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## **Analysis of commuting in the Moscow region using GIS techniques**

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### **Abstract**

The distance and time of home-workplace commuter journeys of more than 700,000 workers in the Moscow region have been determined by GIS techniques using data from the year 2001. This has allowed visualization of commuting patterns in the Moscow region in the framework of a geospatial approach and an analytical study of their individual characteristics. The topicality and perspectives of the proposed innovative analysis techniques of commuting patterns are discussed.

**Keywords:** commuting, GIS, commuting maps, gender, age, incomes, spatial patterns, regional economics.

**JEL codes:** R23, R12, J61, J16, J31.

### **Introduction**

The timeliness of commuting research is closely related to the necessity of monitoring and controlling of commuter roots. Qualitative management and control of labor mobility is a key factor in efficient economic development at any level (institutional, regional and national) since implementation of any project is highly dependent on the presence and quality of the available human capital. It is uncontroversial that the range and intensity of commuting in large modern agglomerations demonstrates a significant macro influence on the socioeconomic situation in the region, as has been demonstrated in our earlier research<sup>1</sup>.

The present paper develops a new approach in the analysis of commuting that involves the implementation of GIS processing technologies. This elevates commuting studies to a new qualitative level in order to address a number of applied and theoretical problems.

### **1 GIS technologies in commuting analyses**

The application of GIS technologies when analyzing commuting can be effective and usually uses two approaches considered below.

#### **1.1 Spatial approach**

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<sup>1</sup> Шитова Ю.Ю. (2006): "Маятниковая трудовая миграция в Московской области: методический и прикладной анализ", Экономический журнал ВШЭ. №1., 63-79; 2. Yu.Yu. Shitova, Yu.A. Shitov (2008) Analysis and Forecast of Labor Commuting //Studies of Russian Economic Development, 19, 2008, 405-412; Шитова Ю.Ю., Шитов Ю.А. (2008): 'Микроанализ маятниковой трудовой миграции в Московской области', Регион: экономика и социология, №4, 119-137.

Visualization of commuter home-workplace routes enables the formation of a spatial pattern of population labor mobility (direction, length and intensity), identification of districts of labor attraction and outflow, analysis of the disproportion between supply (place of residence) and demand (place of work), and estimation of the main loads on transport routes.

## **1.2 Analytical approach**

An analytical approach is possible if the GIS information is linked at the micro-level to the individual characteristics of commuters (gender, age, income, etc.) and/or their employers (industry, form of ownership, enterprise size, etc.). In this case, it is possible to analyze the social structure of the migrants and the impact of individual factors on labor mobility as well as characteristics of the businesses attracting commuters.

However, the main problem of such research is a desperate shortage of data. Therefore, despite generally high interest in the analysis of commuting (about one hundred research articles per year), the total number of papers applying GIS technologies for the last 10 years is numbered in tens. Furthermore, the majority of these papers applied a GIS for aggregation of spatial variables (for example comparative weight of districts according to area, average time estimation, route lengths over the region, etc.). The calculated variables were then used in multiple regression analyses. As examples we mention the research of the spatial interaction of housing and labor markets in North West England<sup>2</sup>, intra-urban variation of commuting time and distance in Columbus (Ohio, USA)<sup>3</sup>. However, in these studies GIS was used as a subsidiary tool.

A direct spatial approach was applied to build commuting transport routes in New York and Amsterdam using the full power of GIS technologies<sup>4</sup>. A good example of an analytical approach is the research of the interregional migration of British students, where the geography of school-university-first job shifts was estimated by way of a GIS platform<sup>5</sup>. One of the fullest researches is an analysis of ecological influence (carbon dioxide emission) on the environment depending on commuter journeys and alternative transport movement models and scenarios based on GIS data (residential and working addresses of 1829 people surveyed)

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<sup>2</sup> Stephen Hincks, Cecilia Wong (2010): "The Spatial Interaction of Housing and Labour Markets: Commuting Flow Analysis of North West England", *Urban Studies*, March 47(3), 620-649.

<sup>3</sup> Fahui Wang (2001): "Explaining intraurban variations of commuting by job proximity and workers' characteristics", *Environment and Planning B: Planning and Design* 28(2), 169-182.

<sup>4</sup> Daniel Arribas-Bel, Michiel Gerritse (2012): "Monocentricity? Commuting flows visually", *Environment and Planning*, A44(9), 2041-2042.

<sup>5</sup> Alessandra Faggian, Philip McCann, (2004): "Human Capital Flows and Regional Knowledge Assets: A Simultaneous Equation Model", ERSA conference paper, ersa04p354, <http://www.sre.wu-wien.ac.at/ersa/ersaconfs/ersa04/PDF/354.pdf>.

from a special transport survey made of the Vodafone company<sup>6</sup>. It is also important to note the analysis of intraday bicycle commuting data in commuter flow analysis<sup>7</sup>.

