Int. j. adv. multidisc. res. stud. 2024; 4(2):614-618

Received: 06-02-2024
Accepted: 16-03-2024

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Improving the Profitability of Public Transport by Daily Forecasting of Passenger Loads and Bus Trip Distribution

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DOI: https://doi.org/10.62225/2583049X.2024.4.2.2546
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Abstract
The degree of utilization of passenger vehicle capacity affects the economic component of public transport operation. This is due to the fact that it depends on the number of passengers transported, as well as on the capacity of the passenger vehicle used for transportation. One of the tasks formulated in the state program of transport development of the Republic of Belarus is to achieve full self-sufficiency of public transport operation. One of the ways to achieve this goal can be maximizing the degree of use of passenger vehicle capacity by ensuring its compliance with the existing parameters of passenger flow.

In this paper, based on the values of passenger flows in one of the cities of Belarus, obtained as a result of field observations in 2019 and 2024, we calculate an indicator that assesses the degree of utilization of passenger vehicle capacity, the factors that determine it, and the regularities of its change. Based on such calculations, the feasibility of creating a new public transport management technology based on daily forecasting of passenger traffic and distribution of passenger vehicles of different capacity to the routes taking this into account is shown.

Keywords: Public Transport, Passenger Capacity, Capacity, Efficiency, Transportation Technology

1. Introduction

Public transportation (PT) plays a huge role in the life of modern cities. Scientific works show that a significant share of urban travel is made by PT:

- 40.5% of residents of 7 European cities report daily or almost daily use of PT for traveling [1];
- 68% of all trips in Gomel are made using PT [2];
- 49% of employees travel to work by bus [3].

A number of works show the impact of PT on urban life [4-6], economy [7-9], ecology [10-12], road safety [13-15], public health [16-18], sustainable development [19-21]. At the same time, the payback of PT operation is not high and is about 70% for the conditions of the Republic of Belarus [22]. At the same time, in Belarus by the end of 2025 it is necessary to ensure the payback of transportation by own revenues of transport organizations [23, Annex 5, p.7]. At present, in practice, cost reduction is actually achieved by reducing the number of flights, which negatively affects the quality of services provided by PT and leads to the outflow of passenger traffic and increase in the intensity of personal transport use.

At the same time, a number of studies have shown the existence of a relationship between the occupancy of passenger vehicles (PV) and the payback of their work [24-25], which determines the expediency of increasing the degree of utilization of PV capacity to achieve the task of reaching the self-sufficiency of PT work.

The issues of assessing the efficiency of PV capacity utilization are reflected in many scientific works. Thus, in [26] the authors found out that Paretto's law applies to the occupancy rate on many routes - only 20% of the bus capacity is used along 80% of the route. In [27], the authors emphasize that occupancy rates for buses vary greatly between European Union states. For example, in the UK a bus transports on average about 9 people, while in France this figure is about 25. The authors attribute the differences between states to the different organization of PT work, as well as the form of ownership. Similar studies with the same conclusions for the USA are given in [28]. They also note the low efficiency of passenger vehicle capacity utilization.

For the conditions of the Republic of Belarus it is established that the level of PV capacity utilization is low, with the passenger load factor averaging 30% [29]. It is also shown that there is a significant unevenness of PV capacity utilization by routes, hours of the day on the route and, on some routes, by directions of movement [30-32].

This article presents the results of research of passenger flows in Mozyr, obtained from field observations conducted in 2019 and 2024. On their basis, we calculate the indicator that assesses the degree of utilization of PV capacity, show the factors that determine it, and establish the established regularities of its changes. On the basis of the calculations, a proposal to improve the efficiency of PT operation is formulated.

2. Investigation of uneven utilisation of PV capacity

To assess the degree of utilisation of PV capacity, the passenger load factor criterion was used - the ratio of maximum passenger traffic per trip (passenger load) to bus capacity. To calculate it, a survey of passenger flows in Mozyr city was made in 2019 and 2024. Such a survey is done by direct counting of the number of inbound and outbound passengers at each stop by the counting staff. The total number of surveyed flights is equal to 659 in 2019 and 781 in 2024. The main statistical characteristics of passenger load obtained are summarised in Table 1.

Table 1: Passenger load values

Year	number of observations	Mean	Median	Min	Max	Standard deviation	Asymmetry	Asymmetry standard error	Excess	Excess standard error
2019	659	0,277	0,24	0,0095	1,18	0,177	1,566	0,095	3,591	0,190
2024	781	0,271	0,21	0,00	1,06	0,219	1,537	0,088	2,369	0,175

The evaluation of descriptive statistics shows that the distribution of the studied random variables is different from the normal law. To assess the normality of the distribution, the histograms of the frequency distribution of the studied quantities, their normal-probability plots and box plots of the spread were also analysed. All the tests performed showed that the distribution of the studied quantities is different from normal, which is in agreement with previous studies [30-32].

