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ASSESSMENT OF THE EXTERNAL MOBILITY TO UKRAINIAN CITIES

Summary. *The problem of citizens' mobility is crucial for most Ukrainian cities. At the same time, besides urban travelling, external travelling also impacts the urban transport system. That is why the study of regularities of external mobility will allow considering it during urban systems planning. In this article, the movement of citizens to Ukrainian cities with a population above 70 thousand persons is reviewed. The source of the data is information from mobile operator Kyivstar. The connection between the quality of life in cities and the general level of external mobility (depending on the number of citizens in cities, they are divided into five clusters) is established. It is detected that larger mobility is inherent for cities located in the western and the central parts of the country. The average value of the consolidated index of the assessment of city possibilities (an integral indicator that considers the possibility to express opinions freely, travel between city districts, impact the process of decision-making in the city, etc.) is determined. There is a positive correlation between this index and the volume of external mobility, i.e., the relative volume of external mobility is larger to cities where citizens admit a higher quality of life. The averaged over the year, an average number of trips which were made from every city is calculated, and for every trip, its distance is determined (by the road network). Also, the regularities of external mobility to cities with different sizes (the average length of trips changes within 39/0–56/5 km; 95 % of trips are on the distance of 150–250 km; 99 % of trips – on the distance of no more than 400–600 km). Obtained results will provide the opportunity to form further recommendations about improving the city's transport system, which should consider the daily volume of its visitors and the tendencies of its (system) change in case of improvement of the quality of life in the city).*

Key words: *external mobility, suburban mobility, average travel distance, data of mobile operator*.

1. INTRODUCTION

Mobility of population is the critical object for the research both on the state and local levels. At the same time, in current conditions of the development of Ukraine, the number of trips between different cities and regions increases. Suppose we consider any administrative unit, then it is possible to allocate external and internal mobility of the population. Internal mobility characterizes such population travelling, the start and the finish of which are located within the settlement. External mobility is the totality of trips that begin within one administrative unit (city, district, region) and finish outside it (or vice versa).

External mobility of the city is formed by the suburban and intercity trips, which are performed by all available ways of travel (cycling, travel by bus, train, plane, taxi, private and rental car, etc.). The general volume of external mobility is formed by citizens of Ukraine who travel to the city and citizens of the city who travel outside it. Such trips can be both regular and irregular. As the share of the urban population in Ukraine is more than 70 %, we can assume that most suburban and intercity trips start and finish in cities.

2. RESEARCH STATEMENT

External mobility of the population to cities is closely related to the operation of the city's transport system as it causes additional load on the urban streets, increases the number of public transport passengers, needs the implementation of external transport nodes, etc. That is why the study of regularities of external mobility to Ukrainian cities is a topical task.

There are several external mobility studies, but in most cases, whether trips to one city-centre or general regularities of external mobility are reviewed without impacting urban mobility. Research that would generalize the regularities of external mobility to Ukrainian cities is almost absent. They need to collect and process a large amount of information (for example, sociological research) or cover only a small part of such trips (for instance, passenger flows analysis).

That is why, during the study of external mobility to Ukrainian cities, conducting research using indirect data is rational. This research is based on the passive collection of data about the millions of users for any time forms other spheres, for example, mobile connection operators data.

The object of research: external mobility to cities of Ukraine.

The subject of study: factors which impact the change of external mobility of population to Ukrainian cities.

Task and the aim of the research is the establishment of regularities of the change of external mobility of Ukrainian citizens taking into account such indicators as the number of cities` population, the dynamics of the shift in population number, the assessment of life quality and distance of trips, and also the determination of change of travel volumes depending on their length.

3. LITERATURE REVIEW

The possibility of the usage of mobile data operators for the investigation of citizens` travel is mentioned in sources [1–4], first of all, because such data contains information about the location and time. Early research of British scientists White and Wells showed that such information is not sufficient and precise enough to build a correspondence matrix [5]. But, other researchers combined this data with additional information to obtain better results, for example, data from mobile applications in Sweden [6], geo-spatial data combined with data about population census in cities of the USA, Portugal and Brasilia [7].

