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STUDY OF THE PASSENGERS` AVERAGE WAITING TIME AT PUBLIC TRANSPORT STOPS

Summary. *When predicting public transport routes in cities, important indicators should be considered: the duration of stay on the bus route, passenger flow on the bus route, points of attraction and the passenger's average waiting time at stops. These indicators are the basis for planning the operation of city transport. In particular, predicting the duration of traffic by studying the average passenger's waiting time at stops is an important planning tool for transport companies. Therefore, this study can improve the quality of scheduled services by reducing the gap between actual and scheduled travel time. This article discusses this relevance and, based on experimental evidence, points to the benefit of using studies of average passenger waiting times, especially considering population groups. In fact, most of the factors which affect public transport operation, as had been proven by previous studies, follow a definite mathematical methodology. The analysis was performed using the data from field studies of passenger flow at bus stops (Lviv, Ukraine). The study of passengers at stopping points makes it possible to improve the quality of public transport services (calculate travel duration between stops and the duration of stay at them more accurately). The duration of stay at selected objects depending on a number of passengers was studied. Also, there are given the results of a study of the waiting time of public transport passengers at bus stops are given. A comparison of the dependence of the bus waiting time on population groups was obtained. After receiving this information, system operators can design and adjust the data according to the estimated trip duration. Nevertheless, it is necessary to carry out research at different types of stops in different parts of cities to clarify these data and for a more detailed analysis.*

Keywords: *bus travel time, bus traffic, passengers, waiting time, public transport stop.*

1. INTRODUCTION

Public transportation services play an important role in the system of the city's economic complex and solve a number of problems in the organization of passenger transportation. These problems are due to the increase in a number of private and commercial cars. The quality of passenger service plays a key role in the city`s transport system. Therefore, providing operators with efficient means to develop or revise service schedules can be an effective tool to increase the attractiveness of transport services. Passenger transport, satisfying the population's need for movement, creates prerequisites for the normal functioning of the region's economy, and serves to increase the free time of the urban population.

When determining the quality of transport services, one cannot do without such an important criterion as the duration of movement, an important component of which is the waiting time of transport at stops. With well-organized and adjusted work, the arrival time of route vehicles is known to passengers in advance due to their schedule, so their waiting time forms to a certain extent under the influence of this factor. Since such a situation is not observed in the market of urban passenger transport in Ukraine, the passenger's waiting time varies greatly depending on the interval and average speed of traffic, the number of vehicles on the route and the duration of the bus at stopping point.

The availability of timely and accurate information about bus travel time is important as it attracts more passengers and increases passenger satisfaction [1]. Therefore, there is an urgent need for research to improve the prediction of travel time, taking into account the passenger flow at the stops of the public transport route in order to provide the passenger with this type of information.

The study, aimed at investigating the average duration of passengers' waiting time at a bus stop, analyzing data from real-time research of the traffic of buses operating in Lviv in mixed traffic, was conducted to achieve the abovementioned goal. Under these conditions, the time buses are on the road and the time they wait at stops are subject to predictability of a high degree, since their time structures are similar to general traffic, which exhibits seasonality and a trend/cycle [2–3]. In addition, the results of this study can help bus operators improve their systems in terms of optimizing timetables and vehicle planning, as well as providing more accurate real-time information at bus stops.

2. PROBLEM STATEMENT

Many studies among Ukrainian and foreign authors were devoted to research the average passenger's waiting time.

So, in particular, in papers [3–4], the waiting time is directly related to the movement interval and is equal to approximately half of it. But this dependence changes somewhat when moving away from the central part of the city, as traffic intervals and the availability of stops also increase. In [2, 5], the waiting time is determined through simulation modeling. At the same time, the traffic schedule is taken into account, and thus the arrival of the bus at the stop is calculated due to the random deviation of its value from the schedule.

These results of studies indicate that the practical aspect was applied to them to a lesser extent. In real life, the results of such a study may show data that is not entirely reliable. It is due to the time-consuming nature of field studies.

Therefore, it is necessary to carry out a comparative assessment of the average waiting time of passengers of different categories of route transport at a stop based on the results of field studies. The following tasks are planned to be solved to achieve it: estimation of the average waiting time based on the analysis of field research data and formation of dependence between this data for different population groups.

3. RELEVANCE OF THE STUDY

The duration of bus traffic, passenger traffic on the route, points of attraction and the average passenger's waiting time at stops are important indicators that should be taken into account when predicting public transport routes in cities. These indicators should be studied and improved as they are the basis for planning the city transport operation. Forecasting the duration of traffic by researching the average passenger's waiting time at stops is an important planning tool for transport companies. Conducting this research can improve the quality of transport services by reducing the gap between actual and planned travel times. With the help of real-time studies of the average waiting time of passengers at stops, it is possible to improve the operation of public transport and upgrade the traffic schedule on the route.

