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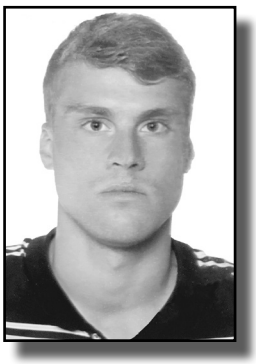
Analysis of Methods for Determining the Optimal Number of Taxi Cars in Megacities



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ABSTRACT

In modern large cities, taxi fleet is a significant component of the urban transport system. The degree of development and impact of taxi services on quality of transport services for residents and users traveling in the city depends on many factors. But one of the basic ones is the optimal ratio of the number of taxi cars and the demand for transportation by them.

The objective of the article was an analytical review of scientific research and practical work in the field of methods for solving the problems of organizing and operating taxi services, in particular, determining the existing population demand for taxi transportation and the required number of taxi cars. For analysis, the research used the method of content analysis of the works of authors of several countries, including Russian ones.

The conducted analysis of existing approaches to determining the demand of the population for taxi transportation and to calculating the required number of taxi cars showed that at present there is no single universally recognized method for this.

The methods used are based on various methods which comprise statistical, sociological (surveys, observations), mathematical methods. The analysis of big data obtained using information systems of megacities is increasingly being used.

It is concluded that there is an objective need for research in the field of developing a universal methodology for determining the required (limit) number of taxi cars in metropolitan areas.

Keywords: urban transportation, population demand for taxi service, estimation of the required number of taxicabs, taxi service.

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Introduction. Currently, as far as we can judge on the basis of the analysis of the scientific sources from a number of countries, there is no any common approach to solving the problem of a balance between the population demand for taxi service and supply of the required number of taxis. The major problem is that the demand is not static, it is variable. Hence, the taxi number has to be corrected for supplying the demand [1]. It should also be noted that in the existing conditions for organizing taxi activities, it is almost impossible to achieve the optimal design ratio without using mathematical modeling, using a computer, without taking into account many factors, for example, uneven load by days of the week, time of day, boarding points, including taking into account mass events, identifying the part of the unsatisfied (presented) demand of the population for taxi services, which is satisfied by using other types of transport, car sharing, rented cars, and in some cases services of illegal carriers operating without permits.

It is high time to carry out researches for solving the taxi service management and operation tasks under the conditions of development of the aggregator market based on matching of the supply (the overall number of taxi vehicles) to the population demand for taxi service, as well as getting the balance between them [2].

Objective. The first step towards such research and the objective of the study is to provide an analytical overview of scientific researches and practical works in the field of methods for solving the problems of organizing and operating taxi services, first of all, determining the existing population demand for taxi transportation and the required number of taxi cars.

Methods. The method of content analysis of the works of the authors from several countries, including Russian authors, was used.

Results.

Methods used in different countries: general and specific approaches

The analysis of the methods used worldwide to determine the required number of taxi cars indicates that the vast majority of researchers use a multi-criteria approach to determining their number.

For example, factors such as population number, incoming and outgoing passenger flow of airports, number of families owning a vehicle, and others are taken into account.

The difficulty of modeling lies in the fact that the system is not constant and depends on many external variables. Implicit factors can influence the demand for a service, and include, for example, taxi waiting time, reliable transportation and impressions of previous trips, changes in parking tariffs in key places of the city, cost of travel, dependence on time of day and peak hours, seasonality and even weather conditions, as well as cultural and social events [3–5]. It is possible to notice that solving such a problem with many variables is possible only with the use of simulation modeling (forecasting methods and models).

The study published last summer in the journal Nature by a group of researchers coordinated by Carlo Ratti, director of Senseable City Lab at Massachusetts Institute of Technology, proposed an efficient method for optimizing city taxi management, which is a modification of Hopcroft–Karp algorithm for a directed acyclic graph [6]. The study describes a network solution to minimize the city taxi fleet in a metropolis, taking into account the set of trips (indicating departure and destination points, as well as the start time), which is necessary for their service, without increasing waiting time for passengers. This method for the first time allowed to solve the problem of calculating the minimum taxi fleet, so that it:

- scales to hundreds of thousands and even millions of daily trips (previous algorithms allowed to do this only for a few thousand trips);
- allows to manage all trips in real time from a single control center;
- provides a near-optimal solution to the problem;
- does not require changing anything (laws, habits of drivers and passengers, etc.), except for transferring control over all the taxis to a single dispatch service and equipping all drivers with a single application for smartphones.