Data of mobile operators can be two types:

- payment data – detailed records about calls that form the list of base stations through which information was transmitted in moments when the user made/received call SMS-message or started an Internet session;
- service data, by which phone and base station are constantly exchanged during the call and in standby mode.

In 2015, in Ile de France, France, the research of transportation using mobile operator data was carried out [8]. The authors compared mobile operators data with data from a global transport questionnaire. They established that the usage of the first realistically reflects the regularities of citizens travel and provides an opportunity to build a correspondence matrix in short terms. The same results were also obtained in the paper [6, 9].

In 2013, in Israel, the research [10] of long-distance trips within the country was carried out, indicating mobile operators' data potential. Such an approach allows gathering data about a large number of users during a long period with small costs. The method is developed by the authors especially for the analysis of long-distance trips. It provides the usage of cellular technologies to assess mobility on a national-wide level and the building of a correspondence matrix for further transport planning and analysis.

In Ukraine, there is also an experience of mobile operators' data usage to investigate citizens` travel. In particular, in 2015, within the cooperation of Kyiv State City Administration and World bank, pilot

research of external mobility of Kyiv with the use of mobile operator Kyivstar data was carried out [11]. Payment data, gathered during one week in October 2014, were used for the analysis. The research allowed determining the actual number of the city population (as of 2014), the number of persons who arrive in Kyiv daily, and measuring the frequency of commuting. The actual population was 3,2 – 3,3 million persons, while official data recorded only 2,91 million persons. The volume of external mobility was nearly 500 thousand persons per day [11]. The exact numbers were published in the report of the Chairman of the Board of the stock company "Ukrzaliznytsia" on the All-Ukrainian Forum "Ukraine 30. Infrastructure" in 2021. In particular, it was mentioned that nearly 450 thousand persons arrive in Kyiv daily, among them 77 thousand use the railway [12].

In 2018, the Lviv city council carried out similar research in cooperation with mobile operator Vodafone. As a result of the investigation of external migration, on average, over 150 thousand persons arrive in Lviv daily and on weekdays – over 180 thousand persons [13]. At the same time, half of the general volume of external mobility create citizens who live in the 15-kilometre zone around Lviv.

Mobile operators data were also used for the investigation of external travel to the region. In particular, in 2018, the research [14] of internal tourism in the Ivano-Frankivsk region was carried out by the data of mobile operator Kyivstar. By research results, both cities and regions from which the flow of tourists was the largest and the average duration of stay of tourists in the studied region were established.

As follows, despite the existence in Ukraine the researches of external mobility of citizens with the use of mobile operators data, the research which would systematize the regularities of external mobility for all cities with the aim of better management of such travel and the improvement of state or local policy is absent.

4. CHARACTERISTICS OF PRIMARY DATA

For the investigation of the external mobility to Ukrainian cities, the data purchased from mobile operator Kyivstar for the national transport model of Ukraine was used. This model is developing in the framework of the project of technical help of European Union for the Ministry of Infrastructure of Ukraine "National transport model and Master-plan" (which is implemented by a consortium of French company Egis and German Company AplusS).

The data about mobility within Ukraine is the matrix with the number of travel between separate transport regions for the average day of every month of 2019. The mode of travel (mode of transport) and the reason for travel are unknown.

Travel, in this case, is an event when the user had registered in different transport regions and the criterion of the beginning/finishing of the trip – continuous stay within the region for above 3 hours. Transport regions in this research are all administrative regions of Ukraine (before the implementation of the new administrative division in 2020) and also cities with a population above 70 thousand persons (without consideration of temporarily occupied territories).

The number of trips between transport regions is not precise. However, this value considers all GSM operators' users (not only Kyivstar), avoiding the problems with two SIM cards (registration of the user was made by MAC-address of telephone). Apparently, a certain operational margin will exist because of several phones per one user or the absence of the phone at all. However, at the level of mobile connection penetration in Ukraine (over 140 % by the data of national telecom-regulator), this margin is minimal and can be neglected.