4. FORMULATION OF THE AIM AND ARTICLE TASKS

The goal is to improve the quality of passenger service on public transport routes by researching the average waiting time at stops, considering population groups. In connection with the set goal, the following tasks are defined:

- conduct theoretical studies of preferred locations of public transport stops and select observation points;
- to carry out real-time research on the duration of passenger's waiting time at bus stops, taking into account population groups;
- to carry out a statistical assessment of the received data on the duration of passenger's waiting time at bus stops;
- evaluate the importance of the received data in planning the public transport schedule.

5. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Authors [6–8] developed and improved various determination models for predicting the duration of a bus trip on a route. Widely used traffic duration prediction models are based on time series and regression models.

These methods estimate the values of the dependent components by the values of the independent variables. The regression model can work in unstable traffic conditions. Complex models such as support vector regression, k-nearest neighbor regression, project regression, and artificial neural networks are the most popular approaches in the study of passenger flow on a route [9–12]. Since they are able to find complex nonlinear relationships between the target variable and independent variables [5], they can work even in unstable traffic conditions. Many authors used these methods [6–8], as they provide more accurate results when investigating the length of passenger's waiting time at stops.

Methods based on studies of passenger flows specify their dependence on the duration of bus traffic, which is observed in historical data [5–8]. The strength of the methods [12–18] based on passenger flow studies is the high speed of calculations due to the simple formulation of the algorithm and does not require a large number of variables. These calculations make it possible to specify the structure of travel time variability and to reveal the influence on time (for example, hours of the day, days of the week, and periods of the year) that related to the bus route. These models areuseful for viewing existing bus routes. If the route, its structure and other variables (such as road network characteristics) do not change, then analysis results can become useful for redefining more reliable schemes and for planning bus traffic.

A review of the literature shows that there are a lot of studies on long-term forecasting of the bus traffic duration, taking into account the passenger's average waiting time at stops. But only a few studies have found a relationship between the indicators of transit systems and the changing time of congestion (which is derived from the general behavior of the traffic flow). Their influence is significant when developing a model for both long-term and short-term forecasting of the duration of bus traffic. Very few studies look at bus journey times, considering ridership and waiting times at stops. The analysis is highly relevant for transit operators who must plan system schedules to limit service interruptions during operations while ensuring that service constraints are met from a reliability perspective [2]. The complexity is associated with the coincidence of various factors during bus transportation. Therefore, the need for a more detailed study of passenger flows behavior in further research is growing.

6. PRESENTATION OF BASIC MATERIAL

The research was conducted on weekdays at public transport stops that are located in the central part of Lviv. During the morning peak period, stopping time of public transport was recorded on a video camera with wide-angle optics. The received recordings were processed with the help of video editors. The data collected includes arrival and departure times from each studied stop and passenger flow data at the stop.

At the first stage, the duration of bus stopping time at the studied stops is determined. The results bus stopping time are shown in Fig. 1.

As can be seen from the figure, the bus stopping time was a maximum of 2.5 minutes and a minimum of less than 10 seconds. On average, the duration of a bus stop was 1 minute.

The results of real-time studies of the length of buses' stay at stops depending on the number of passengers leaving the bus (Fig. 2), entering (Fig. 3), and total passenger turnover (Fig. 4) are shown in the corresponding figures.

The given results make it possible to obtain data on the duration of buses' stay at stops. As we can see from the figures, the average time of the bus stay at the stop varies from 40 to 100 seconds when the demand for this route is up to 21 passengers. When analyzing the data, it was also established that, on average, from one to 10 passengers were observed at each stopping point in the morning peak period. More than ten passengers were at stops in 15 % of the entire sample of values. In addition, the increasing influence of the passenger flow on the duration of the bus stop is observed in the dependencies.