GIS-based studies related to the topic of the present research mostly focus on the following two directions.

### **1.3 Analysis of GIS maps**

Analysis of GIS maps, via graphical identification of natural and artificial landscape objects on the maps, with the purpose of reconstructing nature or human activity patterns and their further analysis. Examples include comparative analysis of the structure and economic force of the regions of China as a whole and the development of agricultural districts in the province of Guangxi in particular<sup>8</sup>; research (simulations) of Madrid agglomeration growth scenarios<sup>9</sup>; comparative analysis of economic development of the administrative districts of Romania<sup>10</sup>; analysis of land use for ecotourism planning in Thailand<sup>11</sup>.

### **1.4 GIS analysis of GPS data**

GIS analysis of GPS data, received from moving objects under study (cars, public transport, etc.), for example analysis of the interaction of participants with the transport network in Minnesota<sup>12</sup>. However, such surveys are more related to transport assessment and modeling and are aimed at research into aspects of driver behavior.

In summary, it should be noted that with all the variety of individual commuting researches and GIS analytics there are only a few works at the interface of these two approaches. The research method described in this paper combines microanalysis with GIS technologies to provide an innovative and unique approach to fine details of the commuting

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<sup>6</sup> Wood G (2003): "Modelling the ecological footprint of green travel plans using GIS and network analysis: from metaphor to management tool?", *Environment and Planning B: Planning and Design* 30(4), 523-540.

<sup>7</sup> Michael S. Smith, Goran Kauermann (2011): "Bicycle commuting in Melbourne during the 2000s energy crisis: A semiparametric analysis of intraday volumes", *Transportation Research B* 45, 1846-1862.

<sup>8</sup> Guo Wen-bo, Wan Qing (2011): "Industrial Structure and Competitive Strength of 31 Provincial Districts --A GIS-based Dynamic Shift-Share Analysis", *Asian Agricultural Research* 3(1), 127-129; Liao Wei-hu (2011): "ESDA-GIS Analysis of Spatial-temporal Disparity in Rural Economic Development of Guangxi", *Asian Agricultural Research* 3(2), 20-23.

<sup>9</sup> Wenseslao Plata-Rocha, Montserrat Gomez-Delgado, Joaquin Bosque-Sendra (2011): "Simulating urban growth scenarios using GIS and multicriteria analysis techniques: a case study of the Madrid region, Spain", *Environment and Planning*, B38, 1012-1031.

<sup>10</sup> Sorin Daniel Manole, Alexandru-Ionuț Petrisor, Antonio Tache, Ecaterina Pârvu (2011): "Gis Assessment Of Development Gaps Among Romanian Administrative Units", *Theoretical and Empirical Researches in Urban Management*, 6(4).

<sup>11</sup> Khwanruthai Bunruamkaew, Yuji Murayama (2012): "Land Use and Natural Resources Planning for Sustainable Ecotourism Using GIS in Surat Thani, Thailand", *Sustainability*, 4, 412-429.

<sup>12</sup> Shanjiang Zhu, David Levinson (2010): "Do people use the shortest path? An empirical test of Wardrop's first principle", University of Minnesota, Nexus Research Group WP 000059,

<http://nexus.umn.edu/Papers/ShortestPath.pdf>; 15. Michael Scharenbroich, Michael Iacono, David Levinson, (2009): "How Local Is Travel?", University of Minnesota, Nexus Research Group, WP 000058,