For the investigation, 47 cities with a population of more than 70 thousand persons were chosen (without consideration of cities on temporarily occupied territories). The list of these cities with a population [15] as of 01.01.2019 is given in Table 1. Besides, the dynamics of population change per period is given in the Table. 1.

Table 1

List of investigated cities and their population

N	City	Population, persons	Dynamics of population change, %	N	City	Population, persons	Dynamics of population change, %
1	Kyiv	2950819	6	25	Lutsk	216887	3
2	Kharkiv	1446107	-1	26	Bila Tserkva	208944	0
3	Odesa	1013159	1	27	Kramatorsk	186831	-10
4	Dnipro	1000576	-2	28	Melitopol	153112	-4
5	Lviv	755822	-1	29	Uzhhorod	114897	-1
6	Zaporizhzhia	738728	-7	30	Sloviansk	114207	-10
7	Kryryi Rih	627304	-8	31	Severodonetsk	113616	-9
8	Mykolaiv	483186	-4	32	Berdiansk	113512	-8
9	Mariupol	461417	-8	33	Lysychansk	111270	-11
10	Vinnytsia	369839	0	34	Nikopol	110669	-13
11	Kherson	326964	-6	35	Brovary	106346	12
12	Poltava	288324	-5	36	Pavlohrad	105238	-7
13	Chernihiv	288268	-4	37	Kamianets-Podilskyi	99755	-4
14	Cherkasy	277258	-4	38	Drohobych	96689	-3
15	Khmenytskyi	271263	4	39	Konotop	90303	-5
16	Chernivtsi	266533	6	40	Oleksandria	88650	-6
17	Sumy	266306	-4	41	Mukachevo	85881	2
18	Zhytomyr	265240	-3	42	Uman	83162	-6
19	Ivano-Frankivsk	260605	6	43	Berdychiv	75439	-6
20	Rivne	246535	-1	44	Shostka	75024	-9
21	Kamianske	240270	-5	45	Bakhmut	74691	-44
22	Kropyvnytskyi	235946	-5	46	Izmail	71780	-6
23	Ternopil	221820	3	47	Kostiantynivka	70841	-15
24	Kremenchuk	220065	-4				

5. RESEARCH RESULTS

For every city, the absolute value of the trip number averaged over the year and the corresponding relative value to the population as of 01.01.2019 was determined. The dependence between the number of population and the external mobility is graphically given in Fig. 1 (cities Kyiv and Brovary are not given in the graph as they are located far beyond given boundaries). We can see that there is no dependence between the number of population and the volume of external mobility, but we can select several clusters which have similar characteristics and need to be studied in more detailed [16]:

- the population is 200–300 thousand persons, the volume of external mobility is over 25 % (Zhytomyr, Ivano-Frankivsk, Rivne, Ternopil, Lutsk, Bila Tserkva);
- the population is 200–300 thousand persons, the volume of external mobility is 15–25 % (Poltava, Chernihiv, Khmelnytskyi, Chernivtsi, Kamianske, Kremenchuk);
- the population is 300–600 thousand persons, the volume of external mobility is less than 15 % (Kryvyi Rih, Mykolaiv, Mariupol, Kherson, Symu, Kropyvnytskyi);
- the population is 70–150 thousand persons, the volume of external mobility is over 20 % (Uzhhorod, Kamianets-Podilskyi, Drohobych, Mukachevo, Uman, Berdychiv);
- the population is 70–150 thousand persons, the volume of external mobility is less than 15 % (Sloviansk, Severodonetsk, Berdiansk, Lysychansk, Nikopol, Pavlohrad, Konotop, Oleksandria, Shostka, Bakhmut, Kostiantynivka).

Cities Kyiv, Kharkiv, Odesa, Dnipro, Lviv, Zaporizhzhia, Vinnytsia, Kramatorsk, Melitopol, Brovary, Izmail had not entered into any cluster as the interrelation between the volume of external mobility and population are sufficiently different from other cities.

