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Evaluation of analytical forecasting methods developed for vehicle occupancy and level of service assessment. The case study of Moscow

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Abstract

Having transport quality standards is the first step in improving the quality of transport services; the next step is the implementation and enforcement of these standards. This article raises the issue of improving the quality of passenger transport services based on forecasting and monitoring vehicle occupancy and managing the transport process according to the forecasting results. The condition for obtaining the forecast data is the use of automated passenger counting systems. The article shows the results of the application of vehicle occupancy forecasting methods on Moscow trunk routes. It is shown that the situation of passenger flow dynamics differs each time for each route, which requires different analytical forecasting methods. Passenger flow control, based on the established standards, will prevent overloading of buses, thus improving the quality of transport service on urban routes.

Keywords: public transport, quality of transportation, vehicle occupancy, passenger flow, overcrowding of busses

Introduction

The intense increase in the rate of motorization in recent years has led to serious problems, environmental, congestion, and in itself, a decline in the quality of life in large cities and megacities of the world. Congested transportation networks reduce the average speed of traffic flow, leading to an unacceptable increase in travel time (U.S. Department of Transportation, 2010). It has been shown that the main cause of congestion is traffic caused by privately owned cars (Roa-Castellanos, 2016). The negative consequences of this situation are significant. For example, in Spain, the total loss of time of citizens in traffic jams is 420 million hours a year, and it is estimated to be 5,500 million euros [Ojo, 2019]. Another example is the city of Moscow, which, according to a study published in February 2018 by INRIX, is the second most congested city in the world. According to this company, in 2017 a driver in Moscow spent on average 91 hours in traffic jams, or about 26% of the total driving time [Ryzkov et al., 2016].

According to statistics, the average number of passengers in a private car is 1.5 persons, while a large-capacity city bus can carry up to 100 passengers at peak hours [Vlasov, 2018]. The minimum dynamic interval when a passenger car is stationary in a traffic jam is about 6.5 m. The minimum dynamic interval for a large capacity bus when stopped in a traffic jam is about 15 m. To transport 100 people the passenger cars will need 67 cars. At the same time in the traffic jam the queue of these cars will extend for 435 m. Therefore, if the passengers from the 67 cars are transferred to a single bus it is possible to decrease the queue of cars in the traffic jam area from 435 m to 15 m. The length of the occupied lane will be reduced by a factor of 30 [Bogumil and Efimenko, 2013].

From this we can conclude that the public transport system can significantly improve the transport situation at peak hours, reducing the load on the road network, provided that a significant part of private car passengers agree to switch to public transport. This would only be achieved if the quality of urban public transport is improved. This idea is supported by the British Royal Academy of Engineering (2015), which says that improving the capacity of the road network can be achieved by improving the performance of public transport, which can and should be considered an alternative to private transport. In order to meet this goal, transport systems have to operate harmoniously, i.e. in harmony with passenger flows on the routes.

The analysis of foreign and Russian sources on the issues of passenger transport quality in urban transport has shown that considerable attention is paid to the quality of transport (Chang and Dongjae, 2017), which is evaluated according to various aspects, primarily on the "regularity of transport" and "vehicle occupancy" (Dell'Olio, 2011). In this regard, all the leading countries of the world have developed regulations on the level of service (Yogeshwar et al., 2020).

In the United States, the level of service is rated based on vehicle occupancy (Transit Capacity and Quality of Service Manual, 2013). The main indicator is space (square meters) per standing passenger. Vehicle occupancy is classified into six levels of service. Level of service "A" is when all passengers are seated (Highway capacity manual, 2010). This level of service is considered the highest. In fact, as passengers are seated, these conditions are similar to those of a private car ride. At the same time, public transport passengers on major routes are guaranteed not to enter a traffic jam during peak hours and will be transported at a significantly higher speed than passengers in private cars (Redman et al., 2013). Thus, in the future, most passengers on major routes should be transported seated and at high speed. However, modern urban passenger transport vehicles are structurally designed for the situation when some passengers will travel standing (Kazhaev et al., 2018). Therefore, the issue of the maximum allowable occupancy of vehicles is both economic and technical and of great social importance. In Russia, service levels are also regulated (Mikhaylov et al.,2015), depending on the number of passengers per one square meter of cabin area. The Russian interstate standard GOST R 54723-2019 the standard sets 6 levels of service (LOS) from A to F, the level of service LOS "A" is provided when all passengers travel seated. The maximum permissible occupancy of the vehicle is 5 persons per one square meter of vehicle interior area; which corresponds to service level LOS "E". This indicator of the maximum permissible passenger load is approved by the regulations of the Ministry of Transport of the Russian Federation (Order of the Ministry of

Transport of Russia, 2018). However, it is not enough to set the service level indicator, depending on the vehicle occupancy, it is also necessary to control it (Bogumil and Duque, 2020).