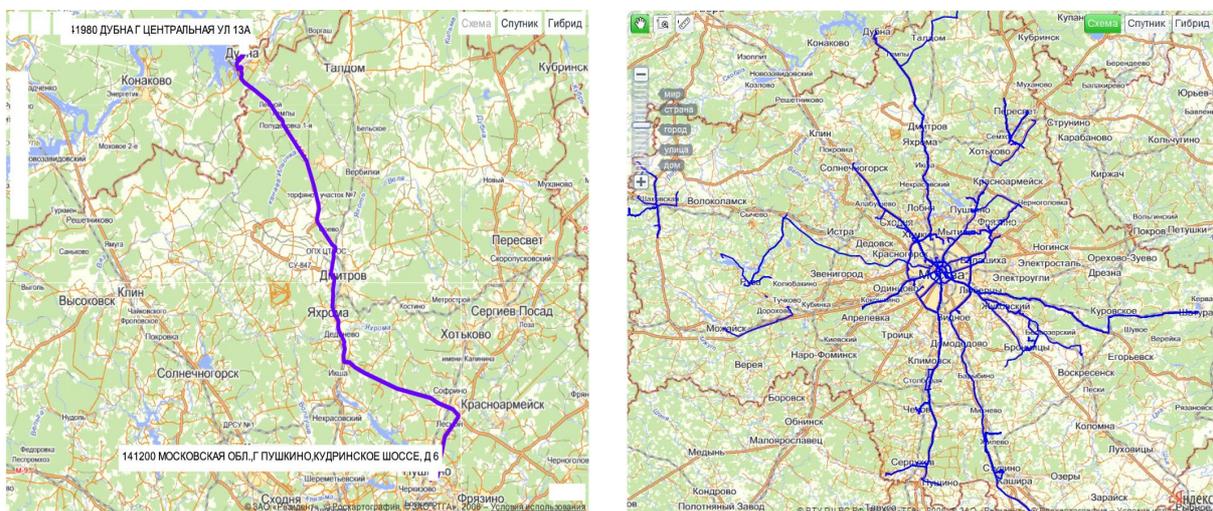
<http://nexus.umn.edu/Papers/HowLocalIsTravel.pdf>; Arthur Huang, David M. Levinson (2012): "Accessibility, network structure, and consumers' destination choice: a GIS analysis of GPS travel data", University of Minnesota, Report no. CTS 12-14; Nexus Research Group WP, <http://nexus.umn.edu/Papers/RetailDestinations.pdf>.

process that still remain an open question. Combining analysis of commuting patterns in the Moscow region together with the individual behavior of commuters is the key to the power of the method proposed and is discussed further.

## 2 GIS processing of micro data

The basis of this research is a unique micro data for the year 2001 that covers 60 per cent of working-age population of the Moscow region. The original data were from data bases (DB) of the Tax inspectorate of the Russian Federation (RF), the Pension Fund of the RF and the State Register of Russian Enterprises. These confidential data have been leaked to open internet access due to the illegal actions of unknown criminals. With these data in the public domain, and with our statistical analysis methods preventing disclosure of personal information, we have found it worthwhile to use this unique information (unavailable by any other means) for scientific purposes<sup>13</sup>. The primary data from different DBs have been merged<sup>14</sup> in order to link the places of residence (*PR*) and work (*WP*) together with employee personal data (*PD*: annual income, age and gender) and employer characteristics (*EC*: activity status, form of ownership, capital, etc.). As a result a secondary DB has been created, which contains almost one million records of employees in the following format:

*Employee (WP, PR, PD, EC)* 1)



**Figure 1.** Reconstruction of a single path using a commuter’s house and work postal addresses (left) and a commuting map reconstructed from a small data sample (right).

<sup>13</sup> Yu.Yu. Shitova, Yu.A. Shitov (2008) Analysis and Forecast of Labor Commuting //Studies of Russian Economic Development, 19, 2008, 405-412; Шитова Ю.Ю., Шитов Ю.А. (2008): ‘Микроанализ маятниковой трудовой миграции в Московской области’, Регион: экономика и социология, №4, 119-137.

<sup>14</sup> The merging was made by key field – employee’s TIN (Tax Identification Number) present in all DBs.

In the next stage, GIS technologies are used to reconstruct the house-workplace route of each commuter. A special web application using the Yandex map API<sup>15</sup> has been created for this purpose<sup>16</sup>. For each commuter this program builds a path on the regional transport network between the commuter's place of residence (*PR*) and work (*WP*) determined by postal addresses in the secondary DB. In fact, the program solves the navigation task in much the same way as a normal car navigation system. The principal difference is that it is performed in semi-batch mode processing large scale data sets and returning quantitative data on reconstructed routes for thousands of records. In comparison, a typical navigation system works in single interactive mode with manual input and graphical output. An example of the results from the program is shown in Fig. 1. After GIS-processing we obtain data in a format:

$$ROUTE(X_1, X_2, \dots, X_N) = GIS(PR, WP) \quad 2)$$

where  $X_I$  are parameters of the commuting path (time, distance, and geo-coordinates) reconstructed as a polyline consisting of  $N$  route segments between the commuter's places of residence (*PR*) and work (*WP*). The total commuting distance,  $D^C$ , and time,  $T^C$ , are the most obvious and easily calculated GIS parameters which have been used for a basic analysis of commuter behavior. Finally we were able to reconstruct GIS information for ~0.8 million records (~80% reconstruction efficiency of the GIS-program) and forming the third and final DB in the format:

$$Employee(PD, EC, ROUTE) = Employee(PD, EC, D^C, T^C, \dots). \quad 3)$$

The DB (3) contains unique information about the majority of commuters in the Moscow region. The first results of its analysis in both the geospatial (commuter patterns) and analytical (analysis of commuter individual characteristics) approaches will be demonstrated further on.