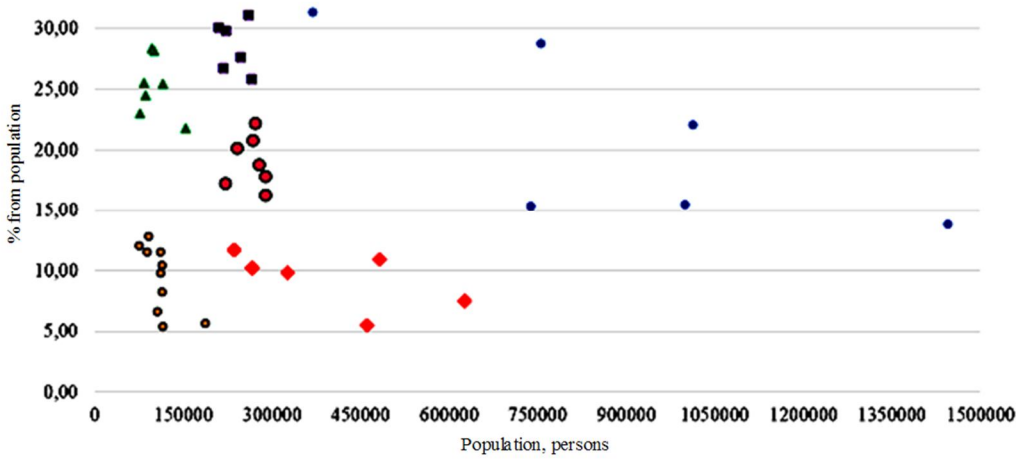

Fig. 1. Dependence between the population number and relative volume of external mobility

The visualization of the volume of external mobility for all cities is given in Fig. 2. The diameters of circles in Fig. 2 show the relative (to the city's population) volume of external mobility, and the colour corresponds to the cluster from Fig. 1. We can see that larger values are observed in central and western parts of Ukraine, while for the cities of southern and eastern parts, they are significantly smaller.

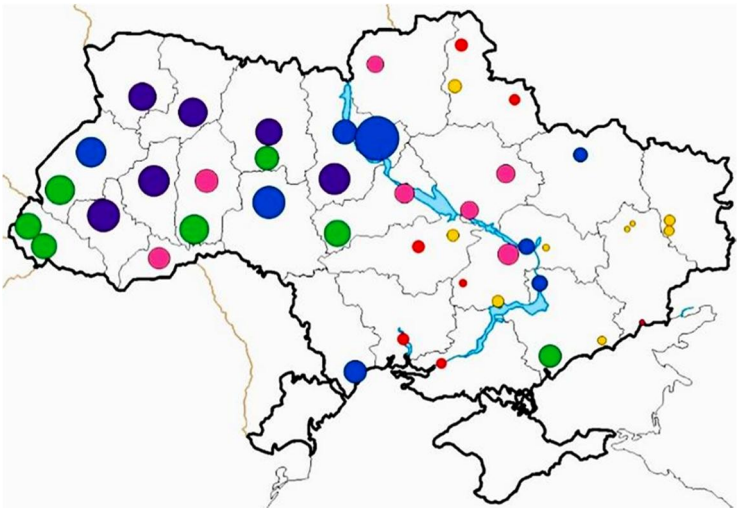

Fig. 2. Graphical interpretation of the volume of external mobility of investigated cities

That is why dependence between dynamics of the population for the last ten years (between 2010 and 2020, by the data [15]) and relative volume of external mobility (Fig. 3) was analyzed. We can see a positive correlation between the change of population and the volume of external mobility. At the same time, the relation of these indicators can be considered close ($R2 > 0,6$).

The change in population number is closely connected with the perception of citizens' quality of life in the city. There is a range of different sociological researches and ratings that determine different aspects of the quality of life in a city. Thus, to minimize the impact of random indicators for the investigation of the connection between the quality of life and the volume of external mobility, the annual all-Ukrainian municipal questionnaire was chosen, which International Republican Institute carried out in region centres by the single methodology. By results of annual all-Ukrainian municipal questionnaires by 2018 [17], 2019 [18], and 2020 [19], the average value of the consolidated index of the assessment of city possibilities (an integral indicator which takes into account the possibility to express opinions freely, travel between city districts, impact the process of decision-making in the city, obtain qualified education in different

specialities, etc.) is determined. Index of the assessment of city possibilities is calculated based on the answers of respondents, and its values change from 1 to 5, where 1 is "terribly" and 5 – "perfectly" (Table 2).

