DEVELOPMENT AND EVALUATION OF ANALYTICAL FORECASTING METHODS FOR VEHICLE OCCUPANCY, IN THE TRUNK ROUTES OF MOSCOW

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Abstract

Passenger transport plays an important role in large cities around the world. According with this, the administration of these cities pays much attention to urban transport, specifically, in the formalization and establishment of standard criteria for the quality of transportation. The main criteria are the "Regularity of transportation" and "Vehicle occupancy". Having standards is the first step to improve the quality of the transport service, the next step is the execution and application of these standards. In this article, the issue of improving the quality of passenger transport services is considered based on the forecast and control of the vehicle occupancy and the management of the transportation process based on the results of the forecast. The necessary condition for the implementation of these tasks is the use of telematic means as the Automated Passenger Counting System for monitoring passenger flow at bus stops. This information is the source data. In the article, we show the results of the study of the trunk routes of urban transport in Moscow. It is shown that the situation regarding passenger dynamics differs every time for each route, which requires different analytical methods for forecasting and control of vehicle occupancy for each case. Various methods for predicting vehicle occupancy were developed, and it is shown that the effectiveness of these forecasting methods depends directly on the characteristics of passenger flow. The control of the flow of passengers based on the established standards will avoid overloading the buses that circulate on the main roads of large cities, thus improving the quality of the transport service on the route.

Keywords: public transport, ITS, vehicle occupancy, passenger traffic, telematics

1 Introduction

The difficult transport and environmental situation in large cities and megacities, caused by the uncontrolled growth of motorization of the population, forces the administrations of these cities to look for alternative solutions that ensure high mobility of the population, which directly affects the economic situation. One of the most effective ways is to develop a system of public transport, [1,2]. It is possible to achieve a significant increase in the share of public transport in the overall structure of passenger transport by providing significant advantages for public transport only.

One of these advantages is a significant increase in the average speed of transportation, which is achieved by organizing public transport on main routes on dedicated lines and with a small number of stops.

The second important advantage to be achieved is the comfort of the ride. The comfort of the ride depends partially on the air temperature in the cabin. Manufacturers of vehicles have begun to produce city buses with air conditioning, which provides a normal temperature inside saloon at any time of the day at any season of the year. Since the trip time is considered by many citizens as wasted time, buses have started to organize access to mobile Internet, which allows most passengers to spend their travel time usefully. However, in this case the most significant factor affecting the level of service is occupancy of vehicle. In this regard, all the leading countries of the world have developed regulations on the level of service, which is evaluated by the vehicle occupancy.

In the United States, level of service is classified, depending on the vehicle occupancy. The main indicator is space (square meters) per one standing passenger [3, 4]. Vehicle occupancy is classified into six levels of service. The level of service “A” is provided when all passengers are sitting. This level of service is considered as the highest. Indeed, since passengers pass while sitting, these conditions are similar to those of a ride in a private car. At the same time, passengers of public transport on main routes are guaranteed not to get into a traffic jam during rush hour and will be transported at a significantly higher speed than passengers of private cars. Thus, in the future, the majority of passengers on main routes should be transported sitting and at a high speed. However, modern urban passenger transport vehicles are structurally designed for the situation when some passengers will pass standing. Therefore, the issue of maximum permissible vehicle occupancy is both economic, technical and of great social significance.

In Russia, the levels of service are also regulated, depending on the number of passengers per one square meter of cabin area. The level of service “A” is provided when all passengers pass sitting. The maximum permissible vehicle occupancy is 5 people per one square meter of the interior area. As shown in table 1, this corresponds to level of service “E” [5]. This indicator of the maximum permissible passenger load is approved by the regulations of the Ministry of transport of the Russian Federation transport [6].

Table 1 Levels of service for public transport in Russia [5]

Level of service	Number of passengers per 1 sq. m inside the bus	Seats occupied [%]
A	0	Up to 100
B	Not more than 1	100
C	1-3	100
D	3-4	100
E	4-5	100
F	More than 5	100

However, it is not enough to set level of service indicator, depending on the vehicle occupancy. It also needs to be controlled. It can be possible using the real-time data on the vehicle occupancy received by the public transportation dispatch system. The system needs these data to prognoses maximum occupancy value during the trip, and to prevent overloading (compared with permissible load) if necessary.