The results of distribution fitting in [33] using p-values of Kolmogorov-Smirnov, Anderson-Darling and Chi-square criteria, showed that the studied random variables are distributed according to the generalised extreme value distribution law, which also agrees with the previously obtained data.

To calculate the average values of the passenger load factor in Mozyr, as well as their marginal absolute error, the methodology given in [32] was used. The results of such calculations showed that the marginal error is 1.7 % for both observations.

It was hypothesised that there were significant differences in the passenger load factor (P) by year. The corresponding scatter diagram is shown in Fig 1.

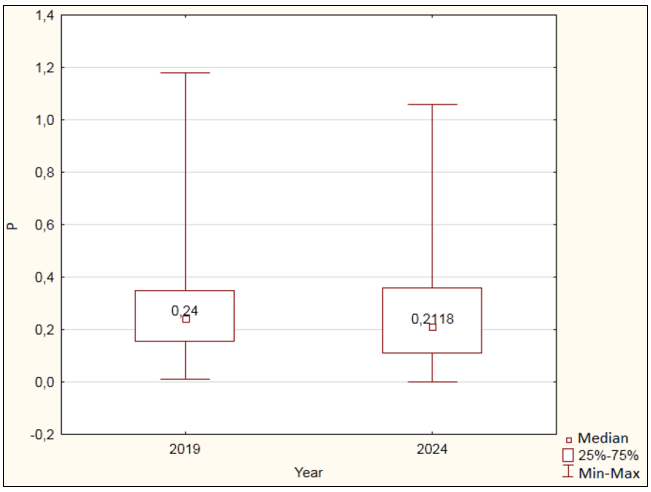

Fig 1: Diagram of passenger load factor (P) values by years

To assess the significance of differences in two samples of passenger load factors values, we used non-parametric criteria for assessing the significance of differences in two independent samples (Wald-Wolfowitz, Kolmagorova-Smirnov and Mann-Whitney U test) implemented in [33]. The results of their calculation allow us to conclude that the differences in the mean values of the analysed indicators by all statistical criteria are significant. That is, the values of the passenger load factor in the city of Mozyr in 2019 and 2024 are significantly different from each other.

The hypothesis was also put forward that there are significant differences in the values of the passenger load factor in Mozyr by route and by time of day. When assessing the significance of differences in passenger load factors by route and by time of day, the Kraskell-Wallace analysis of variance, median test, comparison of mean ranks for all groups, implemented in [33], were used. The Wald-Wolfowitz test, Kolmogorov-Smirnov test, Mana-Whitney U-test, implemented in [33], were used to assess the significance of differences by direction of travel on each route.

The results of calculations show that the values of passenger load coefficients differ significantly by traffic routes and by hours of the day for all statistical criteria used. It can also be seen that the 2024 route network differs from the 2019 route network, i.e. some optimisation has been made over the five-year period. In addition, in 2019 there were 1,276 flights per day, while in 2024 there are 909 flights per day. On the background of such transformations, the payback value has not changed, which against the background of a significant decrease in the passenger load factor shows the need to develop measures to increase the utilisation of PV capacity.

Fig 2 shows a histogram of the distribution of Passenger capacity and bus capacity by trips.

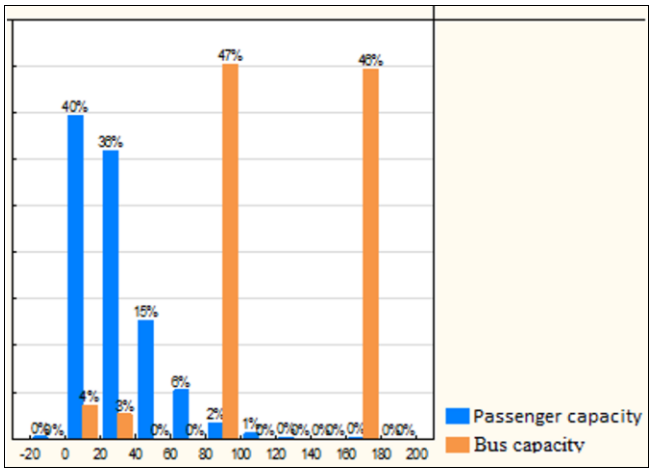

Fig 2: Diagram of passenger capacity and bus capacity

Fig 2 shows that the overwhelming number of trips is performed by buses with a capacity of 80 to 100 passengers (47%) and 160 to 180 passengers (48%). At the same time, passenger capacity of 80 to 180 passengers is observed only in 3 per cent of trips. The vast majority of flights (76 %) have a passenger load of less than 40 passengers. At the same time, the share of trips performed by buses with a capacity of up to 40 passengers is about 7%.

