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Sample Survey of Passenger Traffic by Analysing Wi-Fi Data in Moscow Transport Hub. Part 1

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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.

You can find the first part of the article in the issue.

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

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INTRODUCTION

Urban public transport is among core elements in creation of modern urban environment and in growing quality of life of Moscow residents. The popularity of urban public transport in the capital has been increasing from year to year thanks to the development of the city mass transit system [1, 2, 3], its integration with new transport infrastructure facilities, renewal of rolling stick, adoption of new types of vehicles, and growing integrity of the system components.

The important share of passengers is still transported by Moscow Metro. According to the information of the Transport department of the city of Moscow, in 2021, in 2021 during working day Moscow Metro transported 56,7 % of average passenger flow (including those transported by Moscow Central Circle (MCC) and Metro Big Circle Line (BCL), opened in 2020, 4,135 % each), surface transport – 30,3 %, railways – 13 % (including 4,21 % transported by Moscow Central Diameters (MCD)). The indices of passenger flows (+ 37 %) and of transported unique passengers (+ 38 %) shown in 2021 great progress as compared with 2020, though indices have not yet completely recovered if compared with pre-pandemic 2019. Fastly growing transportation through MCD and MCC is an exception since they have already excelled the 2019 indices[4], and there are all reasons to suppose that the positive dynamics of all types of public transport will be kept and even accelerated in 2022 as to overcome a temporary, pandemic-related change in previously growing trend regarding share of public and individual transportation (the share of public transport in 2019 was of 70 %, in 2020 – of 60 %, in 2021 – of 62 %)[4].

The comfort of travelling with urban public transport and Moscow Metro is improving every year [1]. The phased and targeted developed of urban public transportation and growing comfort of travelling resulted in the increased satisfaction of passengers of public transport (from 76 % in 2019 to 89 % in 2021) and of Moscow Metro (according to CoMET survey Moscow Metro in 2021 was in top-3 of world leading metros according to passenger satisfaction criteria)[4].

Considering the general trend towards growing popularity of using urban public transport, and, namely, of Moscow and St. Petersburg Metros, under different aspects including as of tourist site [2], the analysis of passenger flows becomes a very important factor to optimise routing and clarify the intervals between arrival of urban public transport vehicles (e.g.: [3]).

Now, measuring of passenger flows involves traditional counting methods (visual, survey, ticketed entries counting) as well as those based on processing arrays of digital data input from data from automated fare collection (validation) systems, automatic passenger counting (monitoring) systems, mobile operators, and other techniques. World practices, besides the above data sources that allow partial counting of passenger flows), also apply Wi-Fi analytics; the paper [4] was dedicated, namely, to some of its aspects.

Since 2016, a free Wi-Fi network called «MT FREE» [*abbreviation of Moscow Transport*] [5] has been introduced in the urban public transport of the city of Moscow, at its stopping points, metro stations and other locations. An increase in the number of points of free access to Wi-Fi network in the urban public transport of Moscow, by definition, increases the audience of potential passengers who use this free network. Consequently, with the increase in the number of passengers using the free Wi-Fi network, the flow of received Wi-Fi data increases, which can be used to analyse passenger flows using modern Wi-Fi scanners and Wi-Fi data processing algorithms.

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[1] Transport complex of Moscow. Presentation. [Electronic resource]: https://report2010-2017.transport.mos.ru/download/full-reports/ar_ru_annual-report_spreads.pdf. Last accessed 10.04.2022.

[2] The results of the activity of transport complex of the city of Moscow since 2010. Presentation (in Russian). [Electronic resource]: https://transport.mos.ru/common/upload/public/prezentacii/Презентация_Итоги_работы_%2008_11_19.pdf. Last accessed 10.04.2022.

[3] Index of development of transport complex: comparison of leading Russian and foreign cities. Presentation of Moscow State University at Moscow Urban Forum July 6–12, 2017 (in Russian). [Electronic resource]: https://transport.mos.ru/common/upload/docs/1499956207_PrezentatsiyaMGUv2.10.pdf. Last accessed 10.04.2022.

[4] The results of the activity of transport complex of Moscow in 2021 and plans for 2022. Transport department of the city of Moscow. Presentation (in Russian). [Electronic resource]: https://transport.mos.ru/common/upload/public/prezentacii/106/itogi-raboty-tk-2021-i-plany-na-2022.pdf. Last accessed 10.04.2022.