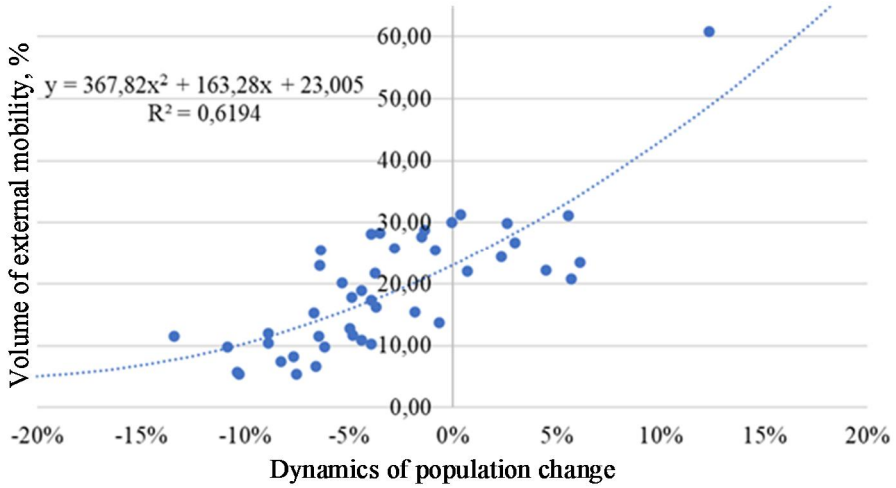

Fig. 3. Relationship between the dynamics of population change and the volume of external mobility

Table 2

Consolidated index of the assessment of city possibilities

City	Index of possibilities and liberties of the city			Average value
	2018	2019	2020	
Vinnytsia	3.4	3.7	3.7	3.60
Dnipro	3.2	3.3	3.3	3.27
Zhytomyr	3.2	3.7	3.5	3.47
Zaporizhzhia	3	3.2	3.3	3.17
Ivano-Frankivsk	3.5	3.7	3.6	3.60
Kyiv	3.1	3.4	3.3	3.27
Kropyvnytskyi	3	3.3	3.3	3.20
Lutsk	3.5	3.5	3.5	3.50
Lviv	3.2	3.4	3.4	3.33
Mariupol	3.1	3.3	3.2	3.20
Mykolaiv	2.9	3.1	3.1	3.03
Odesa	3	3.3	3.3	3.20
Poltava	2.9	3.2	3	3.03
Rivne	3.3	3.4	3.4	3.37
Severodonetsk	2.9	3.1	3	3.00
Symu	2.9	3.3	3.2	3.13
Ternopil	3.2	3.5	3.4	3.37
Uzhhorod	3.2	3.5	3.3	3.33
Kharkiv	3.2	3.4	3.3	3.30
Kherson	2.8	3.4	3.1	3.10
Khmelnytskyi	3.1	3.5	3.4	3.33
Cherkasy	3.1	3.4	3.4	3.30
Chernivtsi	3	3.4	3.4	3.27
Chernihiv	3.1	3.4	3.3	3.27

The dependence between the index of assessment of city possibilities and the volume of external mobility is graphically given in Fig. 4. We can see also a positive correlation with a close connection ($R2 > 0.6$) between these indicators, i.e., the relative volume of external mobility is more extensive to the cities where citizens admit the better quality of life.

