ORIGINAL ARTICLE
DOI: https://doi.org/10.30932/1992-3252-2022-20-4-4

World of Transport and Transportation, 2022, Vol. 20, Iss. 4 (101), pp. 184–204

Sample Survey of Passenger Traffic by Analysing Wi-Fi Data in Moscow Transport Hub. Part 2

Nikolai Yu. ALEKSEEV

Nikolai Yu. Alekseev
Sitronics Group, Moscow, Russia.
✉ *alekseev-trn@mail.ru.*

ABSTRACT

In modern, rapidly developing cities of the world, building an urban transport model requires traffic data. The lack of those data does not allow making timely management decisions on distribution of passenger flows, namely within transport flows.

Currently, there are various methods and systems for counting passenger flows, such as the manual staff counts, survey and counted ticketed entries methods, and various automated technology-based systems. However, those well-known methods have their drawbacks.

For this reason, the task to search for alternative methods and data sources for the study of passenger flows remains relevant.

This article is based on the updated results of the study recently conducted by the author during preparation of his master's thesis. During the study and developing previous author's papers, data on connections of passengers to Wi-Fi routers were chosen as a data source. Since this phase of the study was conducted on the territory of Moscow transport hub, in metro and on Moscow Central Diameters (MCD), where the cars are equipped with great number of Wi-Fi routers, with free connection and Internet access, it has increased the sample Wi-Fi data array significantly.

The objective of the study was to study the possibility of processing Wi-Fi data obtained from Wi-Fi scanners as a passenger flow analysis tool.

The study has revealed that, on average, up to 40 % of passengers in metro and MCD cars on the studied lines use the WI-FI module turned on in their mobile devices.

The results of the study have confirmed that Wi-Fi data can be used as a tool for passenger traffic analysis, but at the same time revealed the necessity to integrate them with other data sources, as well as the strong dependence of the result of Wi-Fi data processing on the technical features of the Wi-Fi scanner and its location in the vehicle during experiments.

This issue contains the second part of the article.

Keywords: *transport, urban public transport, urban mass transit, metro, city railway, passenger flow, data analysis, Wi-Fi analytics.*

Acknowledgements: *the author expresses his sincere gratitude to Pavel V. Zyuzin, Ph.D. (Geography), Senior Researcher at the National Research University Higher School of Economics, for his inestimable assistance in conducting the study and in preparing publication of its results.*

For citation: *Alekseev, N. Yu. Sample Survey of Passenger Traffic by Analysing Wi-Fi Data in Moscow Transport Hub. Part 2. World of Transport and Transportation, 2022, Vol. 20, Iss. 4 (101), pp. 184–204. DOI: https://doi.org/10.30932/1992-3252-2022-20-4-4.*

The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

• © Alekseev, N. Yu., 2022

World Experience in the Field of Wi-Fi Analytics

Given the growing number of Wi-Fi devices and Wi-Fi equipment within the territory of Moscow agglomeration, it was necessary to solve the problem of systematising the existing methods of collecting data in the field of Wi-Fi analytics.

The Case of the Hong Kong Polytechnic University

A relevant case can be studied using the example of the Hong Kong Polytechnic University (PolyU). The empirical data were collected by the author during academic internship from August through November 2018.

There were 12 Wi-Fi/Bluetooth scanners on the territory of the university, designed to monitor pedestrian flows. Besides the stationary Wi-Fi/Bluetooth scanners, video cameras were installed. For the study, the author was provided access to all 12 Wi-Fi scanners, namely, to the daily upload of Wi-Fi and video data.

The main task was to study the pedestrian flows before and after construction of the pedestrian bridge. At the time of the study, there was an underground pedestrian crossing under the highway between the main buildings of the university and the administrative building. The pedestrian bridge, once built, would be an alternative way to move between the main buildings and the administrative one.

The core of the study was to process the so-called MAC addresses. The MAC address, as it is well known, is a six-digit device code (AA: BB: CC: DD: EE: FF) assigned by the device manufacturer. Each hardware manufacturer that manufactures products for use on the Internet assigns a unique MAC address to each device that is released. Each manufacturer has a different number of MAC addresses. The first three values of any MAC address (AA: BB: CC:__:__:__) can be used to identify the manufacturer of the equipment. The next three values (__:__:__: DD: EE: FF) are rather different and unique to each device.

The first two months were devoted to the analysis and processing of Wi-Fi data. To assert that the recorded MAC address belongs to a specific device, and a specific device, respectively, is kept by a potential pedestrian, the researcher studied time periods and compared them with video camera data. In practice, this happened as follows: the researcher chose two Wi-Fi scanners, which were located at the entry and at the end of the pedestrian underpass. Also, in addition to the Wi-Fi scanners there were two video cameras located in the immediate vicinity of them. Accordingly, 15–20-minute time lapses were analysed and then the received Wi-Fi data were compared with the video data. As a result, it was possible to identify the *n*-number of pedestrians by their MAC addresses. Pedestrians were moving in different directions, both towards the administrative building and back. The results of the study allowed to state that potential pedestrian flows and their directions can be determined based on the MAC address of the device and the received timestamp.

Other Sources

The article [17] describes the results of the research in Nairobi, the capital of Kenya, where 42 Wi-Fi scanners were installed near the transport interchange hub to collect and analyse the received Wi-Fi data. The authors managed to determine the average number of mobile devices with the Wi-Fi module enabled, the range of detection of Wi-Fi devices, and to estimate the number of pedestrians (passengers) and their waiting time at public stops. Based on the data obtained, the authors proposed to local authorities to amend the rules for organising bus routes.

According to information obtained from open access sources[1], in most cases, Wi-Fi scanners, also called Wi-Fi sniffers (traffic analysers) and Wi-Fi radars, are used in the Russian Federation at retail facilities, namely, in shopping centres to analyse potential buyers. A Wi-Fi «radar» is installed in the centre of the hall of a shop and scans all the MAC addresses of devices of the owners who enter and exit this particular room. This is based on the prevalence of free Wi-Fi in shopping centres, and, accordingly, of free Internet access, so that potential buyers can turn on the Wi-Fi module in their device (for example, in a phone, laptop, etc.).

In the article [18], the authors studied the technical characteristics of Wi-Fi scanners, namely the influence of antennas on the result of collecting Wi-Fi data. The resulting data were used to estimate travel times for pedestrians and cyclists.

The authors of another article [19] estimated the waiting time for public transport passengers

[1] Website of manufacturers of Wi-Fi radars. [Electronic resource]: https://hot-wifi.ru/radar/. Last accessed: 10.04.2022.

Table 2

Comparative characteristics of Wi-Fi scanners [compiled by the author based on equipment's characteristics][3]

	Meshlium Libelium Scanner	Wi-Fi TP-LINK router
Built-in software	+	+
Built-in Wi-Fi antenna	+	+
Built-in Bluetooth antenna	+	–
External Wi-Fi antenna	+	–
External Bluetooth antenna	+	–
Access to equipment interface	+	–
Built-in PHP Admin	+	–
Access to initial data	+	–

at the largest bus station in Tokyo, using the analysis of Wi-Fi devices. The authors created a method for estimating the time spent by passengers (pedestrians) and concluded that for obtaining more accurate Wi-Fi data, it is necessary to increase the number of observation sites and places for collecting Wi-Fi data.

The authors of the article [20] argue that easy access to the Internet along the route has a great potential to change the activities of passengers during the trip. Accordingly, in large cities the number of Internet users is increasing. Also, there is a possibility that new technologies can improve the quality of life but worsen the environment.

The authors of the article [21] studied the received Wi-Fi data from the point of their subsequent use to calculate passenger flow and concluded that this calculation requires a larger number of Wi-Fi devices. According to the authors, Wi-Fi data correlate with real passenger data, but Wi-Fi data, in their opinion, is not enough to display a complete picture of a particular passenger flow.

Thus, the studied sources have not allowed to find solutions and methods to estimate the routes of movement of potential public transport passengers that might be obtained based on Wi-Fi data.

The analysis of the public procurement website permitted to find a contract concluded in October 2020 for 152 million rubles[2] and aimed at development of an integrated information system for monitoring passenger traffic (CIS MP) as part of development of an intelligent transport system in Moscow. Under this contract, the supplier was bound to supply 20 mobile devices for monitoring passenger traffic and 200 stationary Wi-Fi scanners. The supplier had to mount this equipment, develop software, and to provide maintenance of both installed equipment and software. A reporting module had also to be created, including development of heat maps and of a reporting on the number of users, and others.

Research Methodology

To obtain a result, namely data on passenger flows, it was necessary to independently develop a research methodology that was based on the choice of a Wi-Fi scanner and development of a software for analysing Wi-Fi data in Microsoft Excel. The methodology integrated the choice of routes (research cases) and the time of measurements.

The study applied the equipment with the features shown in Table 2[3].

Within the framework if the study, the Wi-Fi scanner was used as a dynamic one. Dynamic Wi-Fi scanner implies the use of a portable power source.

The chosen Wi-Fi scanner has various technical parameters, in particular, additional Wi-Fi / Bluetooth antennas that allow adjusting the operation of the Wi-Fi scanner. As part of this work, the researcher analysed only Wi-Fi data, the technical parameters of the Wi-Fi scanner were adjusted according to the study's task, experiments were conducted to improve the results. Bluetooth data are not analysed in the work.

Wi-Fi scanner was the source of initial data, and Wi-Fi router was the source of processed Wi-Fi data.

Wi-Fi scanner has various parameters that affect the final result of data processing. The first parameter is a timestamp (TimeStamp), that is,

[2] Official website of public procurement: Creation of an integrated information system for monitoring passenger traffic (CIS MP) as part of development of an intelligent transport system in Moscow. [Electronic resource]: https://zakupki.gov.ru/epz/order/notice/ea44/view/common-info.html?regNumber=0173200001420001132. Last accessed: 10.04.2022.

[3] The numbering of the tables consecutively continues the numbering in the first part of the article.

the time at which a device was deteceted, namely, when its MAC address was detected. The chosen Wi-Fi scanner has several types of scanning intervals. Until recently, the Wi-Fi scanner had the ability to scan every 15–90 seconds, but with the update of the Wi-Fi scanner software, it became possible to scan online. This type of scanning was chosen based on the assumption that it has a great influence on the result of data collection.