This article discusses the development of analytical methods for predicting vehicle occupancy on main routes, using statistics of Moscow public transport routes.

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

The method of forecasting for vehicle occupancy, considered in this article, is based on the assumption that each vehicle on the route is equipped with equipment for 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 t_{ir} can be calculated using the formula [8]:

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

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. 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 table 1, 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:

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

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 [5], as shown in table 2.

Table 2 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 [%]
1	A	Not more than 28	0	
2	B	Not more than 44	From 1 to 16	From 3.5 to 36 %
3	C	From 45 to 76	From 17 to 48	From 37 to 63 %
4	D	From 77 to 93	From 49 to 65	From 63.6 to 70 %
5	E	From 94 to 108	From 66 to 80	From 70.2 to74 %
6	F	More than 108	More than 80	More than 74 %

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:

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

where, Ni - number of passengers at i-th stage of the route (after i-th stop); LOSi - 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.

3 Experimental research and selection of a method for predicting vehicle occupancy based on actual data of passenger occupancy on the bus route M10 “Kitai Gorod - Lobnenskaya ulitza”

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 1 of the article. The reason for choosing this route was that the route is a typical main trunk route, that 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. 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 most 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, 2020 at the critical stop «Rogachevskaya ulitza» is shown in fig. 1.

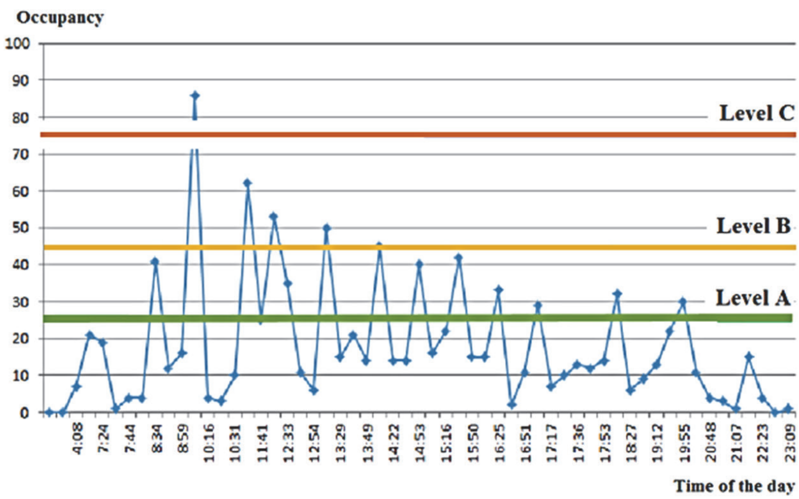

Figure 1 Example of the dynamics of the vehicle occupancy of the M10 bus route during the day at critical stop “Rogachevskaya ulitza” for January 5, 2020

The analysis of data on the vehicle occupancy showed that the highest congestion occurs after the stop “Rogozhskaya ulitza”. In the article [7], such a stop is proposed to be called “critical”. Bold type horizontal lines mark the boundaries of the various levels of service that are evaluated based on the vehicle occupancy of LiAZ-5292 bus.

Since the data for January 5, 2020 is shown for the most loaded bus stop, we can say the following:

- Morning trips (before 8:00) and evening trips (after 20:00) were performed with the service level "A";
- 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, 2020.

Let's evaluate the data of the constructed time series, shown at figure 1, for the presence of outliers according to the Irwin criterion [8] for data suspected of being anomalous, the value of λ_t is calculated using the formula (4):

$$\lambda_t = \frac{| y_t - y_{t-1} |}{S_e} \tag{4}$$

where:

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

y_i - meaning of i level of time series.

Calculated standard deviation S_y= 14.4; average value =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 [9] can lead to large errors. The exponential forecasting method [9], based on the use of 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, 2020. 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 [9,10], and in which the forecast of vehicle occupancy at the i-th stop (O_i) is determined from the ratio:

$$O_i = O_{i-1} + \beta(O_{i-1} - O_{i-2}) \tag{5}$$

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 - some correction factor determined empirically.