### 3 Commuting maps of the Moscow region

In order to visualize geospatial commuting patterns in the Moscow region the following aggregated parameters have been calculated per district using DB (3):

- the number of citizens of the district who work in their region  $N_{Loc}$ ;
- the number of citizens of the district who work in Moscow  $N_{Mos}$ ;
- the number of citizens of the district who work in another district of the Moscow region  $N_{MR}$ ;

<sup>15</sup> <http://api.yandex.ru/maps>

<sup>16</sup> Шитова Ю.Ю., Шитов Ю.А. (2012): 'ГИС-моделирование и комплексный анализ пространственной структуры и потоков маятниковой трудовой миграции в регионе на примере Московской агломерации', XIII Международная научная конференция «Модернизация экономики и общества», 3-5 апреля, ВШЭ, Москва, <http://regconf.hse.ru/uploads/a8cf29519a6283e1882983243c8f6eb22a86e0c5.pdf>, <http://www.gosbook.ru/node/55149>.

- the number of workers in the district who live in other districts of the Moscow region  $N_{FMR}$ .

Commuter fluxes have been normalized to the working-age population of the districts ( $WP$ ) and are presented in Table 1.

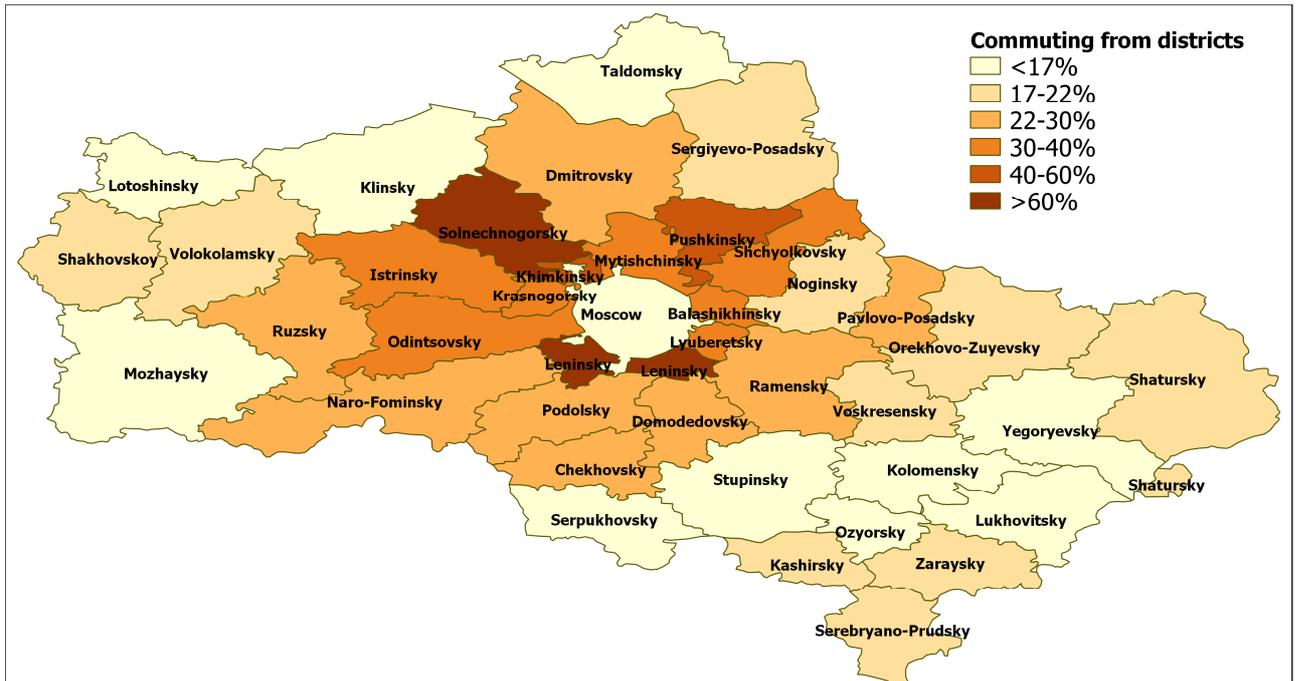
**Table 1** Commuter fluxes in the Moscow region (MR) in 2001.