The second parameter received from the Wi-Fi scanner is the MAC address. Within the framework of the study, the MAC address was a unique parameter that allowed identifying a specific Wi-Fi device, and, accordingly, a potential passenger.

During the study, a database of the MAC addresses was cumulated referring to equipment of manufacturers, such as, for example, Apple, Samsung, etc. Accordingly, given that these manufacturers mainly produce mobile devices, laptops, and other personal gadgets, it was concluded that when devices are detected, with a high degree of probability, this device is with the user, namely, with a potential passenger. And accordingly, the MAC address of this Wi-Fi device could be considered as an attribute of a passenger. The database was replenished with MAC addresses of manufacturers of network equipment such as routers, etc., for example, of D-Link international, Cisco Systems and others. Later, such MAC addresses were identified as «noise» and «cleared» at the first stage of filtering since network equipment cannot be correlated with potential passengers.

Another most important issue was associated with the «randomisation» of MAC addresses[4, 5]. Since a certain time, manufacturers of Wi-Fi devices have started to include in the software section of this device a possibility of «randomisation» of the MAC address. This technology is aimed to protect against Wi-Fi scanning to prevent from processing data and to reduce the efficiency of Wi-Fi data analysis. But after studying the sources [22], after a series of experiments and data analysis, it turned out that the existing randomisation is not used on all Android and iOS devices. Also, a lot depends on the software of the device and the date of its release. There is no exact information about which device randomises MAC addresses and which does not randomise. Moreover, within the framework of this study, a unique MAC address was discovered, more precisely, its first three values characterising the manufacturer of the equipment and attributed to Google. These MAC addresses were not manufacturer-specific but did not change over the entire scan period. On average, within 40–50 minutes when Wi-Fi data were collected, the MAC address attributed to Google did not change. That is, the existing randomisation of MAC addresses is imperfect and does not significantly affect the result.

Also, it should be noted that the MAC address is a tonic parameter that has nothing to do with personal data and mobile operator data. The MAC address is assigned by the manufacturer, the user purchases this device with the MAC address already set[6]. That is, the MAC address is not in any way linked to the mobile phone number or vehicle number. Moreover, if the Wi-Fi search mode is turned off in the mobile device, the device will not be detected. The user independently decides whether he enables Wi-Fi module in his own device.

The third parameter is SSID. SSID (Service Set Identifier) is the name of the Wi-Fi device. According to the name of the Wi-Fi device, it is theoretically possible to determine a type of a device, e.g., a mobile phone or a scanner. For example, during each trip with a dynamic Wi-Fi scanner, a large amount of data was recorded from a network called MT_FREE, which, by definition, is the name of Wi-Fi equipment in Moscow public transport network. Further, these MAC address data were deleted and not processed.

The fourth parameter is RSSI. RSSI (Received Signal Strength Indicator) is an indicator of the level of the received signal. This parameter is very important for the analysis of Wi-Fi data due to the possibility of determining an approximate distance from the Wi-Fi scanner to the Wi-Fi device. In the study, the RSSI parameter was in the range of -89 to -50 decibels. These indicators characterise the fact that all potential passengers were in close proximity to the dynamic Wi-Fi scanner.

[4] What really happens with MAC addresses' randomisation. [Electronic resource]: habr.com/ru/post/375057/. Last accessed 10.04.2022.

[5] Everything you wanted to know about MAC address. [Electronic resource]: habr.com/ru/post/483670/. Last accessed: 10.04.2022.

[6] Meshlium Technical Guide. Documentation of the Wi-Fi scanner. [Electronic resource]: https://development.libelium.com/meshlium-technical-guide/general. Last accessed 10.04.2022.

The fifth parameter is Vendor (manufacturer) described above.

Development of Software for Analysing Wi-Fi Data based on Microsoft Excel

The software is the most important element of Wi-Fi data analysis. In the framework of the study, Microsoft Excel was chosen as the basis for the analysis and processing of Wi-Fi data.

The Wi-Fi scanner collected data online. The received timestamps were synchronised with the door opening mark in MCD and metro cars. The Wi-Fi scanner identified the timestamp with the MAC address. Further, it was compared with the time of opening the car doors. The researcher independently entered the data on the opening of the car doors into a table for each route. Also, the researcher at each MCD or metro station recorded the number of passengers in the car at a given time. Thus, the researcher, along with Wi-Fi scanning, used a visual method to count passengers and then compared the actual number of passengers in the car with Wi-Fi data.

All studies, namely collection and analysis of Wi-Fi data, were carried out exclusively by the author of the work.

Data Filtering

The researcher created the following stages of data filtering and algorithms:

1. The first stage of filtering was intended to exclude Wi-Fi received from all Wi-Fi routers and other stationary Wi-Fi devices.

2. The second stage of filtering was intended to eliminate Wi-Fi data with one and the same timestamp.

3. Next, there was a stage of synchronisation of the Wi-Fi timestamp with the time of opening the car door.

Also, the data were selected to identify various properties of passenger flows such as the average travel distance and the average travel time of passengers. Data collection was carried out during morning peak hours.

Results of Empirical Study

Data collection period: February through May 2021. The studied sections included routes in Moscow Metro and MCD.

The sections described in Tables 3 and 4 were chosen following the criteria below.

All four sections have different input parameters, which, according to the author, affect the results obtained.

1. Route length.

Sections No. 1, 2, 4 are over 20 km long, and section No. 3 is 8,8 km long. Section No. 3 is a complete route and has a transport interchange hub at the Ulitsa Starokachalovskaya station with a transfer to the Bulvar Dmitriya Donskogo station.

2. Prevailing location of the line.

Sections No. 2, 4 are underground metro sections, section No. 1 is ground one, and section No. 3 is both ground and underground. These sections of Butovskaya metro line were chosen due to their different technical characteristics, which may affect the transmitted signal.

3. Nature of rolling stock coupling.

The main feature of the obtained results was that in articulated cars the result after processing Wi-Fi data turned out to be better than in trains without passages. This is due to the specifics of Wi-Fi.

4. Scanner location: floor level / upper rack.

Location of Wi-Fi scanner has key importance for the entire result of the study. When the Wi-Fi scanner was located on the upper luggage rack of the car (section No. 1), the result turned out to be close to ideal, and, accordingly, when the Wi-Fi scanner was located on the floor in trains without passages, the result turned out to be the worst, but only in a car with closed doors.

As a result, out of four sections, the best result according to the received and processed data was the result obtained when the Wi-Fi scanner was located on the upper rack (section No. 1) and for a combination of an articulated car and a Wi-Fi scanner located on the floor (section No. 4). Accordingly, the worst result was obtained in trains without passages and when a Wi-Fi scanner was located on the floor (sections No. 2 and No. 3).

Section No. 1. Butovo station (MCD-2)–Moscow Kurskaya station (MCD-2)

Data collection was carried out at the section No. 1, namely from station Butovo (MCD-2) to station Moscow Kurskaya (MCD-2) during the period from 1 to 5 March 2021. The length of this route was 29,2 km, and the average travel time was 48 minutes.

There are two transport interchange hubs on the route: Tsaritsyno station (MCD-2) and Tekstilshchiki station (MCD-2). The end point for the study was Moscow Kurskaya station (MCD-2), that in fact is also a transport interchange hub. Thus, that experimental section

Table 3

Studied sections [performed by the author]

Sections	Metro line	Initial station of the study on the route	Terminal station of the study on the route	Number of routes processed during the morning rush hour	Length of the route (km)	Average travel time
1	MCD-2	Butovo	Moscow Kurskaya	3	29,2	00:48:00
2	Zamoskvoretskaya line	Alma-Atinskaya	Belorusskaya	3	27,9	00:41:46
3	Butovskaya line	Buninskaya alleya	Bitsevskiy park	3	8,8	00:16:40
4	Tagansko-Krasnopres-nenskaya line	Kotelniki	Barrikadnaya	3	25,1	00:38:00

was used to study the features of data circulation in the areas of transport interchange hubs with a high turnover of passengers. Besides collecting Wi-Fi data, a visual measurement of the number of passengers in the car was carried out at a specific time, namely during opening and closing of car doors. The time of opening the doors and the number of passengers at the time of closing the doors of the car were recorded, thereby excluding passengers who had disembarked.

For uniformity of the study, all measurements were taken during morning peak hours, from 07:00 to 08:30 on weekdays.

To improve the result regarding section No. 1, the Wi-Fi data were also collected on the passengers who entered the starting station of the study (Butovo station (MCD-2)), Those data were collected some time before the arrival of the train near the turnstiles at the entrance to MCD-2 platform. The result depended on the location of the Wi-Fi scanner and the power of the antenna. Further, the researcher, upon the arrival of the train, entered the car, recorded the time of entry into the car, recorded the number of passengers in the car, and placed a dynamic Wi-Fi scanner on the upper rack of the car, being approximately in the middle of the car. Further, throughout the entire journey, the number of passengers in the car and the time of opening the doors of the car were recorded.

After collecting Wi-Fi data, the researcher proceeded to their processing. Using the above data processing algorithm and filtering stages, the indicators shown in Pic. 3 were obtained.

Pic. 3 shows the percentage ratio between real number of passengers and calculated number of passengers with the Wi-Fi module turned on. As we see in Pic. 3 at such stations as Kuryanovo (43 %), Pererva (43 %) and Tekstilshchiki (45 %), the ratio of real passengers and passengers with the Wi-Fi module turned on amounted to almost 50 %, which is a fairly high result.