The algorithm represents a taxi fleet in the form of a graph, a mathematical abstraction consisting of nodes (or circles) and edges (lines between nodes). In this case, the nodes represent trips, and the ribs represent the fact that one particular vehicle can serve two particular trips. Using this graph, the algorithm was able to find the best solution for sharing a fleet of vehicles.

The team, which also included M. M. Wazifeh, the first author of the article and former lead researcher at Senseable City Lab; Giovanni Resta, Research Fellow at CNR Institute for Informatics and Telematics; and Stephen Strogatz, a professor of mathematics at Cornell University, tested the solution on a dataset of 150 million taxi rides made in New York within one year.

They calculated travel time using the actual Manhattan road network and GPS-based estimates from the taxi ride dataset.

They found that real-time implementation of the method with near-optimal service levels reduced fleet size by 30 percent.

The decision does not imply that any people should share the trip. Instead, it simply includes reorganization of the taxi dispatch operation, which can be performed using a simple smartphone application [6].

Genesis of method development in Russia

Analyzing Russian research and practical works, it is possible to conclude that the amount of modern scientific research in the field of main problems of organizing the work of passenger taxi cars, such as determining the current population demand for taxi transportation and determining the required number of passenger taxi cars, is small enough. Most papers consider calculation methods that were proposed back in the 1970–80s. This is mainly the works of P. P. Aboyan, M. D. Blatnov, L. A. Bronstein, V. D. Gerami, T. V. Lazarenko, A. Yu. Turukin, etc.

Currently, there are some studies [7–12] devoted to calculating the required number of taxi cars in a city. The main drawback of these works is that it is proposed to use statistical data on the number of trips for previous periods as initial input data, that becomes the cause of very approximate results.

At the same time, on the contrary, the practical value is provided by the data on real demand of the population of the city for taxi services, as soon as they can provide more accurate results of the calculation of the required number of passenger taxi cars in the city. The calculation methods used in the above works do not allow obtaining reliable data in this regard.

The objective information, which can be obtained as a result of various methods of transport surveys: questionnaire, statistical, tabular, accounting, visual monitoring, is of particular importance.

Of all the above methods, the questionnaire method looks to be the most informative. Ways to determine the demand of the population for transportation by taxi cars are considered in [7, 13–16], in which the authors try to develop a methodology for such surveys. However, the main drawback of these works is that the methods proposed in them determine only the realized demand, while the total demand of the population for transportation is not determined.

It should also be noted that the methods for determining the demand of the population for routed modes of transport cannot be applied to taxi transportation, since formation of demand for transportation by passenger taxi cars is significantly influenced by random factors, therefore it is impossible to apply a deterministic model for them, therefore, to solve the main problems of organizing taxi transportation, it is necessary to use mathematical methods of probability theory.

Mathematical methods were used in [17; 18], devoted to the study of functioning of taxi ranks. The main disadvantage of these works is the lack of methods for determining the needs of the population for taxi services.

One of the works devoted to determining the demand of the population for taxi transportation is the Minavtotrans RSFSR [ministry of road transportation of former Russian Soviet Federative Republic] methodology [19]. In this work, the demand of the population for taxi services is determined on the basis of identifying unsatisfied (presented) demand, using a special survey technique, which consists in a questionnaire survey of the city population at the place of residence. However, such a survey does not allow to obtain the necessary data, since the proposed survey method contains elements of subjectivity. It should also be noted that the methodology provides for the possibility of calculating the need for taxi services without conducting a survey by determining the coefficient of unmet demand. However, its values are given without any justification, as a result of which the value of the method is reduced and the possibility of its application is limited.

An attempt to identify the total demand was made in the work of P. P. Aboyan [20], in which the actual demand was determined by the

results of a transport survey, consisting of a questionnaire survey of passengers of passenger taxi cars and visual observation at taxi ranks. The main disadvantages of the work are complexity and significant cost and time spent on organizing, conducting and processing the survey results.

An approximate form of questionnaires filled in by drivers or passengers is presented in [16; 21; 20–24]. The main disadvantage of the proposed questionnaires was their volume and the lack of conditional alphanumeric filling, which would have significantly reduced time for filling and processing the data entered into the questionnaire.