№	District	Working-age citizen $WP$ , people.	Place of work of the citizens of a district, people			Commuters from MR, $N_{FMR}$ , people.
			Own district, $N_{LOC}$	Moscow, $N_{MOS}$	Other district of MR, $N_{MR}$	
1	Balashikhinsky	215574	20036	65770	5489	9146
2	Volokolamsky	30071	8109	4152	1718	640
3	Voskresensky	92650	26911	14552	4661	2547
4	Dmitrovsky	88910	28138	16946	5079	2095
5	Domodedovsky	73126	6075	15428	2580	3283
6	Yegoryevsky	62983	32286	8089	2160	1048
7	Zaraysky	26906	13536	3026	1552	165
8	Istrinsky	69317	26746	16968	4571	3045
9	Kashirsky	43549	14618	6014	2701	1492
10	Klinsky	80246	18743	8351	2911	4075
11	Kolomensky	114915	65663	10641	3370	4824
12	Krasnogorsky	88778	13038	25581	2488	6817
13	Leninsky	79224	30093	44797	5431	3166
14	Lotoshinsky	10478	2135	1179	398	221
15	Lukhovitsky	37969	10152	3686	2173	1588
16	Lyuberetsky	201192	55310	61677	6864	9140
17	Mozhaysky	39727	19893	5242	1342	3602
18	Mytishchinsky	198087	39431	64433	8670	35075
19	Naro-Fominsky	103838	1180	21757	2753	2530
20	Noginsky	228332	116977	34397	7493	10100
21	Odintsovsky	163496	36164	47394	4091	13512
22	Ozersky	22635	3926	2276	1546	224
23	Orekhovo-Zuevsky	148431	28461	23088	4701	3566
24	Pavlovo-Posadsky	62492	6558	11073	3068	902
25	Podolsky	230686	85395	47107	5206	6332
26	Pushkinsky	164093	73440	61333	29760	12936
27	Ramensky	194238	34152	39588	7443	19060
28	Ruzsky	40258	16728	6906	3738	1067
29	Sergievo-Posadsky	137856	66329	19067	6694	2018
30	Serebryano-Prudsky	14238	6406	1611	1379	82
31	Serpukhovsky	133217	60174	17995	3641	1804
32	Solnechnogorsky	73776	51144	57458	6548	4775
33	Stupinsky	64700	24777	8395	2194	2804
34	Taldomsky	70597	29187	9394	2298	1624
35	Khimkinsky	103915	22777	41364	3873	9955
36	Chekhovskoy	57134	15903	10589	4441	1537
37	Shatursky	56674	27525	9215	2134	1253
38	Shakhovskoy	14418	4034	1826	663	167
39	Schelkovsky	169457	69038	35814	28431	5350
<b>Total</b>		<b>3808183</b>	<b>1211188</b>	<b>884179</b>	<b>196253</b>	<b>193567</b>

The map of outgoing commuting, calculated as:

$$R_{OC} = (N_{MOS} + N_{MR}) / N_{LOC}, \quad (4)$$

is shown in Fig. 2, where one can see a radial increase of commuting intensity when approaching Moscow. This effect, which was discovered and quantified in our previous surveys by other macro analysis methods<sup>17</sup> is confirmed now by the GIS analysis. The total daily commuter flux between Moscow and its periphery was found to be ~ 0.9 million workers which is in good agreement with our previous estimates as well as the estimates of other authors.



**Figure 2.** Map of outgoing commuting flux calculated from (4) for the Moscow region in 2001.

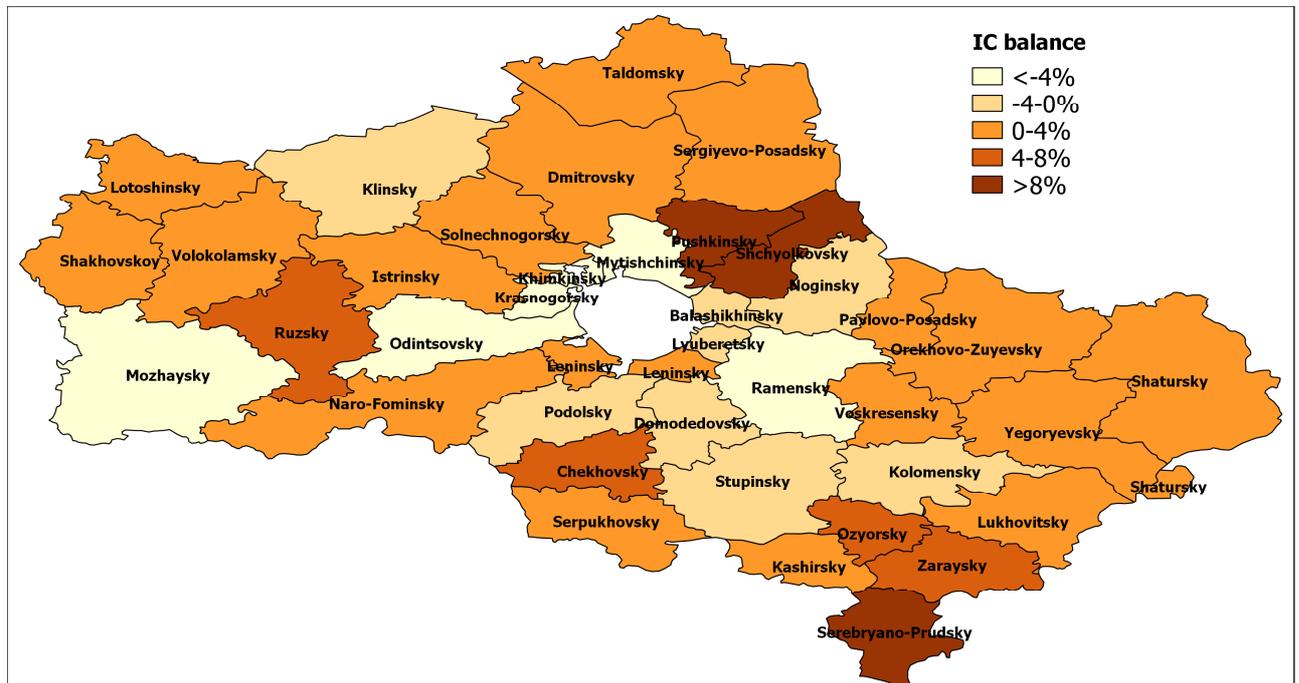
*Interdistrict commuting* (IDC) involves citizens who live and work in different districts of the Moscow region. It is a second order effect in comparison with the mainstream center-to-suburbs flux, but it is also a subject of particular interest. The balance of the IDC pattern, calculated as:

$$R_{IDC} = (N_{MR} - N_{FMR}) / N_{LOC}, \quad (5)$$

is shown in Fig. 3. On Fig. 3 one can see that a positive balance (interdistrict commuting outflow) is typical for districts located far from the center. While negative balance (interdistrict commuting inflow) can be seen in the districts located in the middle of the Moscow region. This means that some of the citizens of the districts situated 50-70 km from

<sup>17</sup> Шитова Ю.Ю. (2006): “Маятниковая трудовая миграция в Московской области: методический и прикладной анализ”, Экономический журнал ВШЭ. №1., 63-79.

Moscow, i.e. more than one-hour accessibility, go from work to districts situated in the middle of the Moscow region in order to decrease time and commuting transport costs.



**Figure 3.** Outflow-inflow balance of inter-district commuting in the Moscow region in 2001.

Let us proceed from the qualitative geospatial GIS analysis to a quantitative assessment of the individual characteristics of commuters.

#### 4 Individual characteristics of commuters in the Moscow region

The analysis of the individual characteristics of commuters gives an insight into factors and mechanisms underlying the phenomenon. The individual behavior of commuters is a subject of intensive study, a detailed review of which is presented in<sup>18</sup>. The use of data from DB (3) makes it possible to perform a detailed analysis of the individual characteristics of commuters.

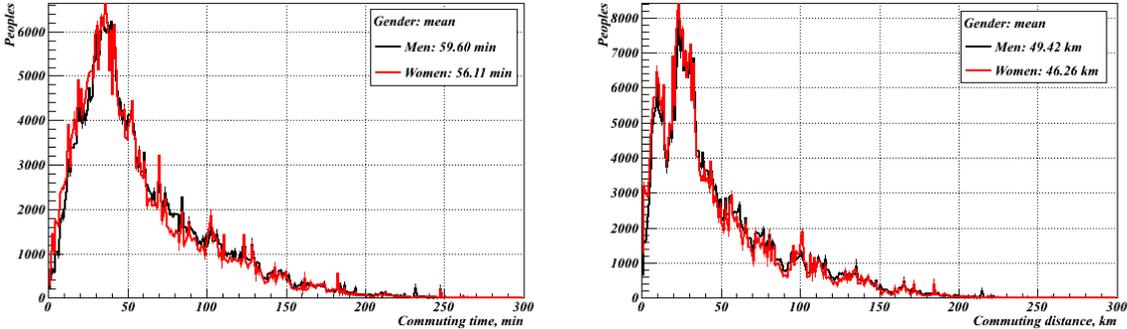
##### 4.1 Gender

Fig. 4 demonstrates the distance and journey time distribution of commuters of the Moscow region according to gender.

It should be pointed out that the average time spent by commuters for a single trip is 1 hour, while the average distance travelled is 50 km. One can see though that many employees spend ~35 minutes for a distance of 30 km (the peaks on Fig. 4). One should also emphasize that the distributions of commuting distance and duration for women and men are almost

<sup>18</sup> 1. Шитова Ю.Ю., Шитов Ю.А. (2011): 'Статус исследований индивидуального поведения маятниковых трудовых мигрантов', Соционет, [http://purgenetik.socionet.ru/files/shitova\\_mtm\\_review.pdf](http://purgenetik.socionet.ru/files/shitova_mtm_review.pdf).