The next stage was devoted to the analysis of the routes of potential passengers. With the help of a Wi-Fi scanner, the start and end timestamps of MAC addresses of mobile devices were determined, which made it possible to identify potential start and end points of entry and exit of a passenger. Synchronisation of the timestamp of opening of car doors was compared with the timestamp from the Wi-Fi scanner. Due to the fact that the timestamp of the MAC address of the device differed from the timestamp of the door opening, comparison of these timestamps was made with an error of 30–40 seconds. That is, a potential passenger, namely the MAC address of his mobile device, could be detected

Table 4

Features of the selected sections [performed by the author]

Sections	Route length over 20 km	Prevailing positioning of the line	Features of rolling stock coupling	Scanner location: floor level / upper rack
1	+	Ground	Articulated cars with a through passage	Upper rack
2	+	Underground	CME (coupled cars without a passage)	Floor level
3	-	Ground / Underground	CME (two-car articulated sections)	Floor level
4	+	Underground	Articulated cars with a through passage	Floor level

Pic. 1. Image of section No. 1. [Electronic resource]: https://yandex.ru/metro/moscow?scheme_id=sc34974011. Last accessed 10.04.2022.

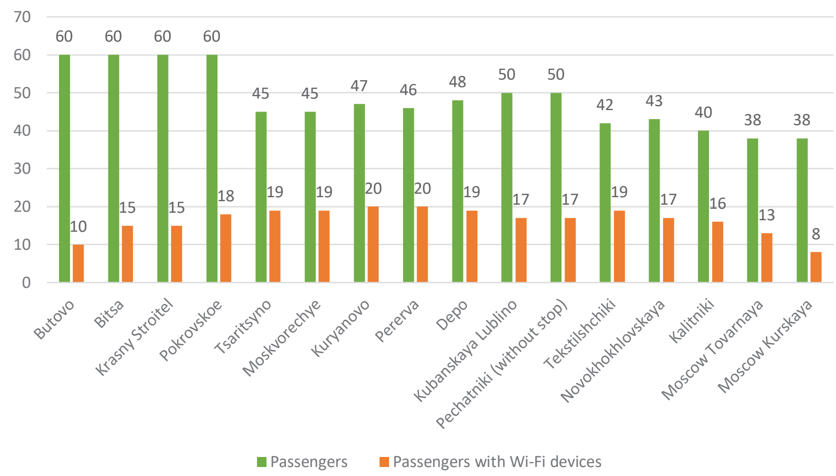
both before entering the car and just after. But considering the first and end timestamps of the Wi-Fi device, it became clear that the period of permanent detection of the Wi-Fi device between the start and end points could be from 1,5 to 38 minutes.

Thus, the routes of potential passengers with their initial and final timestamps were obtained. Detection of a timestamp of a unique MAC address was deemed to be the entry point to the car, and its loss was perceived as the exit point from the car.

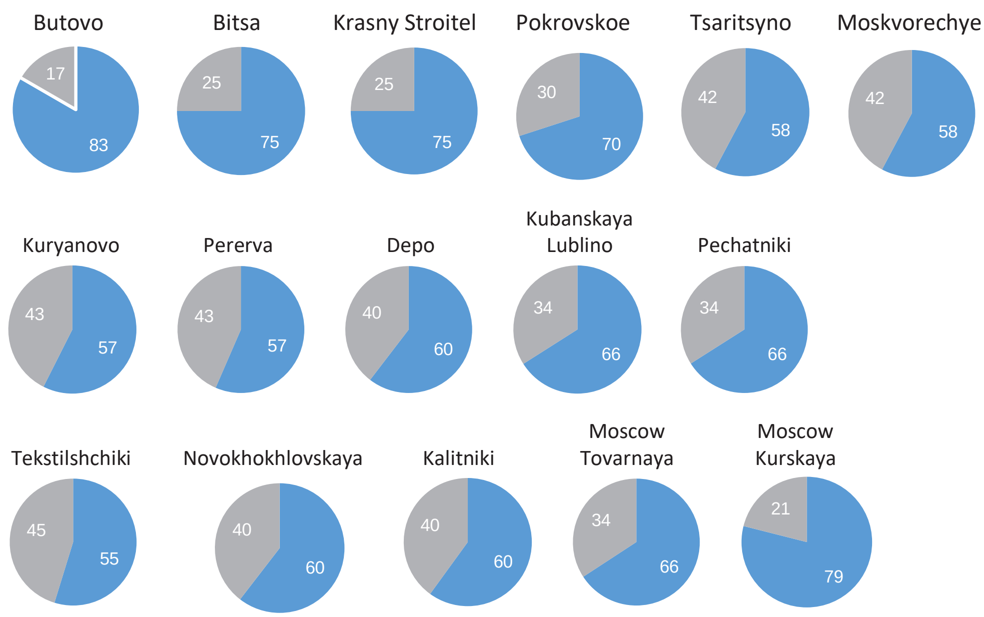
It should be noted that there is a possibility that the Wi-Fi module of the device could be turned on after entering the car as well as it could be turned off at any time. The researcher found it necessary to consider these cases as an error of the system since in this situation the human factor played an important role. But if a potential passenger turned on the Wi-Fi module later than the at the moment of entering the car, the calculation was made with the synchronisation with the nearest door opening timestamp, namely, with the nearest metro station (MCD).

With the help of the created algorithm, it was possible to determine 29 routes of specific users on section No. 1 in the considered case along the entire route. The results are shown in Pic. 4.

For each of 29 potential passenger routes, the following parameters were identified:



Pic. 2. The ratio of real number of passengers to the number of passengers with the Wi-Fi module turned on (indicated further on in the pictures as «Wi-Fi passengers»). MCD Butovo–Moscow Kurskaya section; morning rush hour. March 1, 2021 [performed by the author].



Pic. 3. The percentage ratio of the share of passengers with the Wi-Fi module turned on (grey/lighter sector) and the share of passengers with the Wi-Fi module turned off (blue/darker sector) [performed by the author].

– Travel time of a potential passenger.
– The distance travelled by the passenger.
– Starting point (entry into the MCD car).
– End point (exit from the MCD car).

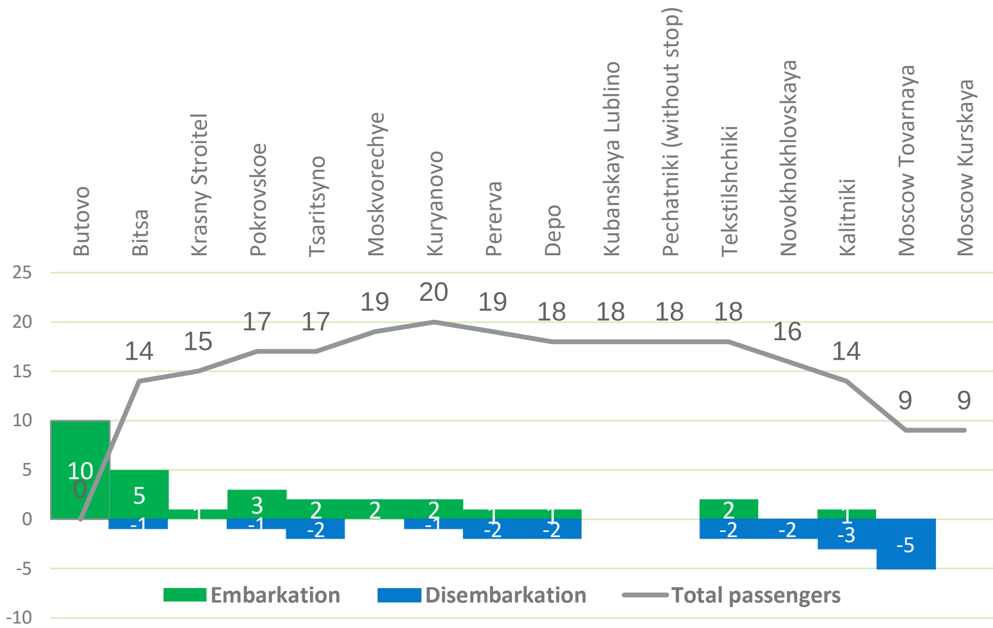
So, on all 29 routes the average travel time was determined to be 23 minutes 35 seconds out of a maximum travel time of the entire measured section of 48 minutes, and the average travel distance was of 15,09 km (out of a total mileage of 29,2 km).

See the task to determine as many characteristics (parameters) of passenger traffic as possible, the next step was to analyse the number of passengers who travelled on the studied section. Pic. 5 shows the number of those passengers, as well as the number of passengers who entered and left the cars at the stations.

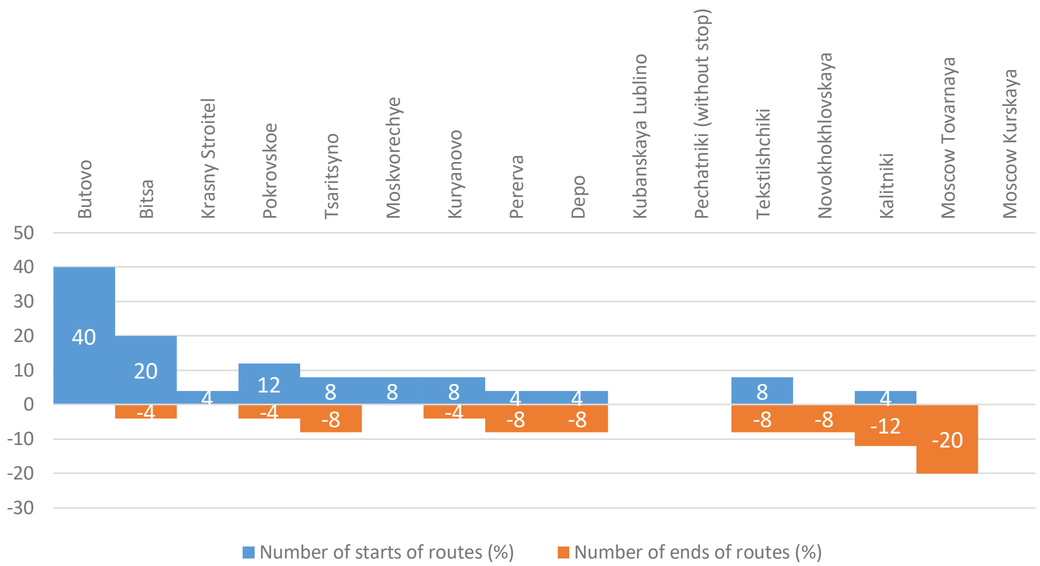
According to Pic. 6, it can be determined that more than 40 % of passengers with the Wi-Fi module turned on entered at Butovo station, or before it, since this station is not the starting one, and 20 % at embarked at Bitsa station.