[5] The single Wi-Fi network is now available in metro and surface vehicles. Moscow transport Website (in Russian). [Electronic resource]: https://transport.mos.ru/mostrans/all_news/14254. Last accessed: 10.04.2022.

The objective of the research is to study and analyse the method of collecting and processing Wi-Fi data as a tool for analysing passenger traffic.

The object of the research is passenger traffic in Moscow transport hub.

The subject of the research is associated with the properties of passenger flows in Moscow transport hub.

The *tasks* of the research comprised study of existing methods for processing Wi-Fi data; collection and analysis of Wi-Fi data in Moscow transport hub during the morning rush hour using a Wi-Fi scanner on selected routes; construction of an algorithm for analysing and processing Wi-Fi data received from a dynamic Wi-Fi scanner; obtaining data on quantitative characteristics of passenger flows, namely, on the average travel distance and average travel time of passengers.

Structurally, the paper supposes three parts. The first one is devoted to the study of methods for counting passenger flows and world experience in the field of Wi-Fi analytics. The second chapter describes the methodology of the data collection, and an algorithm for analysing Wi-Fi data. The third chapter presents the immediate results of the study.

RESULTS

Methods for Studying Passenger Flows

Research in the field of passenger flows is the most important element of analysing and planning activity of transport system of any large city agglomeration since it is directly interrelated with the steps towards improvement of the comfort of movement of passengers and the speed of their travelling.

The growth in passenger traffic in Moscow implies a heavy load on the entire intracity transport network, as well as on the entire Moscow transport hub and its interchange hubs. The risk accompanying load on the city transport network is associated with increased waiting and travel time for passengers. The planning of measures to counter this risk through optimisation of transport infrastructure and route network requires a very thorough analysis of traffic and passenger flows.

Systemising of methods of data collection and analysis of passenger flows existing in the world and in Russia can help to answer the following questions: «what is the most accurate tool for collecting and analysing data on passenger traffic?»; «what are the advantages and disadvantages of one or another method of collecting passenger flow data?»; «is there a single solution for collecting and processing data on passenger flows?»

The term «*passenger flow*» means the concept referring to movement of passengers, which is expressed in the volume of passengers transported by any type of public transport (surface, underground, and others) or individual transport per unit of time.

The case in the paper is assumed to be limited to the study on the passenger flows at urban public transport in the city of Moscow.

Currently, counting of passenger traffic in Moscow city agglomeration can apply already existing, traditional methods for collecting and analysing data, such as:

- Visual method (estimate by staff).
- Questionnaire method (survey method).
- Ticket method (coupon method).
- Automatic systems for monitoring (counting) passenger traffic (ASCPT).
- Automated fare collection (validation) systems (AFCS).
- Data of mobile operators (GSM).
- Video surveillance system.

The article [5] describes in detail the various data collection and processing methods for counting passenger flows and the existing problems that have been identified by Moscow Transport Department.

Nevertheless, it is necessary to offer a short assessment of most wide-spread methods.

Manual (non-automated) methods

Visual (estimate by staff) and tabular (on-site) method

This type of passenger flow calculation is executed through a visual counting of the number of passengers entering and exiting public transport vehicles[6]. To obtain the result, a point scale is used. The task of the person conducting visual observation is to estimate according to his visual perception the number of passengers in the vehicle [occupancy] and set the appropriate score.

Tabular (on-site) method may be considered as its variation since observation is conducted

[6] Roshchin, A. I., Akopov, F. V., Zhukov, A. I. Guidelines for laboratory work for training students in the discipline «Methods for surveying transport processes», MADI publ., 2015, 35 p. [Electronic resource]: https://lib.madi.ru/fel/fel1/fel16M435.pdf. Last accessed 10.04.2022.

by ticket collectors, checkers, drivers and other clerks inside vehicles. Some more detailed data are collected and filled in the tables regarding number of persons boarding and alighting at specific points, passenger categories, etc.

Many Russian city administrations have adopted guidelines to apply this method to assess and forecast passenger flows (e.g.: [7, 8]).

As a result of using the visual method [6], it was possible, for example, to measure such indicators as the average occupancy of urban public vehicles, the rate of its unevenness, the rate of capacity utilisation, the average distance of a passenger trip in both directions of the route.

Advantages: it is a low-cost method of counting passenger flows that can be counted by current employees travelling on a particular public vehicle, such as a checker, fare collector or a driver.