The results of the literature analysis of urban transport in large cities showed that the process of passenger transport is not always consistent with the parameters of passenger traffic [Bogumil and Efimenco, 2013; Pourbaix, 2011; Pucher et al., 2005].

Since the management of urban passenger transport can be more efficient if real-time navigation control systems are implemented (Belokurov et al., 2020), the control of the occupancy of public transport vehicles may be possible using the data obtained in real time on the flow of passengers received by the public transport dispatching system (Vlasov et al., 2018). Thus, in this article it is proposed that the control system would need these data to predict the maximum occupancy value during the trip.

This paper addresses the development of analytical methods for predicting vehicle occupancy on the busiest routes of the network, using the statistics of Moscow public transport routes, with the aim of meeting the requirements set for the quality of the transport process, in order to avoid overloading of buses running on the main roads of large cities, thus improving the quality of transport service on the route.

Materials and Methods

Calculation of vehicle occupancy according to the number of incoming and outgoing passengers at stops and assessment of the level of service

The main method of forecasting for vehicle occupancy, considered in this article, is based on the assumption that each vehicle on the route is equipped with telematic means for automated counting boarding and alighting passengers at stops, and the data transmitted to the dispatch center via mobile communication.

In this case, vehicle occupancy ($C_i(t_{ik})$) in the vehicle performing the k-th trip and leaving the i-th stop of the route at the time of tir can be calculated using the formula (Duque and Bogumil, 2019):

$$C_i\left(t_{ik}\right) = \sum_{j=1}^{i} b_j\left(t_{jk}\right) - \sum_{j=1}^{i} a_j\left(t_{jk}\right) \tag{1}$$

where, b_j (t_{jk})– quantity of passengers, boarding the vehicle at j-th stop of k-th trip at time t_{jk}; a_j (t_{jk}) – quantity of passengers, alighting the vehicle at j-th stop of k-th trip at time t_{jk}.

Let's consider as an example the city bus LiAZ-5292, the most common on the routes of Moscow (Boldin, 2020). The bus has 28 seats. The maximum capacity is 108 passengers at the maximum load rate of 5 people per one square meter. According to the LOS established in Russia, this corresponds to level of service "E". Therefore, the maximum number of passengers passing standing at this level of service is 108-28 = 80 passengers. The floor area of the cabin (S_s) is equal to:

$$S_s = \frac{80\ passengers}{5\ passengers/_{1meter^2}} = 16\ meters^2 \tag{2}$$

Based on the data obtained, it is possible to calculate the number of passengers inside the compartment of the LiAZ-5292 bus for various levels of service according to the Interstate Russian Standard GOST R 54723-2019, as shown in table 1.

Table 1. *Number of passengers in the LiAZ-5292 bus compartment, corresponding to different levels of service.*

Level of service	The number of passengers in the bus.	Number of standing passengers	Percentage of standing passengers, %
A	Not more than 28	0	0
B	Not more than 44	From 1 to 16	From 3.5 to 36%
C	From 45 to 76	From 17 to 48	From 37 to 63%
D	From 77 to 93	From 49 to 65	From 63.6 to 70%
E	From 94 to 108	From 66 to 80	From 70.2 to74%
F	More than 108	More than 80	More than 74%

Calculation of the actual volume of transport work, performed with a certain level of service

Real number of passengers in the bus can be compared with the qualified number, established in the standard for assessing the level of service provided on each stage of the trip. Using the length of each stage of the route, we can calculate the actual volume (V_{qi}) of transport work, performed with a certain level of service at a stage i:

$$V_{iq} = N_i LOS_i L_i \tag{3}$$

where, N_i – number of passengers at i-th stage of the route (after i-th stop); LOS i–level of service at i-th stage of the route, estimated using real vehicle occupancy at this stage; length of i-th stage of the route (kilometers).

Similar results can be obtained for each trip, performed for the route during the operational day.