Station	Butovo	Bitsa	Krasny Stroitel	Pokrovskoe	Tsaritsyno	Moskvorechye	Kuryanovo	Pererva	Depo	Kubanskaya Lublino	Pechatniki (without stop)	Tekstilshchiki	Novokhokhlovskaya	Kalitniki	Moscow Tovarnaya	Moscow Kurskaya
Number of passengers	60	60	60	60	45	45	47	46	48	50		42	43	40	38	0
Time	7:04:00	7:08:43	7:11:55	7:14.47	7:19:10	7:23:50	7:26:15	7:28:50	7:31:55	7:34:30		7:38:15	7:41:30	7:44:05	7:46:45	7:52:00
							7:26:46									7:50:23
		7:08:07										7:37:28				
	7:04:38	7:09:21														
												7:39:49				7:49:24
	7:05:27				7:17:48											
												7:37:59	7:42:47			
	7:07:25												7:42:33			
				7:17:10											7:45:21	
	7:05:33															7:47:52
						7:25:26			7:32:03							
					7:22:50									7:42:46		
							7:27:19									7:52:11
						7:24:33									7:45:54	
	7:05:35														7:45:37	
		7:08:51														7:52:00
								7:27:19						**7:44:29**		
				7:15:01				7:28:16								
														7:45:37		7:51:11
		7:06:38					7:24:44									
			7:13:48													**7:58:46**
	7:07:36							7:28:57								
					7:15:40									7:42:44		
	7:05:17														7:44:49	
	7:01:44			7:14:01												
				7:16:40											7:45:54	
	7:06:02								7:31:59							
		7:08:52														7:51:29
		7:09:58			7:17:50											
	7:04:52											7:38:01				

Pic. 4. Routes of passengers with the Wi-Fi module enabled on the section from Butovo station (MCD-2) to Moscow Kurskaya station (MCD-2). March 1, 2021 [performed by the author].



Pic. 5. Number of passengers on section No. 1 [performed by the author].



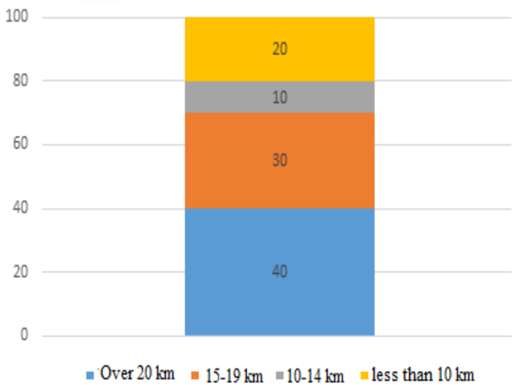
Pic. 6. Percentage ratio of number of starts and ends of routes [performed by the author].

The Pic. 7 shows the information on distribution of routes for Wi-Fi devices from Butovo station depending on the distance of their trip as a percentage. As we can see, more than 40 % of this sample travel more than 20 km, and since the length of the entire route is 29,2 km, their path is close to driving the full route, that is, to the city centre.

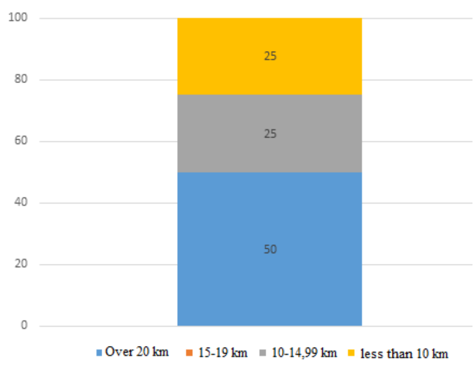
Pic. 8 shows the length distribution of trips of the passengers with Wi-Fi devices that have reached the end station Moscow Kurskaya. This picture shows that more than 50 % of this sample travel more than 20 km, which is also an indicator close to the full route.

Another indicator that can be obtained from the processed data is the share of Wi-Fi devices, namely, passengers who have travelled the entire section, that is, the percentage of the longest routes through all stations of the total number of routes of all lengths, equal to 3,45 %.

Thus, by combining data, it is possible to obtain various parameters and properties of passenger flows depending on the tasks set.



Pic. 7. Distribution of routes of owners of Wi-Fi devices from Butovo station depending on their travel distance (%) [performed by the author].



Pic. 8. Distribution of length of routes of passengers with Wi-Fi devices, which have arrived at Moscow Kurskaya station (terminal station of measurement) (%) [performed by the author].

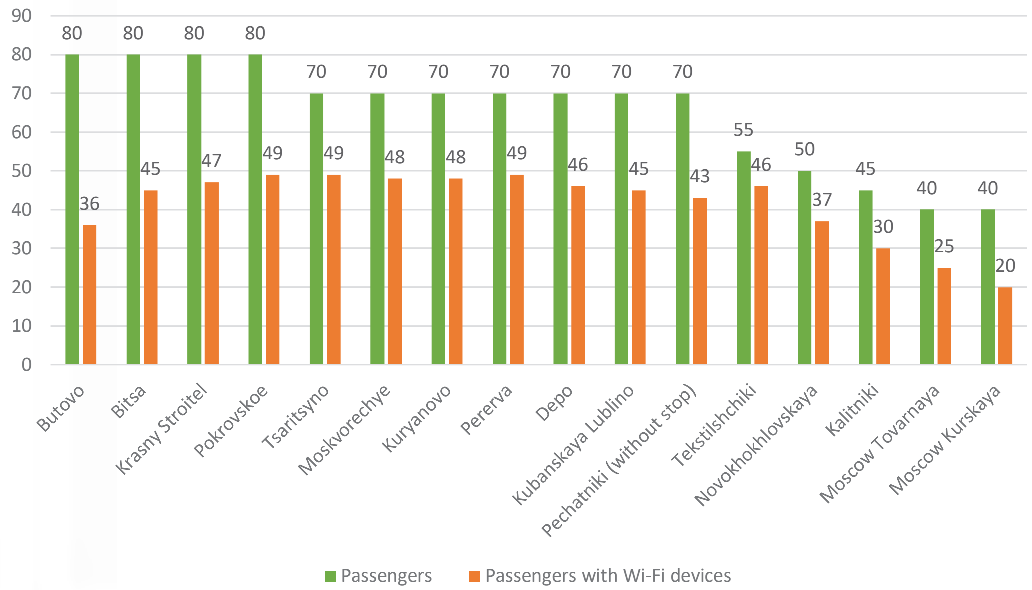
Next, we will analyse the data obtained on the above section from Butovo station (MCD-2) to Moscow Kurskaya station (MCD-2) on March 4, 2021, during morning rush hours (Pic. 9).

As a result of the study on March 4, 2021, data processing and filtering, 83 routes of potential passengers were found (Pic. 10).

As can be seen from Table 5, the result of the data on the number of detected routes of passengers is very strongly influenced by the power of the antenna. During the first survey (March 1, 2021), the Wi-Fi scanner was without an external antenna. For this reason, the result on this day was low. On other days, the result is quite high due to detection of a larger number of routes of passengers. Another interesting fact is that, on average, the average travel distance of potential passengers is almost equal for two surveys, and, accordingly, the average travel time of potential passengers is also very close in terms of values.

Section No. 2. Alma-Atinskaya station–Belorusskaya station (Zamoskvoretskaya metro line)

Further, using the proven method, data were analysed for section No. 2 from Alma-Atinskaya metro station to Belorusskaya metro station (Zamoskvoretskaya line). The data were obtained during morning rush hour as well.



Pic. 9. Ratio of real number of passengers and passengers with Wi-Fi module turned on. MCD Butovo-Moscow Kurskaya section. Morning rush hour, March 4, 2021 [performed by the author].