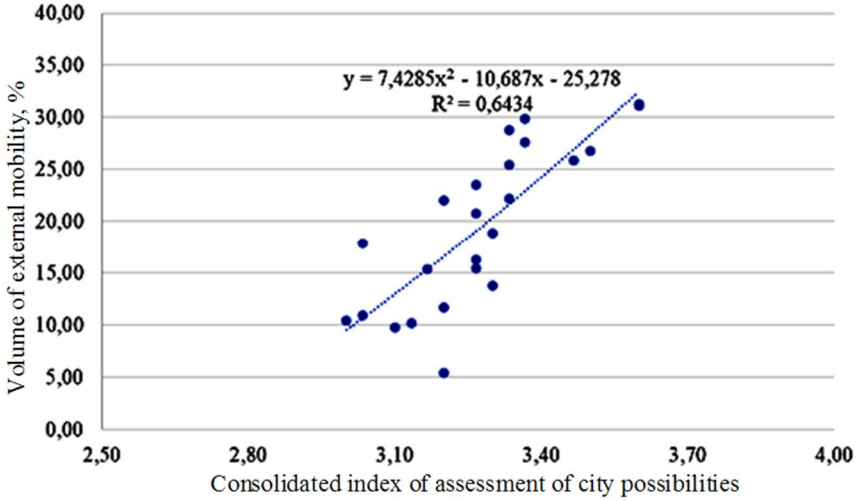

Fig. 4. Relationship between the consolidated index of assessment of city possibilities and the volume of external mobility

General volume of external mobility is a significant indicator during the comparison of parameters of different cities, but it does not provide an understanding of travel distribution by the distance. That is why, for the better understanding of regularities of external mobility, all travels were analyzed for cities which are in such clusters:

- population is 70–120 thousand persons, volume of external mobility is < 15 %;
- population is 70–120 thousand persons, volume of external mobility is > 20 %;
- population is 200–300 thousand persons, volume of external mobility is 15–25 %;
- population is 200–300 thousand persons, volume of external mobility is > 25 %.

Based on the data obtained from the mobile operator Kyivstar, we calculated averaged by year the average number of trips made from every city from clusters given above, and for every trip, we calculated its distance (by the road network).

Considering that suburban travelling by relatively short distances predominates in the structure of external mobility, all trips are divided into groups with uneven intervals (small intervals on short distances and big – on large distances). As different clusters contain a different number of cities with a different population, to summarize the results, we proposed to use the indicator of the number of trips per 1000 citizens and the corresponding share of trips. The distribution of trips by distance for every cluster is given in Fig. 5. Generalized results of calculation for all clusters are given in Table 3.

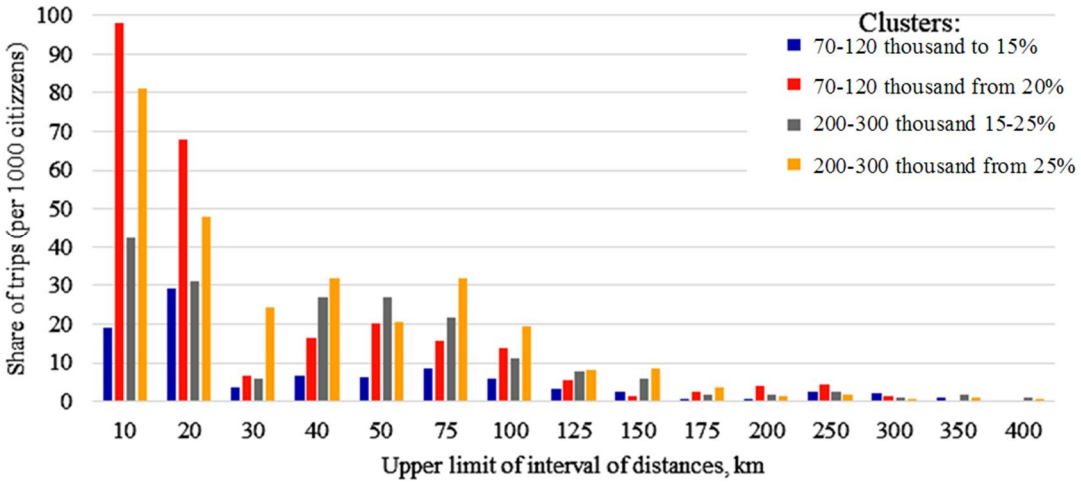

Fig. 5. Distribution of number of trips (per 1000 persons) by distance

Table 3

Generalized results of calculations for all clusters

Indicator	Cluster (group of cities)			
	70–120 thousand to 15 %	70–120 thousand from 20 %	200–300 thousand 15–25 %	200–300 thousand from 25 %
Number of trips (per 1000 persons)	92	260	191	285
Average trip length, km	56,5	39,0	54,3	44,3
Maximal travel distance, km				
85 % of trips	100	75	100	75
90 % of trips	150	100	125	100
95 % of trips	250	175	175	150
99 % of trips	600	400	450	400