In the works of V. D. Gerami [25–27], devoted to improving organization of passenger taxi cars, a technique was developed based on a mathematical model using an integrated approach program, which made it possible to determine the unsatisfied (presented) demand of the population. Consequently, it was possible to identify the complete need of the population for taxi transportation, and also to calculate the required number of passenger taxi cars with significantly less time spent on organizing, conducting the survey and processing the results. However, there is a need to verify the compliance of this methodology with modern conditions of taxi operation by using new computer technologies.

An attempt to confirm the adequacy of the methodology by V. D. Gerami was made in the work of A. Yu. Turukin [28], in which a program was developed and put into practice for automated processing of data for examining operation of passenger taxi cars and functioning of taxi ranks (at the example of Moscow) based on existing survey forms adapted to new operating conditions, algorithms for their systematization and calculation. Statistical processing of the results of the survey was carried out using this technique, an optimization method for determining the required number of taxi cars was developed and applied in practice using computers, taking into account the demand of the population on the basis of mathematical modeling, which in turn is based on a simulation model with elements of statistical modeling of functioning of taxi vehicles.

Analysis of the problem of justifying and establishing the optimal number of taxi cars in a metropolis can be found in the article by N. O. Bludyan and D. G. Moroz [29]. In the article, the authors, as a result of the analysis of existing approaches to determining the number of taxi cars and modern practices,

came to the conclusion that at present there is no single universal method for determining them, and also pointed out the need to develop a methodology that would take into account all existing methods together and would be able to meet the ever-changing needs of the taxi market in the region.

The work [30] provides a methodology for calculating the required number of taxi cars in the cities of resort areas. The calculation of the number of taxi cars during peak hours is carried out according to a special formula that takes into account the following indicators: average daily mileage of a taxi car; the coefficient of uneven transportation by hours of the day, days of the week and by months of the holiday season; average number of passengers carried per trip; average taxi car mileage; mileage utilization coefficient. The main disadvantage of this methodology is that, for example, the formula does not take into account such an important indicator as waiting time for a taxi car, which, in turn, as noted above, in modern conditions of taxi service directly depends on the number of taxi cars in the region. It should also be noted that the formula cannot be used to calculate the number of cars in a megalopolis, since it does not take into account many important parameters inherent in a megalopolis, for example, the number of people who own private cars, the number of public events in the city, etc.

Taxi quantity regulation methods

Although the topic of regulating the number of taxi cars is separate and requires a separate analysis, nevertheless it is closely related to the general problem of their optimal number and therefore deserves at least a brief review.

All these factors and many others need to be taken into account and a «flexible» system capable of responding to changes in the external environment [31; 32] should be created.

According to the experience of regulating the number of taxi cars in various cities of the world, it can be noted that the main tool for influencing their number is the use of licensing of transportation activities by taxi cars.

To ensure the availability of taxi cars throughout the city, regular assessments are made of the number of licenses issued. Otherwise, it is possible to get an excess or, on the contrary, a shortage of taxi cars, which will affect quality of services and tariffs. When working with too few taxis, there is a shortage of supply, which gives rise to a long waiting time or refusal to request transportation, which will reduce quality of the services provided. The work of an excessive number of taxi cars will lead to obsolescence and misuse of fleet, high turnover among low-paid and poorly qualified taxi drivers, which again will worsen quality of transportation.

At the same time, there are various approaches to the number of licenses issued – from a liberal, application-based nature, to rather strict regulation (in the vast majority of cases, and in this case also, there are certainly technical requirements subject to mandatory fulfillment).

It is worth noting that studies conducted in many cities around the world indicate that in cities with similar demographics, the efficiency of the taxi system nonetheless varies. Bruce Schaller writes in his book that in cities where there is control over the number of taxis, there is a more efficient and high-quality provision of services, and the corruption risks are significantly limited. The subject of regulation is the rules of entry into the market of new transport operators, further control over them, the impact on the number of issued licenses and their types, revocation of licenses [31; 32]. In the city of Moscow, for example, the establishment of the license validity period became an effective method, which excluded its transfer and resale between carriers, as was the case with an unlimited validity period.

Conclusion. The analysis of some approaches to estimating the demand of the population for taxi services and the required number of taxis showed that currently there is no common valid estimation method, which could take into consideration all possible factors impacting population demand for taxi service. Further researches should develop a common estimating methodology that would take into consideration all available methods in the aggregate and will be able to meet dynamic taxi market needs in the region.

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