Butovo	Bitsa	Krasniy stroitel	Pokrovskoe	**Tsaritsyno**	Moskvorechie	Kuryanovo	Pererva	Depo	Lublino	Pechatniki (without stop)	**Tekstilshchiki**	Novokhokhlovskaya	Kalitniki	Moscow Tovarnaya	Moscow Kurskaya
7:21:00	7:25:00	7:28:00	7:31:00	7:36:50	**7:41:20**	7:43:45	7:46:00	7:48:30	7:50:30	No	7:54:10	7:57:00	7:59:00	8:01:30	8:07:20
80	80	80	80	**70**	70	70	70	70	70	No	55	50	45	40	0
		7:28:43	1	1	1	1	7:45:33								
			7:35:17	1	1	1	7:45:19								
				7:39:41	1	1	1	1	1	1	1	7:56:55			
7:20:54	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8:04:37
	7:25:50	7:28:13													
							7:46:17	1	1	1	1	1	1	1	8:08:35
7:21:36	1	1	1	1	7:38:35										
	7:27:22	1	1	1	1	1	1	1	1	1	1	1	7:58:44		
7:22:14	1	1	1	1	1	1	1	1	1	1	1	1	7:59:25		
					7:41:24	1	1	1	1	1	7:54:28				
7:21:09	1	1	1	1	1	1	1	1	7:49:41						
						7:42:44	1	1	1	1	1	7:57:25			
	7:24:30	1	1	1	1	1	7:45:28								
		7:27:50	1	7:36:50											
		7:27:35	1	1	1	1	1	1	1	1	1	1	1	8:01:15	
7:23:59	1	1	1	1	7:38:29										
7:20:53	1	1	1	1	1	1	1	1	1	1	1	1	7:59:45		
7:20:30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8:04:01
7:14:00	1	7:26:30													
			7:35:22	1	1	1	1	1	1	1	1	1	1	1	8:02:32
						7:44:50	1	1	7:50:59						
	7:25:58	1	1	1	1	1	7:46:10								
	7:25:04	1	1	1	1	1	1	1	1	1	1	1	1	8:00:42	
		7:28:50	1	1	1	1	1	1	1	1	7:54:18				
												7:58:14	1	1	8:09:16
				7:40:36	1	1	1	1	1	1	1	1	1	1	8:12:37
		7:28:27	7:30:06												
									7:53:15	1	1	1	1	1	8:11:37
											7:55:01	7:57:40			
						7:43:33	1	7:48:42							
7:21:28	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8:02:21
7:20:24	1	1	1	1	1	1	1	1	1	1	7:52:03				
								7:49:15	1	1	1	1	1	1	8:08:46
											7:53:49	1	1	1	8:06:33
						7:44:48	1	1	1	1	1	7:56:56			
7:22:41	1	1	1	1	1	1	1	1	1	1	1	1	1	8:00:16	
				7:38:55	1	1	1	1	1	1	1	1	1	1	8:07:27
											7:54:33	1	7:58:10		
7:23:11	1	1	1	7:36:31											
7:24:15	1	1	7:30:39												
7:20:53	7:24:47														
7:21:21	1	1	1	1	1	1	1	1	1	1	1	7:57:21			
7:22:07	1	1	1	7:37:22											
7:22:44	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8:03:53
													8:00:00	1	8:08:00
					7:41:51	1	1	7:47:10							
								7:48:27	1	1	7:54:31				
7:19:29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8:08:45
				7:37:22	1	1	1	7:48:42							
7:20:46	1	1	1	1	1	1	1	1	1	1	1	7:57:15			
7:20:42	1	1	7:31:05												
	7:27:19	1	1	1	1	1	1	1	1	1	1	1	7:58:27		
7:20:55	1	1	1	1	7:38:22										
7:21:28	1	1	1	1	1	1	1	1	1	1	7:52:35				
7:21:19	1	1	1	7:33:01											
7:20:23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8:10:07
			7:30:52	7:36:28											
7:22:17	1	1	7:29:13												
7:20:46	7:23:06														
7:21:36	1	1	1	1	1	1	7:45:14								
			7:31:43	1	7:40:48										
				7:37:50	1	1	1	1	1	1	1	1	1	8:02:19	
7:20:24	1	7:28:45													
		7:26:39	1	7:32:22											
7:20:38	1	1	1	1	1	1	1	1	1	1	7:54:18				
7:21:02	1	1	7:31:30												
7:20:53	1	1	1	1	1	1	1	1	1	1	7:53:51				
			7:33:48	7:35:24											
	7:24:22	1	1	1	1	1	1	1	1	1	1	1	1	1	8:04:53
					7:41:12	1	1	1	1	1	7:54:52				
7:21:36	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8:09:05
7:21:10	7:25:49														
7:20:55	1	1	1	1	1	1	1	1	1	1	1	7:50:45			
									7:53:03	1	1	1	1	1	8:08:46
						7:43:20	1	1	1	1	7:52:03				
					7:38:24	7:42:15									
	7:25:30	7:27:58													
				7:37:36	1	1	1	1	1	1	1	1	1	1	8:07:59
	7:26:01				1	1	1	1	1	1	1	1	1	1	8:07:59
			7:33:13		7:38:51										
							7:47:20	1	1	1	1	1	1	8:01:19	
7:17:39	1	1	1	1	1	1	1	1	1	1	1	7:57:42			
7:20:50	1	1	1	1	1	1	1	1	1	1	7:52:28				

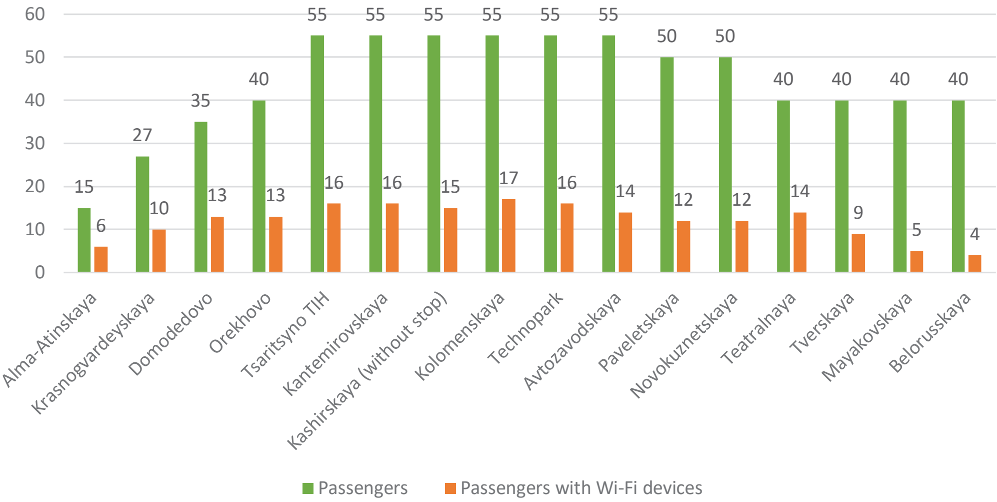
Pic. 10. Routes of potential passengers with Wi-Fi module enabled on the section from Butovo station (MCD-2) to Moscow Kurskaya station (MCD-2). March 4, 2021 [performed by the author].

Table 5

The result of research on the section from Butovo station (MCD-2) to Moscow Kurskaya station (MCD-2). March 4, 2021 [performed by the author]

Route from Butovo station (MCD-2) to Moscow Kurskaya station (MCD-2)	Number of identified routes	Average travel distance of passengers	Average travel time of passengers	Presence of an external antenna
March 1, 2021 – morning rush hour	29	13,56 km	0:20:13	–
March 4, 2021 – morning rush hour	83	15,09 km	0:23:35	+
March 5, 2021 – morning rush hour	60	13,3 km	0:19:48	+
Total averages	57,3	13,98 km	0:21:12	

Pic. 11. Image of section No.2. Source: https://yandex.ru/metro/moscow?scheme_id=sc34974011/. Last accessed 10.04.2022.



Pic. 12. Ratio of real number of passengers and passengers with Wi-Fi module turned on. Section No. 2 from Alma-Atinskayastation to Belorusskaya station (Zamoskvoretskaya line). Morning rush hour. February 20, 2021 [performed by the author].

Table 6

The result of the study on section No. 2 from Alma-Atinskaya metro station to Belorusskaya metro station (Zamoskvoretskaya line). Morning rush hour [performed by the author]

Route No. 2 from Alma-Atinskaya metro station to Belorusskaya metro station (Zamoskvoretskaya line). Morning rush hours	Number of identified routes of passengers	Average travel distance of passengers	Average travel time of passengers
February 20, 2021 – morning rush hour*	33	9,4 km	0:12:28
February 24, 2021 – morning rush hour	35	8,7 km	0:11:46
February 26, 2021 – morning rush hour	32	10,4 km	0:13:52
Total averages	33,33	9,5 km	0:12:42

* February 20, 2021 – Saturday.

According to Pic. 12, it can be seen that the percentage of detected Wi-Fi devices that can be used to build routes is lower than in the analysis of section No. 1. The reason is due to the fact that the Zamoskvoretskaya metro line operates cars without passage and the scanner was located on the floor during the Wi-Fi analysis, which also reduced the percentage of collected data. Also, the measurement was carried out in the morning period from 07:26 to 08:08 on February 20, 2021, on Saturday, which is a day off for most residents of Moscow and passengers staying in the city. But even when analysing data obtained on February 24 and 26, 2021, (working days), Wi-Fi data on potential passengers in percentage terms were also lower than for section No. 1. From this it follows that the location of the scanner on the floor and high density of people in the car significantly reduces results. Also, the results can be affected by working Wi-Fi routers and routers in the same frequency range[7].

As a result, 33 routes of potential passengers with the Wi-Fi module turned on were identified (Pic. 13).

As a result, the following values were obtained (Table 6).

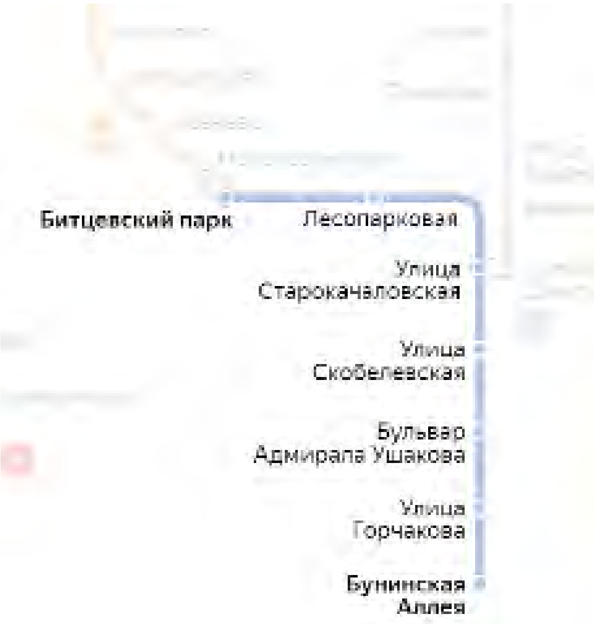
Section No. 3. Buninskaya alleya station–Bitsevskiy park station (Butovskaya line)

Section No. 3 is the shortest (8,8 km) compared to the other studied sections. In this study, the Wi-Fi scanner, as well as during data collection at the section No. 2, was on the floor.