Experimental research and results

As an object of experimental research the bus route number M10 "Kitai Gorod–Lobnenskaya ulitza" was chosen. This route is served by the "Mosgortrans" state enterprise, which uses LiAZ-5292 buses for the route. This bus model was described in section 2 of the article.

The reason for choosing this route was that the route is a typical main trunk route, which runs from the center of Moscow to the Northern outskirts of the city. The time interval for this route during rush hour is 7-8 minutes (Petrova et al., 2020).

The tasks of experimental research were:

1) Evaluating the level of service on each stage based on actual data of the passenger compartment occupation;
2) Determining the busiest stop on the route based on the occupation analysis results;
3) Analysis of the possibility of various methods usage for predicting vehicle at a critical (the mo3st occupied) stop of the route and selection of a forecasting method that allows dispatching system to make decisions on changing the mode of movement of vehicles on the route in order to prevent passenger overflow.

We collected and processed data on the number of boarding and alighting passengers at stops on the M10 route for several days, including weekdays and weekends. Calculations were made for the vehicle occupancy at each stage using the formula 1. An example of a time series that reflects the dynamics of the passenger occupation range of the M10 buses during the operational day January 5, 2021 at the critical stop «Rogachevskaya ulitza» is shown in figure 1.

Analysis of vehicle occupancy data showed that the highest congestion occurs after the stop "Rogozhskaya ulitza". In our previous work (Duque-Sarango and Bogumil, 2019), it was proposed that such a stop should be called a "critical bus stop". Bold horizontal lines mark the boundaries of the different levels of service that are evaluated based on the occupancy of LiAZ-5292 bus vehicles.

Since the data for January 5, 2021 is shown for the most loaded bus stop, we can we can postulate that:

1. Morning trips (before 8:00) and evening trips (after 20:00) were performed with the service level "A";
2. The most part of the days’ time trips were operated with service level " B "and only a few trips operated a level "C" at one segment of the route.

Therefore, we can conclude that the level of service on the M10 route was high during most of the day January 05, 2021.

Let's evaluate the data of the constructed time series, shown at figure 1, for the presence of outliers according to the Irwin criterion for data suspected of being anomalous (Irwin, 1957), the value of λ_t can be calculated using the formula 4:

$$\lambda_t = \frac{|y_t - y_{t-1}|}{S_y} \quad (4)$$

Where:

$$S_y = \sqrt{\frac{\sum_{t=1}^{n}(y_t - \bar{y})^2}{(n-1)}}; \; \bar{y} = \frac{\sum_{t=1}^{n} y_t}{n}, \quad (5)$$

y_t – meaning of i level of time series.
Calculated standard deviation S_y= 14.4; average value $\bar{y}$=11

For our sample size (n=54), the value of the Irwin criteria is 1.1. Analysis of the data of the considered series showed that 14 of its values are anomalous according to the Irwin criterion. In our case, this indicates a high variability of the series levels. Therefore, forecasting, using a built-up trend can lead to large errors (Degtyareva, 2018). The exponential forecasting method, using actual data on vehicle occupancy at a critical stop, based on the forecast of the previous step and actual data on vehicle occupancy in the current trip, will also give significant errors. In this regard, we proposed to consider the trend of vehicle occupancy in each trip up to the critical stop. This section of the time series is sufficient if the task is to regulate interval of movement on the route depending on the forecast results in order to ensure the required level of service.

Figure 2 shows the graphs of vehicle occupancy changes on the route stops of the trip, performed during the considered day on January 5, 2021. The horizontal axis shows the route stops in the order in which they occur on the route. The vertical axis indicates the number of passengers in the passenger compartment after each stop. Each polyline simulates the vehicle occupancy changes during the each trip during the day. Formally, this model can be described as random process realizations during each trip. The state of the process changes at each bus stop. In this figure, one can see that the occupancy of first few stops of each trip form a certain trend of the vehicle occupancy, which persists until the critical stop of the route. The presence of a the trend allows us to put forward a hypothesis that we can use the so-called "naive model" for predicting the vehicle occupancy at the next stop, which is used for predicting time series (Lukashin 2003), and in which the forecast of vehicle occupancy at the i-th stop (O_i) is determined from the ratio:

$$O_i = O_{i-1} + \beta(O_{i-1} - O_{i-1}) \tag{6}$$

Where, O_{i-1} fact of occupancy at previous (i-1) stop, O_{i-2} fact of occupancy at a stop before previous stop;

β– a correction factor determined empirically.