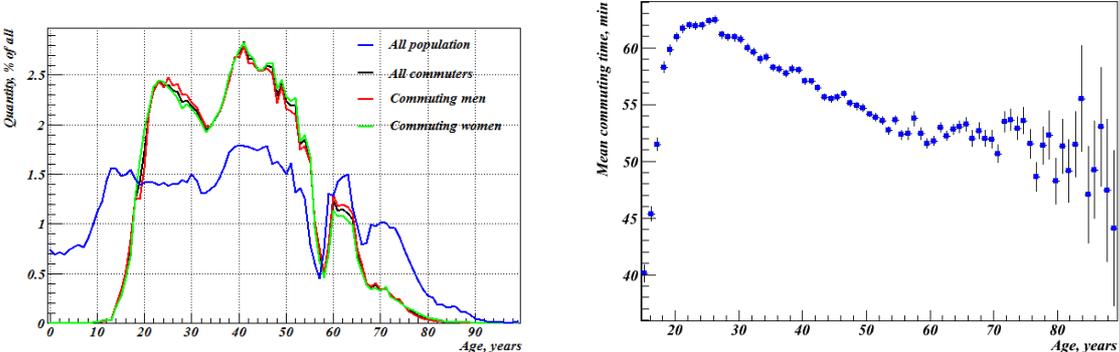
identical. The differences in average values are essentially less than their dispersion. Thereby, this result rejects the hypothesis of a lower commuting mobility of women and proves that women in the Moscow region commute on an equal basis with men.



**Figure 4.** Distribution of time (left) and distance (right) of commuter journeys in the Moscow region.

### 4.2 Age

The age distribution of commuters as well as average time of home-workplace routes in relation to age are shown on Fig. 5. It should be noted that the age distributions of commuting men and women are almost the same and this once again confirms the gender equality in relation to participation in commuting<sup>19</sup>. At the same time the age distribution of all citizens differs from that of the commuters. Comparing the two, it is evident that individuals of the “golden working age”, 20-50 years, dominate the group of commuters with a corresponding lack of older workers (>55 years). It is also clear that the youngest commuters (20-30 years old) are making the longest commuting journeys (see Fig. 5, right). Hereafter the commuting time steadily decreases with age.



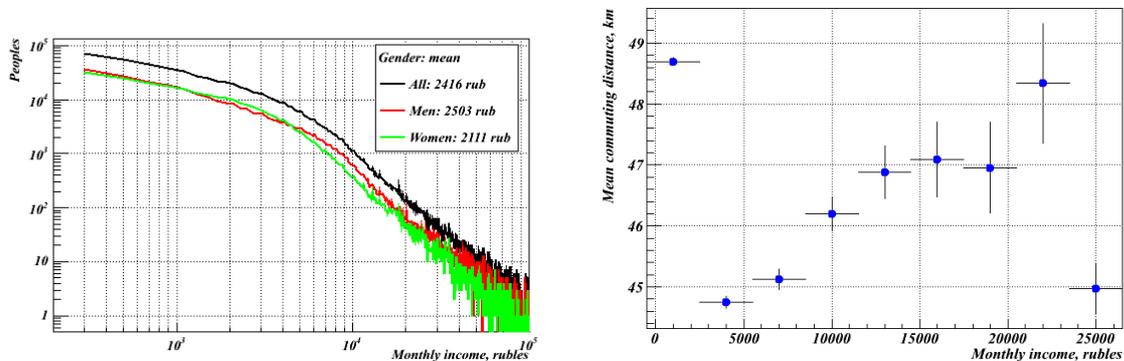
**Figure 5.** Age distributions of all the population and commuters of different genders (left).

<sup>19</sup> The sharp drop at the age of 68 years is a clearly visible consequence of the Second World War.

All histograms are normalized to the total number of individuals in the corresponding groups taken as 100%. Average commuting time as a function of age (right). Moscow region, 2001.

### 4.3 Income

The income of commuters declared to the Pension Fund of the Russian Federation (PFRF) is a decreasing exponential curve, as is shown in Figure 6 (left). Whereas it should be noted that there is an anomalously large number of low declared wages, below the living wage of 1581 RUB<sup>20</sup> (average value in the Moscow region in 2001). This indicates an enormous amount of cash-in-hand<sup>21</sup> wages as already pointed out in our earlier research (Shitova, 2008). We believe that this group includes workers with shadow wages as, based on common sense, it is impossible to assume that 50-60% of commuters work for a wage that is below the poverty line.



**Figure 6.** Distribution of commuter income (left) and average distance of commuter trips as a function of commuter income (right).