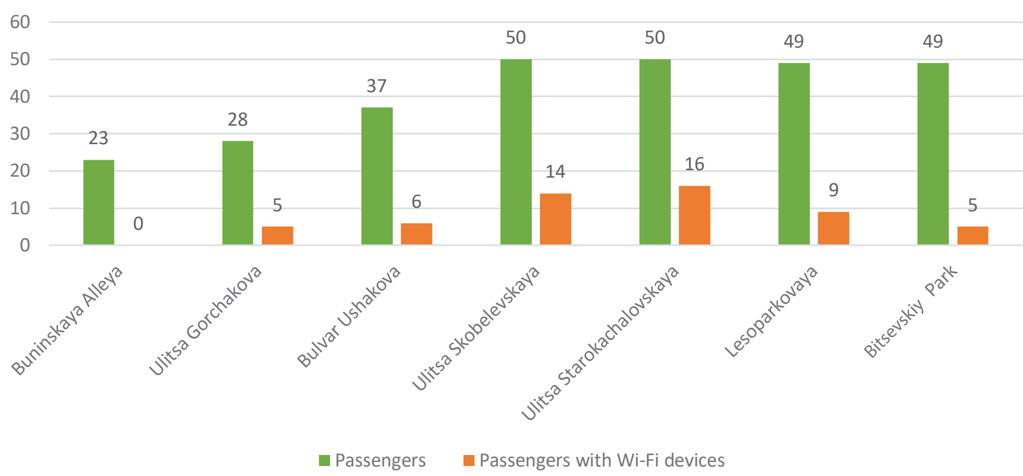
[7] Recommendations from the manufacturer of Wi-Fi routers Keenetic. [Electronic resource]: https://help.keenetic.com/hc/ru/articles/ 213968709-Что-влияет-на-работу-беспроводных-сетей-Wi-Fi-Что-может-являться-источником-помех-и-каковы-их-возможные-причины- Last accessed: 10.04.2022.

Alma-Atinskaya	Krasnogvardeyskaya	Domodedovo	Orekhovo	Tsaritsyno TIH	Kantemirovskaya	Kashirskaya (without stop)	Kolomenskaya	Technopark	Avtozavodskaya	Paveletskaya	Novokuznetskaya	Teatralnaya	Tverskaya	Mayakovskaya	Belorusskaya
7:26:29	7:33:02	7:34:06	7:36:28	7:39:25	7:41:57	No	7:49:50	7:53:06	7:55:13	7:58:22	8:00:16	8:02:55	8:04:54	8:06:32	8:08:15
15 (4)	27	35	40	55	55		55	55	55	50	50	40	40	40	40
											7:59:20	8:02:56			
	7:32:28	1	1	1	1	1	1	1	1	1	1	1	1	1	8:08:28
												8:03:43	8:04:01		
7:24:48	1	1	1	7:38:40											
	7:32:49	1	1	1	1	1	1	1	1	1	1	1	8:04:44		
							7:50:51	7:53:24							
												8:03:56	8:04:32		
7:24:39	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8:07:33
7:31:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8:09:10
									7:56:12	7:57:30					
7:24:06	1	1	1	1	1	1	1	1	1	1	8:00:25				
												8:03:46	8:04:48		
				7:39:47	1	1	1	1	1	7:58:50					
	7:32:37	1	0:00:00	7:37:44											
				7:40:12	1	1	1	1	1	1	1	8:02:44			
7:32:00	1	1	7:35:12												
											8:01:52	8:02:15			
7:25:25	7:32:52														
					7:42:05	1	7:48:47								
											8:00:41	1	1	1	8:08:35
					7:43:52	1	7:45:25								
	7:32:36	1	1	1	1	1	1	7:52:24							
		7:34:37	1	1	1	1	1	1	1	1	1	8:03:26			
							7:50:56	7:51:42							
		7:35:24	1	1	1	1	1	1	1	7:57:31					
								7:52:27	7:54:32						
				7:39:45	7:40:16										
											8:00:56	8:05:05			
		7:35:14	1	7:38:01											
		7:35:03	1	1	1	1	1	1	1	1	1	1	1	8:06:16	
								7:54:05	1	7:56:43					
					7:46:42	1	1	1	7:54:25						
				7:40:02	1	1	7:46:12								

Pic. 13. Routes of passengers with Wi-Fi module enabled on section No.2 from Alma-Atinskaya station to Belorusskaya station (Zamoskvoretskaya line). Morning rush hour. February 20, 2021. [performed by the author].



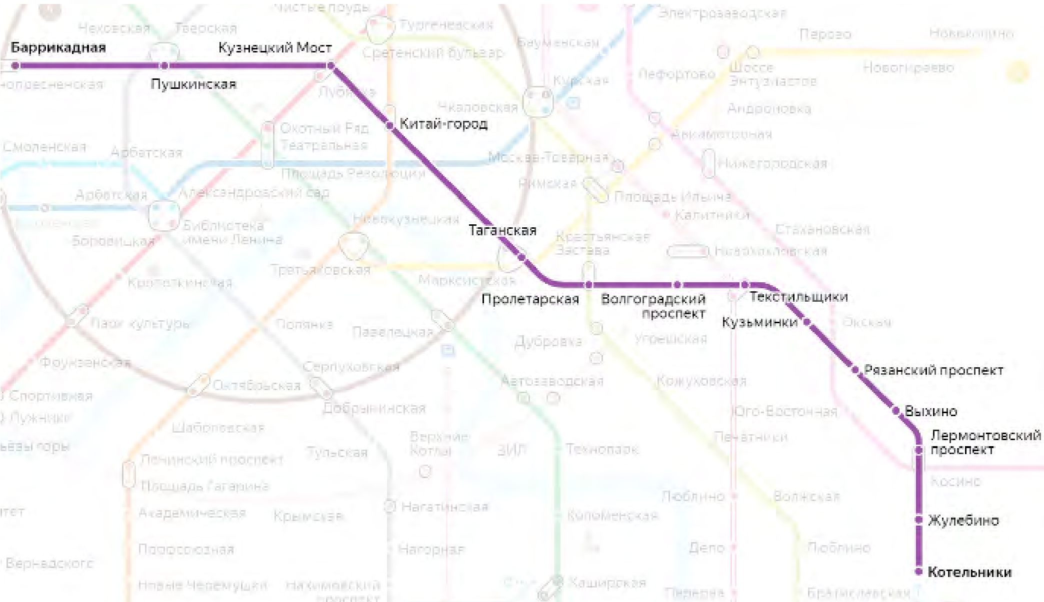
Pic. 14. Image of section No. 3. [Electronic resource]: https://yandex.ru/metro/moscow?scheme_id=sc34974011. Last accessed 10.04.2022.



Pic. 15. Ratio of the real number of passengers and passenger with Wi-Fi module turned on. Section No. 3 from Buninskaya alleya station to Bitsevskiy park station (Butovskaya line). February 9, 2021 [performed by the author].

Buninskaya alleya	Ulitsa Gorchakova	Bulvar Ushakova	Ulitsa Skobelevskaya	Ulitsa Starokachalovskaya	Lesoparkovaya	Bitsevskiy park
8:17	8:19	8:21	8:22	8:28	8:31	8:33
23	28	37	50	50	49	49
			8:23:45	8:27:54		
				8:29:15	8:30:33	
			8:25:22	8:27:51		
	8:20:34	1	1	8:28:08		
	8:20:20	1	1	1	1	8:33:34
	8:20:23	1	1	8:27:32		
	8:19:50	1	8:21:55			
			8:23:58	1	1	8:32:48
			8:25:41	8:27:53		
	8:19:58	1	1	1	8:30:01	
		8:20:48		8:23:38		
					8:30:16	8:32:19
			8:26:20	1	1	8:34:05
			8:22:25	8:28:06		
			8:25:18	1	8:29:31	
			8:23:46	1	8:29:12	
			8:24:53	8:25:46		
				8:27:49	1	8:34:30

Pic. 16. Routes of potential passengers with Wi-Fi module enabled on Section No. 3 from Buninskaya alleya station to Bitsevskiy park station (Butovskaya line). February 9, 2021 [performed by the author].



Pic. 17. Image of route No. 4. [Electronic resource]: https://yandex.ru/metro/moscow?scheme_id=sc34974011. Last accessed 10.04.2022.

The results are shown in Pic. 15.

As a result, 18 routes of potential passengers were identified (Pic. 16).

The results obtained are shown in Table 7.

Section No. 4. Kotelniki station–Barrikadnaya station (Tagansko-Krasnopresnenskaya line)

The section No. 4 is characterised by the existing transport interchange hubs (Lermontovsky Prospekt and Vykhino stations).

Pic. 18 shows a diagram of data collection carried out on May 18, 2021.

The result of processing of 58 routes of potential passengers is shown in Pic. 19.

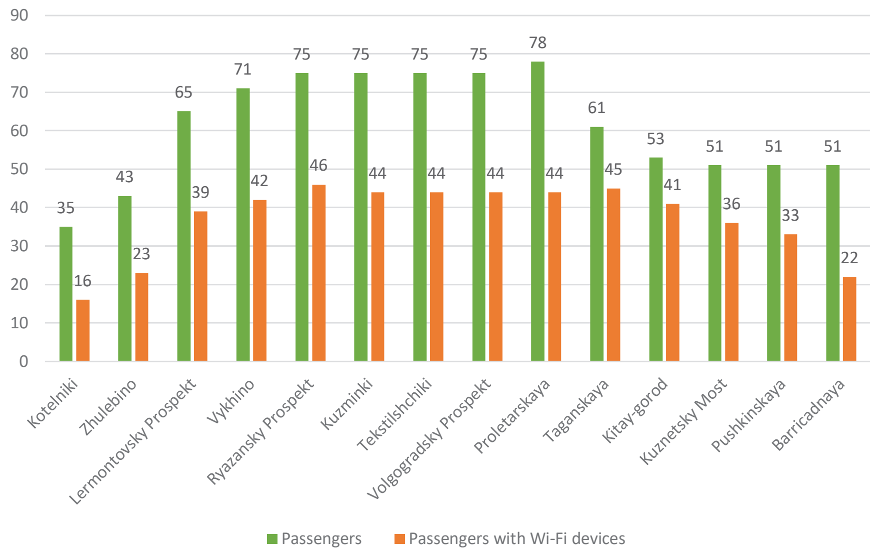
As a result, the values shown in Table 8 were obtained.

CONCLUSION

The study resulted in identification of the main features of the obtained data, namely in the following most important conclusions on the studied method of collecting and analysing WI-FI data.

1. Location of a Wi-Fi scanner

When conducting a Wi-Fi study, the scanner was located either on the floor of the car (Butovskaya metro line, Zamoskvoretskaya metro line) or on the upper rack of the car (MCD-2). The results have conformed the information of the manufacturer of



Pic. 18. Ratio of real number of passengers and passengers with Wi-Fi module enabled on. Section No. 4 from Kotelniki station to Barrikadnaya station (Tagansko-Krasnopresnenskaya line). May 18, 2021 [performed by the author].

