	6699,2	1278,8	7978,0	83,97	16,03
Lviv region	16437,1	6317,6	22754,7	72,24	27,76
Ternopil region	8338,4	3287,7	11626,2	71,72	28,28
Khmelnysky region	3923,8	1587,8	5511,6	71,19	28,81
Ivano-Frankivsk region	6701,4	2089,1	8790,4	76,23	23,77
Chernivtsi region	1736,3	442,3	2178,6	79,70	20,30
Zakarpattia region	2927,0	1624,2	4551,1	64,31	35,69
All Western region	54733	18325	73058	74,92	25,08

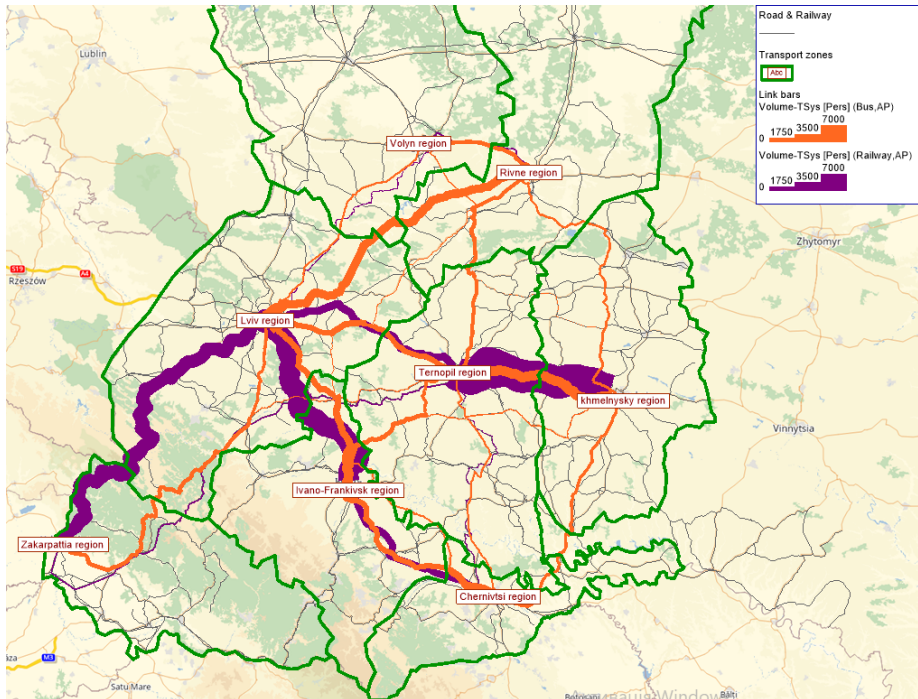


Fig. 13. The modeled volumes of passenger flow between the regional centers of the Western region

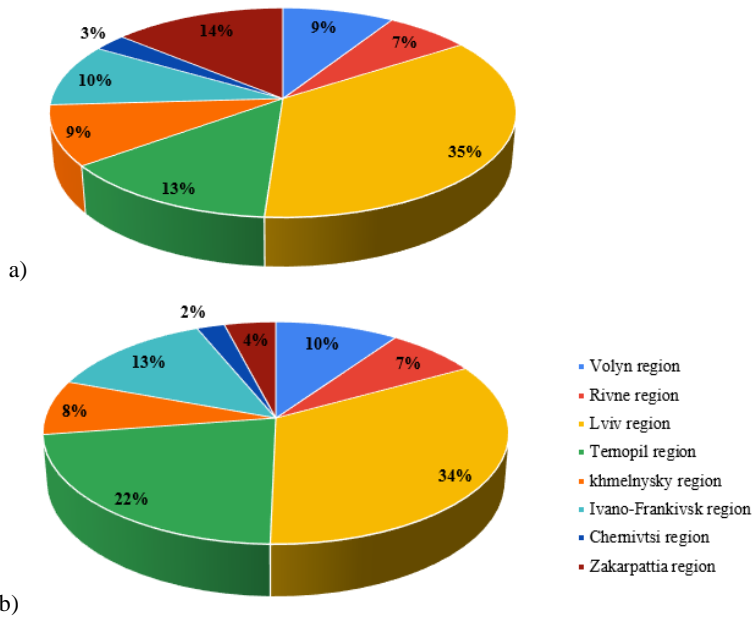


Fig. 14. Distribution of the total passenger traffic by rail by region : a) departure; b) arrival

Based on data on the number of days in 2020, during which the region was in the "red" quarantine zone (limited communication between regions), and the decline in population mobility in intercity traffic in 2020 compared to 2019, the dependence is obtained (Fig. 15):

$$y = -1,67 \cdot \ln(x) + 10,07 \quad (6)$$

where:  $x$  - the duration of the "red" quarantine zone in the region, days;

$y$  - projected intercity mobility of the population in the region, trip/year.

The probability coefficient of approximation is  $R^2 = 0.79$ .

The sharpest decrease in population mobility is observed when the duration of restrictions changes from their absence to 60 days/year. The entry into force of restrictions causes the greatest decline in passenger traffic (fear of the unknown, unpreparedness for the requirements imposed by restrictions, etc). As the duration of restrictions increases (the duration of the factor that led to the introduction of such restrictions increases), the rate of decline in mobility is slowing down. There is a process of habituation - getting used to the restrictions and adapting to them.