6. CONCLUSIONS AND RESEARCH PERSPECTIVES

By results of the research of external mobility to Ukrainian cities, we can make such conclusions:

- relative (to the general population of the city) volume of external mobility for the majority of cities is 10–30 % from the city population; herewith, the cities both with smaller and larger values exist;
- relative volume of mobility is larger for cities of western and central Ukraine;
- connection between the population of the city and the relative volume of external mobility is absent;
- dynamics of population and the index of assessment of city possibilities have a positive correlation with the relative volume of external mobility (the share of external trips is more extensive in cities where the population grows and in cities where citizens assess the level of quality of life by higher values);
- larger cities generate larger volumes of travel (number of trips per 1000 persons is more extensive);
- average length of travel outside the city changes in the range 39.0–56.5 km;
- 85 % of trips are made on the distance no more than 75–100 km, i.e., the majority of trips outside the city is suburban;
- 95 % of trips are made on the distance 150–250 km (no far than neighbouring region); herewith, for the smaller cities, this distance is more extensive, i.e., citizens of smaller cities make shorter trips in comparison to citizens of larger cities;
- 99 % of trips are made on a distance no more than 400–600 km.

Obtained regularities provide an opportunity to understand a range of factors which impact the volume of external mobility, to assess its volume and to form recommendations for improvement of transport system of the city which should consider both daily volumes of visitors and tendencies of its change in case of improvement of the quality of life in the city.

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ДОСЛІДЖЕННЯ ЗОВНІШНЬОЇ МОБІЛЬНОСТІ ДО МІСТ УКРАЇНИ

Анотація. *Проблема мобільності мешканців є однією з ключових для більшості українських міст. Окрім міських пересувань, на міську транспортну систему впливають також зовнішні (позаміські) пересування. Тому дослідження закономірностей зовнішньої мобільності дасть змогу враховувати її під час планування міських транспортних систем. У цій статті розглянуто пересування мешканців до українських міст з чисельністю населення понад 70 тис. осіб. Джерелом даних є інформація від мобільного оператора Kyivstar. Встановлено зв'язок між якістю життя у містах та загальним рівнем зовнішньої мобільності (залежно від чисельності жителів у містах їх поділено на п'ять кластерів). Виявлено що більша мобільність характерна для міст, що у західній та центральній частині країни. Визначено середнє значення зведеного індексу оцінки можливостей міста (інтегральний показник, що враховує можливість вільно висловлювати думки, пересуватись між районами міста, впливати на формування рішень у місті тощо. Між цим індексом та обсягом зовнішньої мобільності існує позитивна кореляція, тобто, відносний обсяг зовнішньої мобільності є більшим до міст, у яких мешканці відзначають вищу якість життя. Обчислено усереднену за рік середню кількість поїздок, що здійснюються від кожного з міст і для кожної поїздки визначено її відстань (по мережі автомобільних доріг). Також встановлено закономірності зовнішньої мобільності до міст різних розмірів (середня довжина поїздок змінюється у діапазоні 39,0–56,5 км; 95 % поїздок – на відстані 150–250 км; 99 % поїздок – на відстань не більше 400–600 км). Отримані результати дадуть змогу сформувати в подальшому рекомендації з удосконалення транспортної системи міста, яка повинна враховувати як щоденний обсяг його відвідувачів, так і тенденції її (системи) зміни в разі покращення якості життя у місті.*

Ключові слова: *зовнішня мобільність, міська мобільність, приміська мобільність, середня відстань поїздки, дані мобільного оператора.*