Disadvantages: it is mostly intended for one-time use, it misses opportunity to systemise data collection and is dependable on a large number of human resources.

Questionnaire method (survey method)

This method supposes interviewing passengers (already travelling or potential (e.g., awaiting) passengers) by filling in the questionnaire (collecting answers) directly at the segments of street-and-road network or on Internet. question–answer on the road network or through a questionnaire survey on the Internet. The questionnaires may contain questions regarding the purpose of the passenger's trip, its destination and time. Answers to the questions asked can be applied and used to solve problems related to the prospect of developing the transport network of both the whole city and an individual community.

This method is also widely practised by administrative bodies of Russian cities and entities. The contents of the questionnaire depend on the goal set for a researcher, e.g., by a representative of the transport directorate of the city or urban agglomeration. The result of the questionnaire depends on the human factor and the list of questions asked, and, to a larger extent, on the amount of data received from passengers.

This method allows also to obtain data on the transport network of a particular community (microdistrict) in case of a targeted survey of residents of this community. Data obtained can be sufficiently reliable and valid since residents of a particular community are interested in improving transport accessibility of the nearest transport interchange hub (TIH), and of transportation, particularly to the place of work during the weekdays, and the residents own detailed reliable information on the transport situation in the community [7].

Advantages: an opportunity to get detailed feedback from passengers, as well as the feedback from potential passengers from a particular city community.

Disadvantages: the inability to count the passenger flow, obtaining only partial data on estimate use of public transport, impossibility to identify the routes of movement through intermediate stops and TIH.

Fare (ticket) accounting method

This method consists in counting the number of tickets sold in a particular vehicle. To improve the result of application of indicators obtained with this method, the following work scheme is often used: a checker is at the front door of a public vehicle, recording the time and location (stopping point of public transport) of a passenger's boarding and issues a coupon or a ticket to this passenger, and the second checker picks up these coupons or tickets, recording the time and location of the passenger's alighting. Thus, as a result, origin-destination matrix can be built, which will allow obtaining data on the boarding and alighting of specific passengers of public transport. This information is very important for planning the number of vehicles serving the route, scheduling, and the possibility of introducing a stop on demand, which will increase the speed of vehicles and, as a result, can reduce the travel time of passengers.

Meanwhile, this method (in the form of ticket collection) is not applicable to Moscow

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[7] Decree of the Administration of the Angarsk City District of Irkutsk Region dated 06.12.2016 No. 2697-pa «On approval of the Procedure for surveying passenger flows on regular city and suburban routes of road and surface electric public transport within the territory of Angarsk City District» (in Russian). [Electronic resource]: https://angarsk-adm.ru/upload/iblock/5c4/2697_pa-poryad-obsled-passazhiropot.doc. Last accessed 10.04.2022.

[8] Order of the Department of industry, transport and communications of Bryansk Region dated 17.10.2016 No. 175-P «On the approval of the Procedure for studying passenger flows». Annex 1 (in Russian). [Electronic resource]: https://base.garant.ru/42574462/53f89421bbdaf741eb2d1ecc4ddb4c33/. Last accessed 10.04.2022.

and several other cities, where there is no paper tickets for trips in public transport or there are many passengers not using single trip tickets.

Advantages: the method does not require special training for counting.

Disadvantages: the inability to count passengers with reduced fares; the method is not applicable if paper tickets are not in use, it requires many human resources.

All the above passenger counting methods are not automated and require involvement of many human resources, they do not offer enough information, may potentially generate many errors, that make them rather obsolete under modern conditions.

Moreover, the results obtained by these methods are one-time, not systemic, do not allow conducting long-term measuring.

Considering higher efficiency of modern technologies, the above methods can be used in special cases, or in small towns where there is no possibility of using automated systems due to lack of funding, or the absence of the need to implement them due to the low intensity of transport flows.

Automated methods

Automated systems that do not require the presence of a person conducting the counting immediately in a vehicle, or at a public stop are now also well-known.

Automated systems for monitoring passenger flows in urban passenger transport (ASM-PF)

Those systems [*or ASM-PP for its literally translated abbreviation in Russian*] are sufficiently widespread on the territory of the Russian Federation.

Transnavigation Research and Production Enterprise was among the first to introduce this technology[9]. To implement this technology, it is necessary to equip the fleet of urban public transport with special equipment, including infrared sensors, navigation and communication units with GSM and GPS/GLONASS antennas.