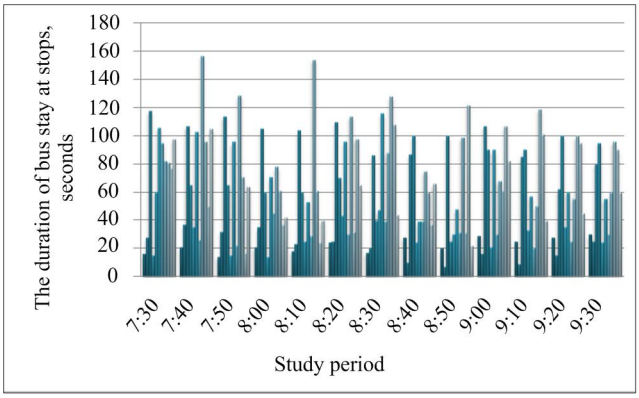

Fig. 1. The duration of bus stay at stops

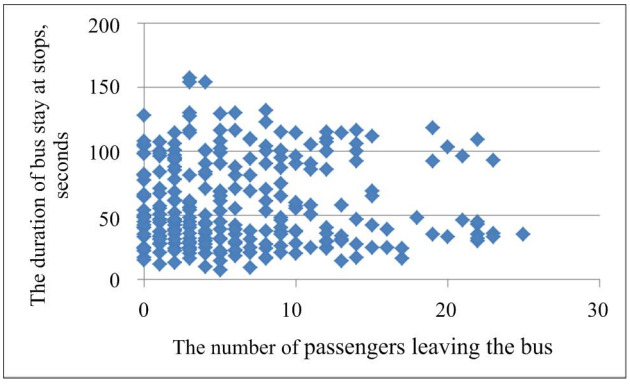

Fig. 2. The results of field studies of the duration of bus stay at the stop depending on the number of passengers leaving the bus

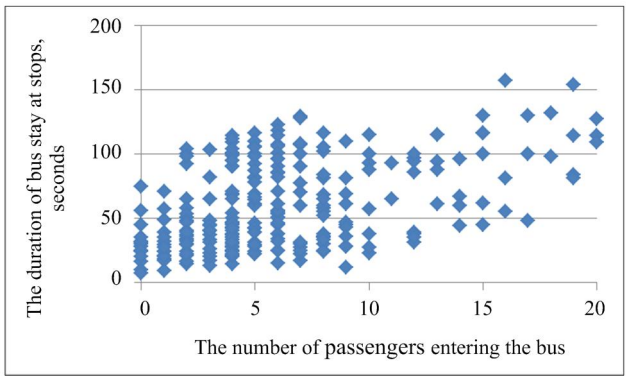

Fig. 3. The results of field studies of the duration of bus stay at the stop depending on the number of passengers entering the bus

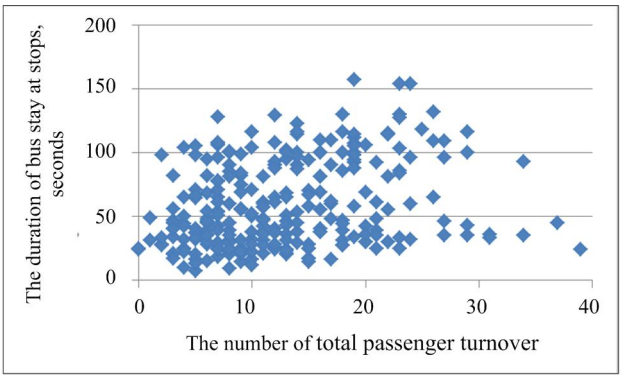

Fig. 4. Results of field studies of the duration of bus stay at the stop depending on the number of total passenger turnover

During the analysis of passenger traffic in the second stage, three main groups of passengers at stops were identified: working people, students (pupils) and pensioners. The division into categories was carried out visually. The duration of waiting time for public transport was determined for each representative of

the corresponding category. It happened due to the recording of the passenger's arrival time at the stop and the duration of his boarding in the route vehicle.

The data array was organized for each category, processed and analyzed in the "Statistica" software environment. The mean waiting time and the standard deviation of the waiting time for each of the established groups were determined. The results of the research are presented in Figures 5-7.

Figure 5 shows that the average waiting time for the population group "working people" is 3.8 minutes, with a minimum value of 0.4 minutes and a maximum of 14.5 minutes. The standard deviation of the waiting time is 3.65 minutes.

For the population group "students (pupils)" (see Fig. 6), the average waiting time is 3.93 minutes, with a minimum value of 0.4 minutes and a maximum of 14 minutes. The standard deviation of the waiting time is 3.38 minutes.