Kotelniki	Zhulebino	Lermontovsky Prospekt	Vykhino	Ryazansky Prospekt	Kuzminki	Tekstilshchiki	Volgogradsky Prospekt	Proletarskaya	Taganskaya	Kitay-gorod	Kuznetsky Most	Pushkinskaya	Barricadnaya
6:56:00	6:59:00	7:03:00	7:08:00	7:10:00	7:13:00	7:15:50	7:19:30	7:22:00	7:24:00	7:27:00	7:28:20	7:30:20	7:32:40
45	43	65	71	75	75	75	75	78	61	53	51	51	51
6:56:25	1	1	1	1	1	1	1	1	1	1	1	1	7:32:33
		7:02:31	1	1	1	1	1	1	7:24:07				
			7:07:19	1	1	1	1	1	1	1	1	7:30:35	
									7:26:11	1	1	1	7:31:50
									7:25:24	1	1	7:30:49	
	6:59:36	1	7:08:38										
				7:11:04	1	1	1	1	1	7:26:40			
	6:59:12	1	1	1	1	1	1	1	1	1	1	7:29:35	
		7:03:04	1	1	1	1	1	1	1	1	1	1	7:31:01
6:56:58	1	1	1	1	1	1	1	7:22:02					
				7:09:24	1	1	1	1	1	1	1	1	7:33:06
		7:02:58	1	1	1	1	1	1	1	1	1	1	7:32:50
		7:03:58	1	1	1	1	7:19:17						
6:59:09	1	1	1	1	1	1	1	1	1	1	1	1	7:32:25
				7:09:23	1	1	1	7:22:23					
								7:22:38	1	7:27:00			
									7:25:42	1	1	1	7:32:52
		7:03:50	1	1	1	1	1	7:22:08					
6:56:04	1	1	1	1	1	1	1	1	1	1	1	1	7:32:35
6:56:27	1	1	1	1	1	1	1	1	1	1	1	7:29:19	
				7:12:08	1	1	1	1	1	7:27:07			
							7:20:03	1	1	1	1	7:30:17	
				7:10:26	1	1	1	1	1	1	1	7:30:31	
	7:01:17	1	1	1	1	1	1	1	7:24:32				
		7:04:06	1	1	1	1	1	1	7:23:35				
			7:07:06	1	1	7:14:05							
		7:03:18	1	1	1	1	1	1	1	1	1	7:30:07	
	7:00:59	1	1	1	1	1	1	1	1	1	7:27:46		
									7:25:27	1	1	1	7:31:23
		7:03:47	1	7:09:57									
					7:13:02	1	1	1	1	1	1	1	7:31:51
		7:04:00	1	1	1	1	1	1	1	7:26:55			
						7:15:35	1	1	1	1	1	1	7:31:02
		7:05:33	1	1	1	1	1	7:22:08					
		7:04:14	1	1	1	1	1	1	1	1	7:28:33		
6:57:34	1	1	1	1	1	1	1	1	1	1	1	7:30:00	
												7:30:22	7:32:50
										7:27:00	1	1	7:32:55
6:57:20	1	1	1	1	1	1	1	1	1	7:25:43			
									7:24:56	1	1	1	7:32:39
		7:02:48	1	1	1	1	1	1	1	1	1	1	7:32:52
6:57:10	1	1	1	7:09:45									
			7:07:51	1	1	1	1	1	1	1	1	1	7:32:18
6:56:11	1	1	1	1	1	1	1	1	1	1	1	7:29:14	
		7:03:18	1	1	1	1	1	1	1	1	1	1	7:31:51
		7:03:43	1	1	1	1	1	1	1	1	1	1	7:31:03
6:54:29	1	1	1	1	1	1	1	1	7:22:53				
6:56:16	1	1	1	1	7:13:05								
		7:02:58	1	1	1	1	1	1	1	1	1	7:30:07	
6:56:15	1	1	1	1	1	1	1	1	7:25:39				
6:56:32	1	1	1	1	1	1	1	1	1	1	1	1	7:32:49
	7:01:16	1	1	1	1	1	1	1	1	1	7:28:01		
6:56:40	1	1	1	1	1	1	1	1	1	1	7:28:28		
	6:58:05	1	1	1	1	1	1	1	1	1	1	7:30:32	
	6:59:13	1	1	1	1	1	1	1	1	1	1	1	7:32:19
6:56:07	1	1	1	7:10:26									
6:56:21	1	1	1	1	1	1	1	1	1	1	1	1	7:32:52
		7:03:45	1	1	1	1	1	1	1	1	1	1	7:32:50

Pic. 19. Routes of passengers with Wi-Fi module turned on. Section No. 4 from Kotelniki station to Barrikadnaya station (Tagansko-Krasnopresnenskaya line). May 18, 2021 [performed by the author].

Table 7

The result of the study on section No. 3 from Buninskaya alleya station to Bitsevskiy Park station (Butovskaya line). February 9, 2021 [performed by the author]

Section No. 3 from Buninskaya alleya station to Bitsevskiy Park station (Butovskaya line)	Number of identified routes of passengers	Average travel distance of passengers	Average travel time of passengers
February 9, 2021 – morning rush hour	18	3,9 km	0:05:15
February 10, 2021 – morning rush hour	23	3,87 km	0:05:48
February 26, 2021 – morning rush hour	11	4,4 km	0:07:14
Total averages	17,33	4,06 km	0:06:06

Remark: Based on the results obtained, it can be concluded that the average travel distance is almost equal to half the path of the entire section.

Table 8

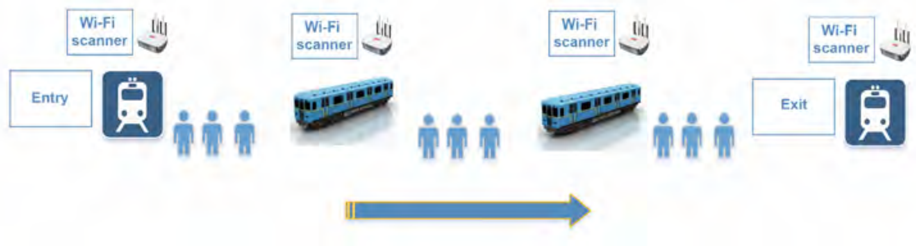
The result of the study on section No. 4 from Kotelniki station to Barrikadnaya station (Tagansko-Krasnopresnenskaya line). May 18, 2021 [performed by the author]

Section No. 4 from Kotelniki station to Barrikadnaya station (Tagansko-Krasnopresnenskaya line)	Number of identified routes of passengers	Average travel distance of passengers	Average travel time of passengers
May 17, 2021 – morning rush hour	26	11,07 km	0:14:30
May 18 2021 – morning rush hour	58	15,95 km	0:21:31
May 19, 2021 – morning rush hour	59	12,47 km	0:18:06
Total averages	47,67	13,16 km	0:18:02

Table 9

Comparison of processed Wi-Fi data [performed by the author]

	Average number of identified routes of potential passengers (units)		
Location of a Wi-Fi scanner	MCD-2	Zamoskvoretskaya line	Butovskaya line
Floor level of the car	–	33,33	17,33
Upper rack of the car	57,3	–	–



Pic. 20. Layout of Wi-Fi scanners [performed by the author].

Wi-Fi routers indicating that for more stable operation of Wi-Fi devices, it is recommended to place Wi-Fi devices at a height of 1–2 meters[8]. The number of detected Wi-Fi devices when the Wi-Fi scanner is located on the upper rack of the car is higher than when the Wi-Fi scanner is located on the floor of the car (Table 9).

2. Presence/absence of an external antenna

According to the results of the study, it was revealed that the presence of an external antenna significantly increases the result, but provided that the Wi-Fi scanner is located on the upper rack of the car.

3. Dynamic/stationary Wi-Fi scanner

It was shown that using a dynamic Wi-Fi scanner it is possible to obtain data on the routes of passenger flows, and in particular on its properties, such as:

– Average travel distance of potential passengers.

– Average travel time of potential passengers.

This study used a dynamic Wi-Fi scanner was used, but stationary Wi-Fi scanners are required for better results. Moreover, with the location of Wi-Fi scanners at the exit and entrance of metro, and in metro cars themselves, the possibility of determining the routes of potential passengers will increase significantly. Also, the cumulative effect will play a big role. If there will be more Wi-Fi data on passenger traffic, it will be possible

[8] General recommendations for placing a Keenetic Internet Centre in an apartment for stable and high-quality Wi-Fi network operation. [Electronic resource]: https://help.keenetic.com/hc/ru/articles/213968849. Last accessed 10.04.2022.

Table 10

The result of Wi-Fi data processing for all four sections [performed by the author]

Section	Metro line	Route length (km)	Average travel time for the entire route	Average number of identified Wi-Fi devices as per the actual number of passengers (%)	Average number of potential passengers who travelled almost the entire route (%)	Average travel distance of potential passengers (km)	Average travel time of potential passengers
1	MCD-2	29,2	0:48:00	53	32	13,98	0:21:12
2	Zamoskvoretskaya line	27,9	0:41:46	28	18	9,5	0:12:42
3	Butovskaya line	8,8	0:16:40	21	8	4,06	0:06:06
4	Tagansko-Krasnopresnenskaya line	25,1	00:38:00	41	24	13,16	0:18:02

to analyse the received data with their further forecasting.

Also, to obtain a qualitative result on passenger flows, adoption and installation of stationary Wi-Fi scanners is required. A possible scheme is shown in Pic. 20.

According to the above scheme, it is required to install one Wi-Fi scanner at the entrance to the metro or at the entrance to the MCD platform, install one Wi-Fi scanner in each metro car and install one Wi-Fi scanner at the exit from the metro or from the MCD platform. Equipping with additional Wi-Fi scanners will improve the results and allow collecting and accumulating Wi-Fi data for further processing and analysis.

At the moment, on the territory of Moscow agglomeration, the Wi-Fi zone is increasing from year to year[9]. This factor is of great importance to enhance the possibility of obtaining better Wi-Fi data and processing it to get data on passenger flows.