The bottom line of the technology: infrared sensors are installed above the doorways of urban public vehicles (in particular, of buses, trolleybuses, trams), and they record the boarding and alighting of passengers, including time and place. This results in collection of data on the ridership of passengers, including those entered and alighted from a particular vehicle [4, pp. 197–198].

Advantages: operation of the system does not require human resources in vehicles.

Disadvantages: financial costs of system implementation, system errors, complexity of system synchronisation with GPS/GLONASS modules.

Automated fare collection (validation) system (AFCVS)

Currently, in the author's opinion, AFCV system [*or ASCP for its abridged name in Russian that in full literally means «Automated trip control system»*] is among the most accurate methods of collecting data on passenger flow widely used both in the Russian Federation and in the world.

In Russia, this technology was first introduced on the territory of Moscow agglomeration in 2001 on bus routes in the territory of Zelenograd Administrative District[10].

The main task of AFCVS is to check travel documents and fare collection. The implementation of AFCVS requires the installation of validators in urban public transport. This technology is quite simple for use: to receive data, a passenger needs to attach a travel document to a validator that reads the data from the travel document and accounts the payment. The moment of attaching the travel document will be simultaneously the time of counting a passenger [4, p. 197; 8].

The *advantage* of this system is the accuracy of the received data.

Disadvantages: possible error in the absence of obligatory attachment of the ticket to the validator, the cost of implementation.

As for public transport of Moscow agglomeration, AFCVS mainly works when a passenger enters compartment of a bus, trolleybus, tram, and metro car. Thus, the disadvantage of AFCVS is the lack of data on the place of alighting of the passenger, which

[9] Automated system for monitoring passenger flows in urban passenger transport (ASM-PF). Website of RPE «Transnavigation». [Electronic resource]: http://www.transnavi.ru/projects/asmpp/about/about.php. Last accessed: 10.04.2022.

[10] See, e.g.: The capital introduces Automated control system for surface urban public transport (in Russian). [Electronic resource]: https://duma.mos.ru/ru/34/news/novosti/v-stolitse-vvoditsya-avtomatizirovannaya-sistema-kontrolya-na-gorodskom-nazemnom-transporte. Last accessed: 10.04.2022.

significantly affects the counting of passenger traffic.

Another disadvantage of the system is that introduction of AFCVS is often accompanied by the installation of turnstiles. The installation of turnstiles can significantly increase the boarding time of passengers and, accordingly, the travel time of passengers. Considering that a turnstile is installed in the front door of the vehicle, i.e., of a bus, and that the turnstile works only after the fare is accounted, in case of an unsuccessful attempt to validate the fare because of malfunction of the travel document, the potential passenger has an increased waiting and travel time. This problem is of great importance during morning and evening rush hours for passengers moving daily on weekdays from their place of residence to the nearest metro station and back.

In Moscow agglomeration in urban public transport, turnstiles have recently been disabled by the decision of the City Department of Transport and Development of Road Transport Infrastructure and Mosgortrans State Unitary Enterprise; fares are paid by the passenger using a validator[11, 12]. This decision allowed to significantly speed up the time of boarding and alighting of passengers of surface public transport. Earlier, before turning off the turnstiles, the researcher observed this problem on his own example, e.g., on the bus route No. 906 of the Mosgortrans State Unitary Enterprise.

Data of mobile operators (GSM)

Mobile operator data are also used to count passenger traffic [4, p. 197–198]. The article [9] reveals possibilities of using the data of GSM mobile operators, describes collection of data on movement of five hundred thousand users using mobile communications, development of a model for changing the routes of urban public transport. The model was used and tested in the city of Abidjan, the largest city of Côte d'Ivoire (the population of the city of Abidjan was 3,8 million in 2013). The data were obtained from the largest mobile operator for the period between December 2011 and April 2012. All data used were de-identified, which is very an important element of maintaining confidentiality. The authors of the article suggested to optimise sixty-five existing routes and create three new urban public transport routes. The authors also pointed to a 10 % reduction in waiting time, measured in passenger-minutes.

The main feature of this model, in the author's opinion, is the possibility of optimising the existing route networks for new city communities.