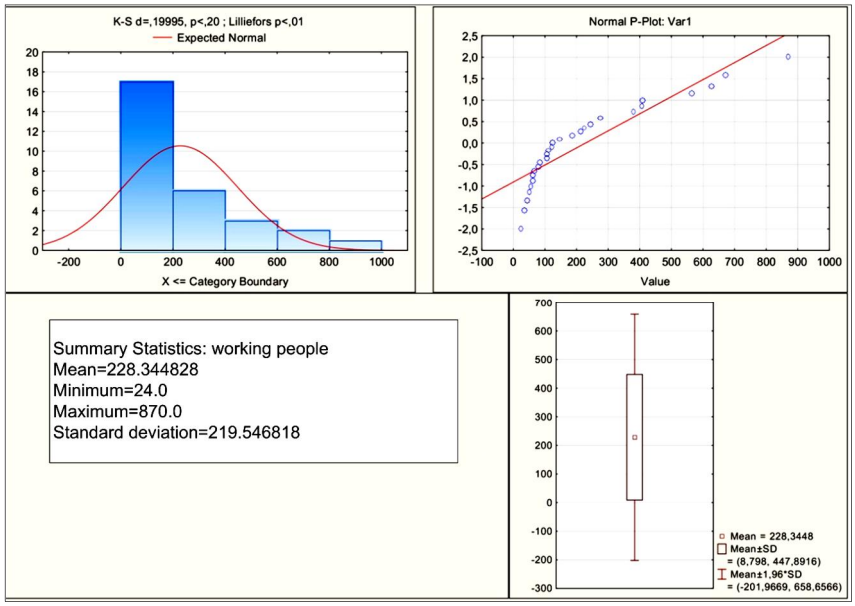

Fig. 5 Processing data on the duration of passengers waiting time at the stop for the population group "working people"

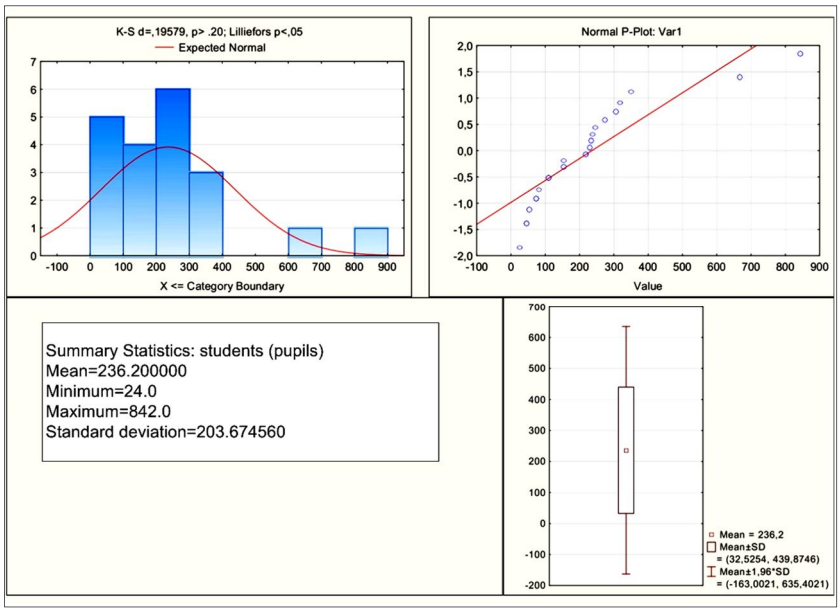

Fig. 6 Processing data on the duration of passengers waiting time at the bus stop for the population group "students (pupils)"

For the population group "pensioners" (see Fig. 7), the average waiting time is 2.85 minutes, with a minimum value of 0.53 minutes and a maximum of 8.78 minutes. The standard deviation of the waiting time is 2.06 minutes.