As one can see from the formula, the forecast is made only for the current trip starting from the third stop on the route.

Figure 2 shows the trajectory of the vehicle occupancy process during the busiest trip, which according to the schedule began at 8:59. The red polyline is the vehicle occupancy forecast based on the naive model (Formula 6) with the coefficient β=1. As a result, the model rather accurately predicts the vehicle occupancy up to the critical stop. The error at each step is several passengers only, which is not important for large and articulated buses. However, as shown in figure 2, the process may follow a completely different trajectory on the next trip.

Discussion

Although several methods of passenger flow simulation modeling on urban routes have been developed taking into account route parameters and stopping points (Kazhaev et al., 2018), treating traffic flow as a statistical process only, is not sufficient (Greenberg, 1959). These methods still need improvements in terms of accuracy because passenger flow data constantly exhibit fluctuations (Liang et al., 2019) considering that travel demands are scattered and unstable (Chu et al., 2022). Consequently, traditional methods of constructing bus schedules using statistical passenger load data (Ceder, 1987) are no longer an alternative to respond to actual passenger demand, it is necessary to take into account minute-by-minute passenger flow data.

Analysis of passenger flow data obtained by telematic means, i.e. automated counts of passengers boarding and alighting at stops, on one of Moscow's trunk bus routes shows that passenger flow is unstable during "peak hours". This fact does not allow to effectively use classical methods, used in time series forecasting, for vehicle occupancy. At the same time, it is shown that vehicle occupancy on a particular trip to the critical stop has a well-defined trend, which can be described by a linear trend. However, this information can only be used for a specific trip. Already on the next trip, the dynamics in the process of vehicle occupancy may have a different trend.

Conclusion

This study has developed methods for predicting vehicle occupancy using the statistics of Moscow public transport routes, demonstrating that the effectiveness of these prediction methods depends directly on the characteristics of passenger flow. The proposed methods suggest the future use of databases obtained from telematic means of automatic passenger counting. These methods of predicting vehicle occupancy can be the basis for regulating the movement of urban passenger transport vehicles (Bogumil and Kasimov, 2022), to avoid saturation of urban buses. Since the improvement of transport service directly depends on the implementation of a successful transport management system (Papanikolaou and Basbas, 2021), overcrowding of buses on the main roads of large cities can be avoided by controlling the passenger flow based on the established rules, and including technologies such as the use of predictive modeling of factors such as vehicle occupancy, which will consequently improve the quality of transport service on the route.

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Figures

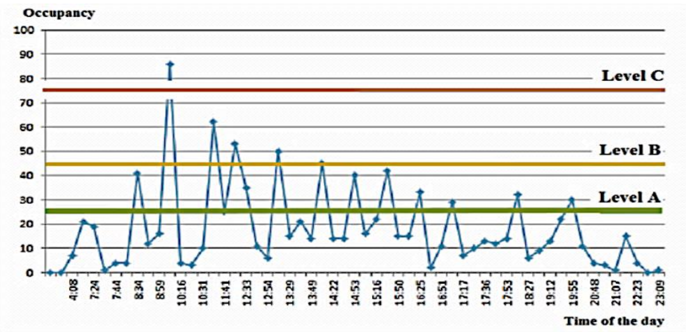

Figure 1. *Example of the dynamics of the vehicle occupancy of the M10 bus route during the day at critical stop "Rogachevskaya ulitza" for January 5, 2021*

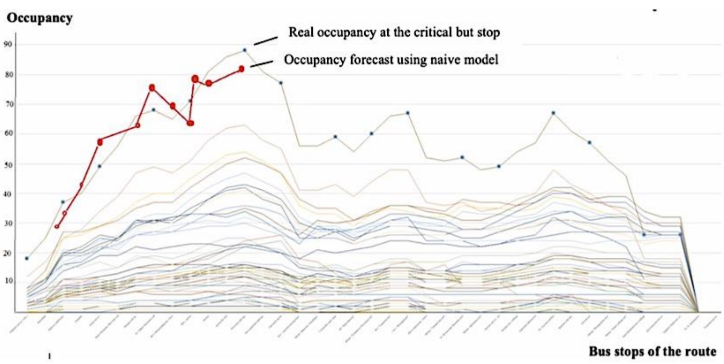

Figure 2. *Dynamics of the vehicle occupancy process during the busiest trip*