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

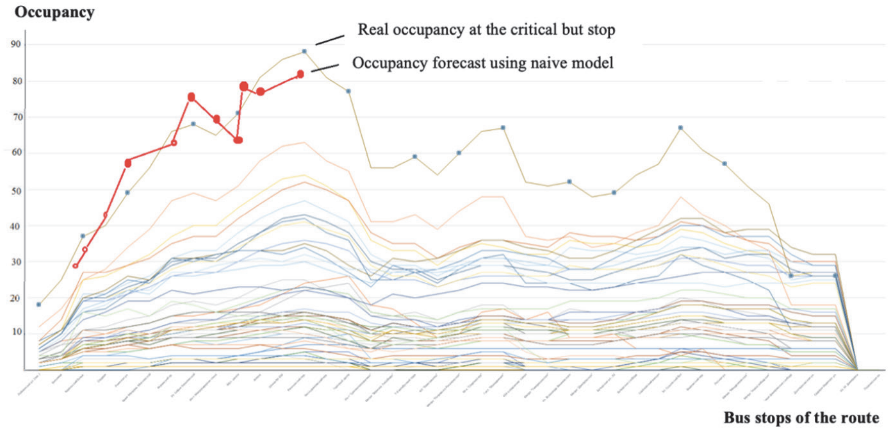

Figure 2 Dynamics of the vehicle occupancy process during the busiest trip

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 (4) with the coefficient $\beta=1$. 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 1, the process may follow a completely different trajectory on the next trip.

4 Conclusion

Analysis of data on passenger flows obtained by instrumental means on one of the trunk bus routes in Moscow shows that the passenger flow is unstable during “rush hours”. This fact does not allow us to effectively use the classical methods, used in forecasting time series, for vehicle occupancy. At the same time, it is shown that the vehicle occupancy in a particular trip to the critical stop has a well-defined trend, which can be described by a linear trend. However, you can only use this information for a specific trip. Already on the next trip, the dynamics in the process of the vehicle occupancy may have a different trend.

References

[1] Bogumil, V., Efimenko, D.: Urban Transport Dispatch Control System Helps to Increase Intelligent Transport Systems Effectiveness, 11th European transport congress – ETC 2013, pp. 20-25, Prague, 2013.

[2] Vuchic, V., Wilew, J.: Urban Transit Systems and Technology, First edition, 2007.

[3] Transit Capacity and Quality of Service Manual, The national academies of Sciences, Engineering, and Medicine, Third edition, Washington, 2013.

[4] Highway capacity manual, Transportation Research Board of the National Academy of Sciences, Washington, 2010.

[5] ГОСТ Р 54723-2019. Глобальная навигационная спут-никовая система. Система управления городским пассажирским транспортом комплексная. Назначение, состав и характеристики решаемых задач подсистемы анализа пассажиропото-ков, Interstate Russian Standard

[6] Распоряжение Министерства Транс-порта России. от 31.01.2017 N НА-19-р (ред. от 13.04.2018) “Об утверждении социального стандарта транспортного обслуживания населения при осуществлении перевозок пассажиров и багажа автомобильным транспортом и городским наземным электрическим транспортом”, Order of the Ministry of Transport of Russia

[7] Duque-Sarango, M., Bogumil, V.: Mathematical model for predicting the vehicle occu-pancy for urban passengers transport on the route, International Conference on Advanced Technol-ogies for Communications ATC - 2019, pp. 248-251, Hanoi, Vietnam, 17-19 Oct. 2019.

[8] Irwin, G.: Analysis of stresses and strains near the end of a crack traversing a plate, Third edition, Trans. ASME, 1957.

[9] Degtyareva, N.: Models of analysis and forecasting based on time series, publishing house of JSC A. Miller Library, 2018.

[10] Lukashin, Yu.: Adaptive methods of short-term forecasting of time series: textbook for universities, Finance and statistics, 2003.