Similarly, it was found that there is a mismatch (excess) between bus capacity and passenger load both by route and by hour of the day. All this makes it advisable to implement a reasonable bus procurement policy and bus management technology, including the allocation of buses to routes, taking into account the minimisation of the difference between their capacity and passenger load.

3. Uneven passenger traffic

It should be noted that the data shown in Figures 1-2 are obtained based on the study of passenger flows for 1 day. At the same time, it has been established [34] that the volume of traffic, and therefore the passenger load factor, is variable and depends on the day of the week, month of the year, calendar year, type of day of the week (holiday/weekend), precipitation, wind, and air temperature. This necessitates the study of relevant dependencies and the accumulation of certain data. Therefore, a new technology for organising PT operation is proposed [35], which assumes the availability of retrospective data on passenger capacity on each flight of each route and the factors influencing it, as well as appropriate formalised dependencies describing such influence. On the basis of such data it is proposed to forecast daily passenger load on each flight of each route and on this basis to assign compositions of PV modules (Fig 3) ensuring maximum compliance with the capacity and capacity of passenger flow.

Fig 3: Use of modular PV trains with different number of modules: a - one module during passenger traffic decline; b - three modules during passenger traffic growth [35]

To implement the proposed technology of PT operation organisation it is necessary to:

1. Equip the PV park with sensors for passenger flow counting.
2. Develop a software product that allows:

- To determine the passenger load for each flight of each route using the data of counting the number of incoming and outgoing passengers;
- Store information on passenger load for each flight of each route;
- Enter calendar information and weather forecasts for each subsequent day;
- Store calendar information and weather forecasts for each subsequent day;
- Forecast (including using data mining methods) for each subsequent day passenger load values for each flight of each route based on the analysis of available passenger load information, calendar information and weather forecasts;
- Based on the forecast passenger load values for each flight of each route, distribute the fleet of passenger vehicles taking into account minimising the difference between the capacity of the PV performing the flight and the passenger load on this flight.

This approach to organising PT work involves the use of modern technologies such as data mining, machine learning, big-data technologies. The general scheme of functioning of such an intelligent PT control system assumes that daily information from passenger counting sensors goes to the server, where information about passenger load on each flight of each route is extracted from it. Here, the operator

also enters daily calendar information (day of the week, its type, month, etc.) as well as weather forecast information for the next day. Based on the array of such entered information, a daily forecast of passenger load values on each flight of each route for the next day is made. On the basis of such forecast values, as well as taking into account the available fleet of modular PVs, the structure of the route transport network, the calculation of the composition of modular PV to work on each flight of each route is made.

At the same time, it should be noted that at the moment manufacturers do not have modular PVs in their arsenal. Although the experience of operating trailed PVs was successfully realised in the recent past [36-38]. At present, certain works in this direction are just underway [39-41], but the final mass production of such PVs is far away. Considering the importance of the issue under consideration and the need to improve the efficiency of PT operation, it is currently possible to implement the proposed intelligent PV fleet management scheme to manage not a modular PV fleet, but a fleet of PVs with different capacities.

4. Conclusions

Thus, the conducted work allows us to formulate the following main conclusions:

1. The values of the passenger load factor in Mozyr are distributed according to the law "Generalisation of extreme values" and are 0.278 for 2019 and 0.271 for 2024.
2. During the period under consideration there was a significant decrease in the passenger load factor on the routes of Mozyr.
3. There is a significant change in the passenger load factor by bus routes and by hours of the day.
4. There is a discrepancy between the capacity of buses carrying out transportations and voyage values of passenger load, that predetermines low values of payback of PT work.

A new technology of PT work organization is proposed, which implies: Equipping the PV park with sensors for passenger flow counting, development of a software product, which allows to determine passenger load on each flight of each route and to forecast on each following day the values of passenger load on each flight of each route, and then to distribute the PV park taking into account the minimization of the difference between the capacity of the PV performing a flight and passenger load on this flight.

Further directions of scientific works it will be expedient to concentrate on development and development of mathematical model of assignment of the available PV fleet of different capacity to the flights of the routes taking into account maximisation of PV capacity utilisation degree, observance of labour and rest modes and other factors.

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