Moreover, Wi-Fi analytics can be used as an additional tool for passenger traffic analysis, along with such instruments as validation, automated passenger traffic monitoring system, video analytics, etc.

4. Data processing software. Randomisation

The most important element in obtaining traffic data results is data processing. For data analysis in this study, the author used the capacity of Microsoft Excel, but when scaling data processing, Microsoft Excel will not be enough. Programming languages such as Python, My SQL, etc. will be more opportune.

The problem of randomisation of Wi-Fi data was also stated in the work. The following conclusions were made: randomisation itself does not interfere with processing of the received data, since randomisation of MAC addresses occurs neither every minute nor hourly, but daily, weekly. Within the observation period of 1–2 hours, randomisation does not affect the result.

5. Empirical results

Intermediate empirical results of the study have shown that, on average, 20–45 % of the actual number of passengers use Wi-Fi devices that might be detected by described methods. This can testify that not all passengers use the Wi-Fi module enabled on the Wi-Fi device. Plus, in the early hours of the day, many passengers sleep, respectively, the sample of the received data is reduced and, accordingly, the number of passenger routes detected is reduced. But the positive thing is that the data obtained can be used to analyse passenger flows.

Table 10 shows the result of processing Wi-Fi data for all four sections.

For all four sections, the percentage of the average number of detected Wi-Fi devices regarding the actual number of passengers was 35,75 %, and the average number of passengers who travelled almost the entire route was 20,5 %.

Existing technologies allow various methods to collect data on passenger flows. But for qualitative results, that is, close to the real, and not predicted by the data sample, it is necessary to use combined systems for counting passenger flows, a system for collecting and analysing all possible data on passenger flows on the territory of Moscow transport hub.

It is also advisable to collect and analyse Bluetooth data, which in the future can also give interesting results in the field of passenger traffic research.

[9] Moscow Wi-Fi is seven years old. Moscow 24. [Electronic resource]: https://www.m24.ru/news/mehr-Moskvy/27092020/134649. Last accessed 10.04.2022.

REFERENCES

1. Pashina, A. S., Kravchuk, I. S. Innovations in the infrastructure of Moscow metro [*Innovatsii v infrastructure Moskovskogo metropolitena. Sovremennoe sostoyanie, problemy i perspektivy razvitiya otraslevoi nauki*]. In: Proceedings of the conference «Current state, problems and prospects for development of branch science». Moscow, Pero publ., 2019, pp. 330−335. [Electronic resource]: https://www.elibrary.ru/item.asp?id=39227779. Last accessed 10.04.2022.

2. Dolmatenya, Yu. V., Trandina, E. V. Features of the Metro as Area for the Organization and Development of Tourist Events. In: Topical problems of development of service sector [*Aktualnie problem razvitiya sphery uslug*]. Collection of scientific works, Vol. XIII. St. Petersburg State University of Economics, 2019, pp. 135–139. [Electronic resource]: https://www.elibrary.ru/item.asp?id=42476132. Last accessed 10.04.2022.

3. Podkhalyuzina, V. A. Analysis of passenger traffic in the Moscow ground public transport. *Challenges of the global world. Vestnik IMTP*, 2015, Iss. 2 (6), pp. 31−34. [Electronic resource]: https://www.elibrary.ru/item.asp?id=24245177. Last accessed 10.04.2022.

4. Alekseev, N. Yu., Zyuzin, P. V. Assessment of Applicability of Wi-Fi Analytics in Studies of Urban Public Transport Passenger Flow (Moscow Case Study). *World of Transport and Transportation*, 2021, Vol. 19, Iss. 3, pp. 196–208. DOI: https://doi.org/10.30932/1992-3252-2021-19-3-6.

5. Petrova, D. V. Modern approaches to the organisation of public transport passenger traffic monitoring in urban agglomerations. *International Journal of Open Information Technologies*, 2020, Vol. 8, Iss. 1, pp. 47−57. [Electronic resource]: https://www.elibrary.ru/item.asp?id=42340332. Last accessed 10.04.2022.

6. Borovikov, A. V. Analysis of passenger traffic of city bus route. *Mezhdunarodniy studencheskiy nauchniy vestnik*, 2019, Iss. 3, Art. 46. [Electronic resource]: https://www.elibrary.ru/item.asp?id=38318095. Last accessed 10.04.2022.

7. Novikov, A. N., Radchenko, S. Yu., Sevostyanov, A. L., [*et al*]. Study of passenger flows and transport mobility of the population in the city of Oryol. *Mir transporta i tekhnologicheskikh mashin*, 2011, pp. 69–77. [Electronic resource]: https://www.elibrary.ru/item.asp?id=17280343. Last accessed 10.04.2022.

8. Rubtsova, K. A. Peculiarities of accounting for passenger flow on ground public transport. *Ekonomika predprinimatelstva, organizatsiya i upravlenie predpriyatiyami, otraslyami, kompleksami*, 2015, pp. 168–172. [Electronic resource]: https://www.elibrary.ru/item.asp?id=24866446. Last accessed 10.04.2022.

9. Berlingerio M., Calabrese F., Lorenzo G., Nair R., Pinelli F., Luca Sbodio M. AllAboard: A System for Exploring Urban Mobility and Optimizing Public Transport Using Cellphone Data. *Mobile phone Data for Development*, 2013, pp. 397−411. DOI: https://doi.org/10.1007/978-3-642-40994-3_50.

10. Namiot, D. E., Nekraplonna, M. N., Pokusaev, O. N., Chekmarev, A. E. OD-matrix and passenger flow analysis. *International Journal of Open Information Technologies*, 2020, Vol. 8, Iss. 4, pp. 25−30. [Electronic resource]: https://www.elibrary.ru/item.asp?id=42748922. Last accessed 10.04.2022.

11. Pomatilov, F. S., Namiot, D. E. On the analysis of passenger traffic of Moscow Metro [*Ob analize passazhiropotokov Moskovskogo metropolitena*]. *Modern information technologies and IT education*, 2019, Vol. 15, Iss. 2, pp. 375–385. DOI: 10.25559/SITITO.15.201902.375-385.

12. Brusyanin, D. A., Vikharev, S. V., Popov, V. Y., Gorbenko, A. A., Sheka, A. S. Intelligent system monitoring passenger transport complex of the region. *Innovatsionniy transport*, 2012, Iss. 2 (3), pp. 41–43. [Electronic resource]: https://www.elibrary.ru/item.asp?id=18225474. Last accessed 10.04.2022.

13. Shchetinin, N. A., Koryakov, V. B., Semikopenko, Yu. V. Passenger traffic survey methodology. *European Journal of Natural History*, 2020, Iss. 3, pp. 105–108. [Electronic resource]: https://www.elibrary.ru/item.asp?id=43172623. Last accessed 10.04.2022.

14. Stepanchenko, I. V., Krushel, E. G., Panfilov, A. E., Lyutaya, T. P. Algorithm for simulating passenger flows at the stops of the metropolitan transport network. *Matematicheskie metody v tekhnike i tekhnologiyakh*, 2019, Vol. 10, pp. 19–23. [Electronic resource]: https://www.elibrary.ru/item.asp?id=41261453. Last accessed 10.04.2022.

15. Sytnik, R. A. On the question of the study of passenger traffic in urban transport and logistics systems. *Izvestiya Volgogradskogo gosudarstvennogo tekhnicheskogo universiteta*, 2016, Vol. 7, Iss. 186, pp. 43–48. [Electronic resource]: https://www.elibrary.ru/item.asp?id=26322476. Last accessed 10.04.2022.

16. Yankov, K. V., Lavrinenko, P. A., Fadeev, M. S. Experience in forecasting passenger flows and socio-economic effects in accelerated railway communication in Samara–Togliatti agglomeration. *Scientific works: Institute of Economic Forecasting of RAS*, 2016, Vol. 14, pp. 622–646. [Electronic resource]: https://www.elibrary.ru/item.asp?id=27633857. Last accessed 10.04.2022.

17. Nakagawa, Y., Nishida, J., Asao, H., Mukoko, B., Tamura, K. Application of AMP Collectors in Nairobi CBD for Transport Planning. *Transportation Research Procedia*, 2018, Vol. 34, pp. 107−114. DOI: https://doi.org/10.1016/j.trpro.2018.11.020.

18. Abedi, N., Bhaskar, A., Chung, E., Miska, M. Assessment of antenna characteristic effects on pedestrian and cyclists travel-time estimation based on Bluetooth and Wi-Fi MAC addresses. *Transportation Research Part C: Emerging Technologies*, 2015, Vol. 60, pp. 124–141. DOI: 10.1016/j.trc.2015.08.010.

19. Kusakabe, T., Yaginuma, H., Fukuda, D. Estimation of bus passengers' waiting time at a coach terminal with Wi-Fi MAC addresses. *Transportation Research Procedia*, 2018, Vol. 32, pp. 62−68. DOI: 10.1016/j.trpro.2018.10.012.

20. Hong, J., Thakuriah, P. Examining the relationship between different urbanization settings, smartphone use to access the Internet and trip frequencies. *Journal of Transport Geography*, 2018, Vol. 69, pp. 11–18. DOI: 10.1016/j.jtrangeo.2018.04.006.

21. Oransirikul, T., Nishide, R., Piumarta, I., Takada, H. Measuring Bus Passenger Load by Monitoring Wi-Fi Transmissions from Mobile Devices. *Procedia Technology*, 2014, Vol. 18, pp. 120−125. DOI: https://doi.org/10.1016/j.protcy.2014.11.023.

22. Martin, J., Mayberry, T., Donahue, C. [*et al*]. A Study of MAC Address Randomization in Mobile Devices and When it Fails. *US Naval Academy, Proceedings on Privacy Enhancing Technologies*, March 2017, 23. DOI: 10.1515/popets-2017-0054.

Information about the author:

Alekseev, Nikolai Yu., *master in transport planning of National Research University Higher School of Economics, project leader of Sitronics Group, Moscow, Russia, Alekseev-trn@mail.ru.*

Article received 21.06.2022, approved 11.07.2022, accepted 13.09.2022.