The authors of the article [10] suggest using the data of mobile operators to count passenger flows entering and exiting the metro. The authors describe the received origin-destination matrix and further possible use of the received data, for example, when opening a new metro station. They also believe that the data obtained should be used when planning construction and operating metro lines, when planning the number of cars operated in morning and evening rush hours, that is, to use the data not only for economic purposes, but also for urban transport planning. The authors also believe that the data obtained can be used to synchronise the entire urban public transport, especially during peak hours and different seasons, for example, in summer and winter.

Another article [11], thanks to the data of mobile operators, offers a method for classifying stations during morning and evening peak hours and words four groups of their features.

Thus, the advantage of using data received from mobile operators to count passenger traffic and optimise existing urban public transport routes is the large array of information received from mobile operators, and a possibility of its consequent automatic processing and analysis.

The potential disadvantage is associate with the accuracy of the received data, which directly depends on the location of the base stations of the mobile operator. There are also risks of keeping confidentiality of received data, their protection against infringements of intruders.

Video surveillance system

The application of video surveillance to obtain data on passenger flows is described in the article [12] as a comprehensive solution for counting the number of passengers who are seated in the vehicle (car). To implement this solution, CCTV cameras and an on-board computer are required, which, using a Wi-Fi

[11] Validator v. Turnstile: passengers save up to 20 minutes paying the fares in the compartment. Website of the Mayor of Moscow (in Russian). [Electronic resource]: https://www.mos.ru/news/item/38508073/. Last accessed 10.04.2022.

[12] Fare collection without turnstiles has been introduced since 01.09.2018 on all the routes of surface public transport in Moscow – entry by all the doors. Website of SUE Mosgortrans (in Russian). [Electronic resource]: https://www.mosgortrans.ru/alldoors/. Last accessed 10.04.2022.

Table 1

Advantages and disadvantages of existing methods and systems for counting passenger flows [compiled by the author]

Method / system	Advantages	Disadvantages
Visual and tabular (on-site) method (estimate by staff)	Cheapness of use	One-time use, lack of systematisation of data collection, dependence on human resources
Questionnaire (survey) method	Feedback from potential passengers of a particular city community	Inability to calculate passenger traffic, fragmented data on assessment of public transport use
Fare (ticket) accounting method	Does not require special training for counting	Inability to count passengers with reduced fares, requires large human resources
Automated systems for monitoring passenger flows (ASM-PF)	The system allows counting the number of boarded and alighted passengers	Requires additional equipment of public transport and financial investments. With a large flow, duplications are likely
Automated fare collection (validation) system (AFCVS)	High accuracy of data on boarding passengers	In the absence of exit validators, there is no information about the points of passengers' alighting
Data of mobile operators (GSM)	Large array of data received from cellular operators with the possibility of their further processing and analysis	Data accuracy, which is directly dependable on the location of the base stations of the mobile operator
Video surveillance system	Allows getting accurate data on passenger traffic	Requires financial investments and building of a data processing algorithm

network, sends data to the server via the Internet. Further, the received data are processed on the server: each video fragment is assigned a GPS/GLONASS coordinate and a marking with the number of the train, car, camera, date and time of receipt of the video fragment. The second solution mentioned in this article is the previously described ASM-PF.

Comparative features of existing methods of counting passenger flows

Summarising the above types of passenger traffic counting, it is possible to show the advantages and disadvantages of the methods of passenger traffic counting (Table 1).

As we see in Table 1, there is no ideal tool or method for analysing and counting passenger flows.

A research article [13] confirms the theory about problems inherent in existing methods for collecting and analysing data on passenger flows, along with that it offers quantitative estimate of advantages of more modern methods (namely of video surveillance).

There are works aimed at studying the behaviour of passengers, and, accordingly, their origin-destination patterns [14], and works that classify passenger flows [15]. The information is also confirmed that the data received from the carrier is often unreliable [16].

The totality of above circumstances highlights relevance of a search for new methods of counting passenger flows that will be exonerated of all or at least of most of the above disadvantages.

One of the most important criteria for the search for a new, more reliable and multifunctional method for collecting data and analysing passenger flows refers to ability to identify the routes of potential passengers, and consequently the occupancy of relevant vehicles (in the case of the study, of metro cars) at a specific urban public transport stop.

Based on the general hypothesis on possibility of using as such a method of collection of data on the use of Wi-Fi connections and see the widespread of Wi-Fi technology in Moscow city agglomeration, technologies are being actively introduced in Moscow agglomeration, it was determined that this hypothesis merits in-depth study and experimental approval.

To be continued

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