## 5. Conclusions

The location of the Western region of Ukraine, the number of inhabitants in the region, and the development of transport infrastructure affect the volume and distribution of population mobility. For example, the population of Lviv region is twice as large as the population of Ivano-Frankivsk region (this region ranks second in this indicator). The number of inhabitants of the smallest region of Western Ukraine, the Chernivtsi region, is only 33% of the population of Lviv region. As for the volume of passenger traffic, in Ivano-Frankivsk region in 2020 33% was transported, and in Chernivtsi region - 11% of the volume of passenger traffic in Lviv region (which amounted to 11,604 thousand passengers). There is also a correlation between the density of transport networks and population mobility. The highest density is in Lviv and Ternopil regions, where the highest population mobility is recorded. However, for example, in Chernivtsi region, despite the high density of the transport network, population mobility is the lowest in the region, which may be due to economic factors (low per capita income). Virtually all passenger movements within the Western region are performed by rail and road. There are existing airports in Lviv, Ivano-Frankivsk, Rivne, Uzhhorod and Chernivtsi, but there are no regular flights between these cities.

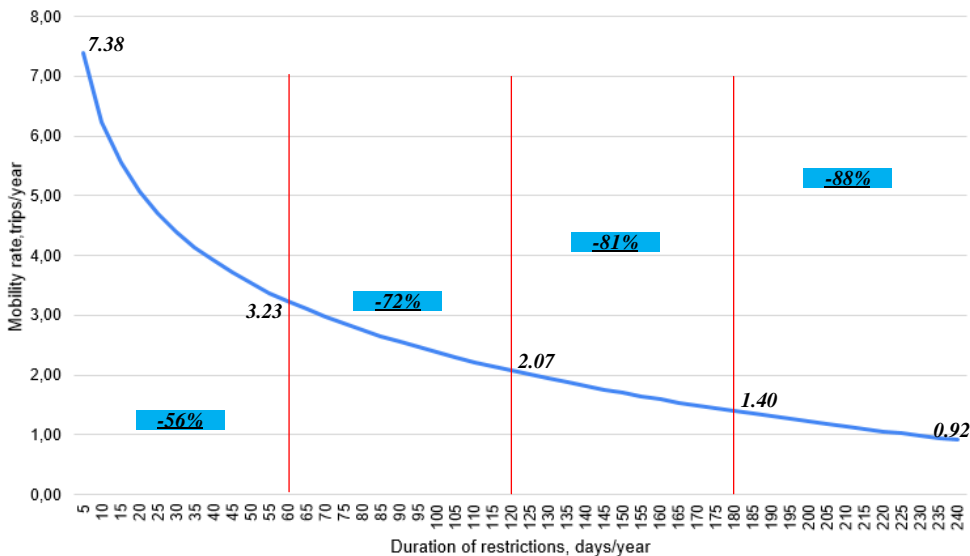


Fig. 15. Modeling the impact of the duration of transport restrictions on intercity mobility of the population

Quarantine restrictions related to the Covid-19 pandemic have significantly affected the volume of passenger traffic and its distribution by mode of transport. In 2020, there was a sharp decline in passenger traffic compared to the previous year: from 43.2% for Ternopil region to 64.3% - for Rivne region. The difference between the distribution of population mobility between bus and rail transport has also increased. For example, for the Lviv region in 2019 this difference was 12.7% in favor of buses, and in 2020 - already 52.6%. In general, the more capacity has the railway station in the regional center, the greater the negative impact on passenger traffic. The pandemic also significantly increased the number of intercity trips by own transport (according to surveys, for trips up to 50 km the share of such movements increased from 20% to 59%, for trips from 50 to 100 km - from 10% to 55%, for trips from 100 to 200 km - from 8% to 46%, and for trips over 200 km - from 4% to 38%). The mode of choice is also influenced by age, gender, and the presence of children. Users over the age of 30 are more likely to use their car for intercity travel, regardless of distance. However, travelers under the age of 30 are much more likely to choose to travel together. Men, unlike women, do not use the railway for travel up to 100 km (3% and 18% respectively). Women, on the other hand, avoid traveling by bus when traveling more than 200 km, preferring rail (41%), own car (44%), or joint travel (15%). Travelers with small children do not use the services of joint trips (perhaps due to the reluctance of drivers), and also prefer not to travel by bus for long distances. Among users who have their car, 91% use it for intercity trips with children. Among users who do not have a car, 45% use the bus for trips up to 100 km and 55% use the railway, while the share of railway users increases to 80% for trips longer than 100 km.

Changes in the magnitude and structure of demand for regional trips that have taken place under the influence of the pandemic have affected the sustainability of the region as a whole and will continue for some time after its completion. Each of the elements of sustainability (economic, social, and environmental) is affected. Transport operators have lost part of their revenues due to reduced passenger traffic, and some of them may need support to maintain their competitiveness. The tourism industry is also projected to be significantly affected. The increase in the use of private transport has a negative impact on

environmental sustainability. And for the part of the population that does not have its car, the possibilities of mobility during the quarantine measures on transport (complete ban on certain modes of transport, reducing the frequency or increasing the cost of trip) are significantly limited. The approach presented in the paper contributes to the expansion of existing innovative methods of transport management, demand forecasting, and sustainable sustainability management in the region.

The use of PTV Visum software environment for modeling the mobility of the population of the Western region of Ukraine based on statistical information and the results of population surveys before and during the pandemic made it possible to determine the estimated volume of trips between regions. Such data can be further taken into account when planning the work of transport enterprises and meeting the demand of the population for transportation. Modeling the impact of the duration of the "red" quarantine zone in a given region on the decline in intercity mobility suggests that the sharpest decline in population mobility is observed at the beginning of the introduction of quarantine restrictions. As the duration of restrictions increases, the rate of decline in mobility begins to decline (people adapt to new requirements).

The practical application of the research results is that the identification of trends in the mobility of residents of the region depending on the impact of pandemic restrictions makes it possible to predict the type of trip and type of vehicles used. Based on these data, you can determine marketing strategies for the development of certain types and directions of trips. Further research may be based on the consideration of volumes and changes in transit passenger traffic, including international passenger transportation, which has not been studied in this paper.

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