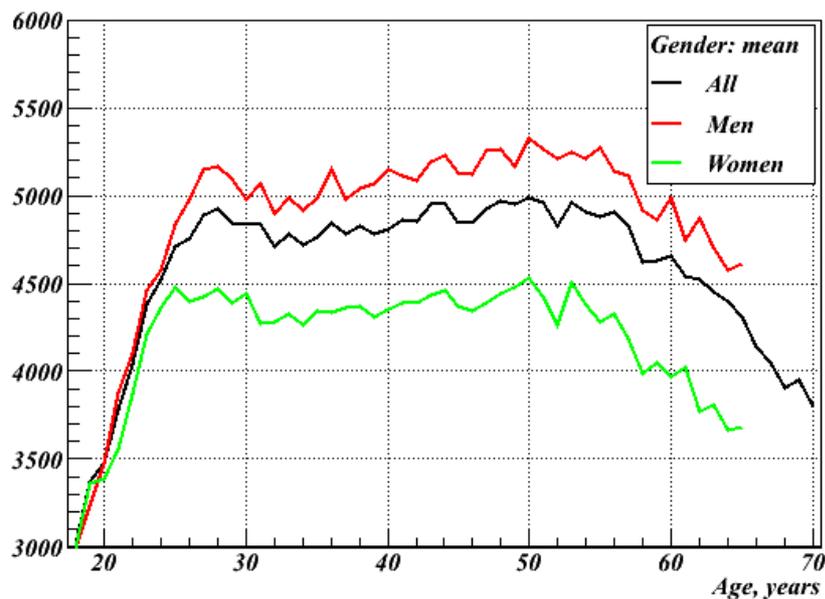
In addition, we note that the average income of women was 2111 RUB, that is 18.6 per cent less than that of men whose average income is 2503 RUB. Thereby on the scale of the Moscow region there are signs of gender discrimination according to the level of income.

The distribution of the average length of commuting journeys depending on commuter income is shown in Fig. 6 (right). The first data point on the graph includes commuters with cash-in-hand wages and hence with unknown actual income. Therefore the obvious conclusion from this data point is that it confirms the fact that a cash-in-hand wage is a global phenomenon happening at all working places and, as a result, does not depend on commuting length. The data of the last point should also not be considered qualitative due to the nature of the data. The data for the group of commuters with very high income is contaminated by income from other non-wage assets (shares, property, dividends, etc.), which moves into the

<sup>20</sup> Here and further values are given in Russian Rubles (RUB). In 2001, one U.S. dollar was worth ~29 RUB on average.

<sup>21</sup> Other terms widely used in Russia are grey, dark, gray, hidden, illegal, backdoor, and shadow wages, which implicitly demonstrates how widespread this phenomenon is.

last bin commuters from lower level groups. After exclusion of these two problematic boundary points we observe that the average length of commuting journeys grows with increasing income. It means that high-skilled workers (HSW) commute farther and longer than low-skilled workers (LSW), which follows from most theories of commuting. Figure 7 shows the distribution of average income of commuters depending on their age. The maximum income is earned by workers of 25-55 years old. Inside this group a peak is observed at 27-28 years, and a slight increasing slope between 30 and 50 years. The steep slope at the left of the figure corresponds to the careers of youngsters starting paid jobs, while the slope at the right might correspond to wage discrimination of aged workers forced to take less well paid positions. It is interesting that the shape of the curves is the same for both men and women, while the difference in amplitudes undoubtedly demonstrates the aforementioned gender discrimination.



**Figure 7.** Distribution of the average income of commuters depending on their age and gender.

## Conclusion

The present work demonstrates the application of GIS technologies to the analysis of commuting in the Moscow region. The use of such an approach became possible thanks to the ability to reconstruct the commuting journeys of 0.8 million workers using GIS analysis.

The geospatial patterns of the main center-periphery and additional inter-district commuting fluxes in the Moscow region have been built. Reconstructed GIS information in combination with micro data were used to analyze commuting from a point of view of the individual characteristics of workers: gender, age and income. On average, commuters cover

50 km between home and work, spending one hour one way. No difference has been found between the commuting length and time of men and women. At the same time, women's wages are 20 percent lower than those of men. The farthest and the longest trips are made by commuters of 22-30 years old, after which mobility decreases steadily with age. Finally, highly skilled commuters with high wages commute farther and longer than low skilled and low paid workers.

The approach proposed in this work has great potential for further development. This work demonstrates only the first results of an analysis of combined GIS-micro data. The next phase will be a more detailed quantitative analysis of the geospatial patterns of commuting in order to monitor areas of attraction and outflow of the work force, disproportions between supply (place of residence) and demand (work place), and the loading maps of commuter transportation routes in the agglomeration. These data are very important and relevant for both the theory and practice of regional management.

The combined GIS-micro data approach proposed for the analysis of commuting in this work is a pioneering one and it has been applied for the first time in world practice on a dataset of such a scale.

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