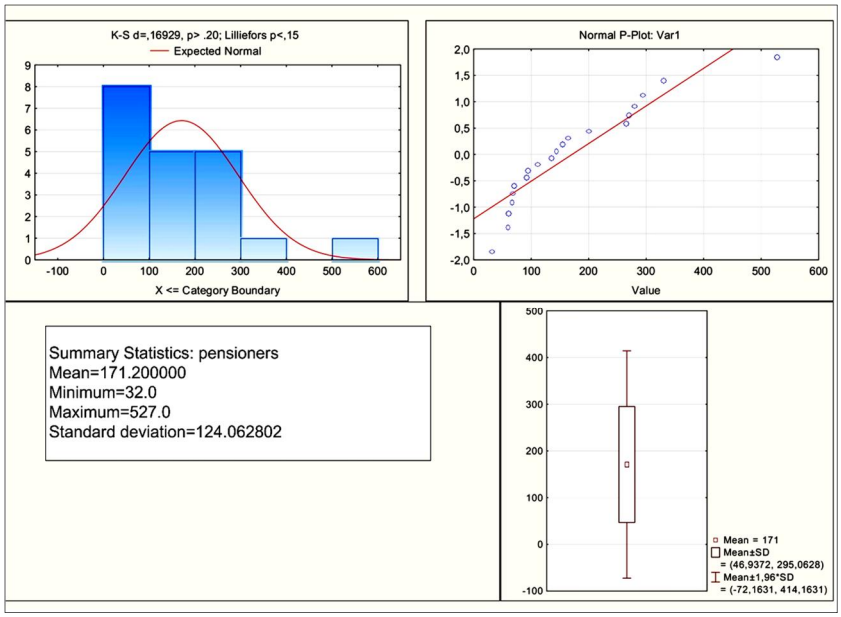

Fig. 7 Processing data on the duration of passengers waiting time at the stop for the population group "pensioners"

The results of data analysis in the "Statistica" software environment made it possible to determine the average waiting time for passengers by population groups and in general. For example, for the groups "workers" and "students (pupils)", the average waiting time is about 4 minutes, and for the group "pensioners" – about 3 minutes. The existing discrepancies are caused by the fact that the "pensioners"group makes their choice when getting into a bus mostly randomly, because they need to make a short trip mainly. So choosing a specific route vehicle for them does not become so important. Instead, the group of "workers", "students (pupils)" purposefully choose a route vehicle, because in order to get to their places of work and study, they have to cover longer distances. Because of this, they chose of a non-stop trip in a vehicle along a route that will take them from point A to point B is more important for them than for the "pensioners" group.

The proposed segmental approach for predicting the time of a bus trip, taking into account the determination of the time spent at a stop, can improve the accuracy of predicting the total travel duration on the route under different conditions. In this way, it is possible to determine the influence of traffic conditions and the demand for transportation on the duration of bus travel in real time.

7. CONCLUSIONS AND FUTURE RESEARCH PERSPECTIVES

The study of passengers at bus stops will provide an opportunity to improve the quality of public transport services (calculate the travel time between stopping points and the duration of stay at them more accurately). This work focuses on determining the dependence of the length of stay of buses at stops depending on passenger demand for different population groups.

It follows from the research that the duration of the bus stop was a maximum of 2.5 minutes, and a minimum of less than 10 seconds. On average, the time of a bus stop is 1 minute. It was also established that the duration of the bus stay at the stop varies from 40 to 100 seconds when the demand for this route is up to 21 passengers. On average, from 1 to 10 passengers were observed at each stop during the morning peak period. More than ten passengers were at stopping points in 15 % of the entire sample of values. In addition, the increasing influence of the passenger flow on the duration of the bus stop is observed in the dependencies.

The duration of waiting time for public transport was determined for each representative of the relevant category: working people, students (pupils) and pensioners. It was determined that the average waiting time for the population group "workers0 is 3.8 minutes, with a minimum value of 0.4 minutes and a maximum of 14.5 minutes. The standard deviation of the waiting time is 3.65 minutes. For the population group "students (pupils)", the average waiting time is 3.93 minutes, with a minimum value of 0.4 minutes

and a maximum of 14 minutes. The standard deviation of the waiting time is 3.38 minutes. For the population group "pensioners", the average waiting time is 2.85 minutes, with a minimum value of 0.53 minutes and a maximum of 8.78 minutes. The standard deviation of the waiting time is 2.06 minutes.

The results of data analysis in the "Statistica" software environment made it possible to determine the passengers' average waiting time by population groups and in general. For example, for the groups "workers" and "students (pupils)", the average waiting time is about 4 minutes, and for the group "pensioners" – about 3 minutes.

The results of field studies confirmed the differences in the average waiting time for a route vehicle between different population groups. System operators can design and adjust the data according to the estimated trip duration with this information. Nevertheless, it is necessary to research the different types of stops in different parts of cities to clarify these data and for a more detailed analysis.

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ДОСЛІДЖЕННЯ СЕРЕДНЬОЇ ТРИВАЛОСТІ ОЧІКУВАННЯ ПАСАЖИРІВ НА ЗУПИНЦІ ГРОМАДСЬКОГО ТРАНСПОРТУ

Анотація. *Зазначено, що у прогнозуванні маршрутів громадського транспорту у містах важливими показниками, які необхідно враховувати, вважають тривалість перебування на маршруті автобусів, пасажирооборот на маршруті, точки притягання та середню тривалість очікування пасажирів на зупинках. Ці показники є основою у плануванні роботи міського транспорту. Зокрема, прогнозування тривалості руху в дорозі методом дослідження середнього часу очікування пасажирів на зупинках є важливим інструментом планування для транспортних компаній. Оскільки це дослідження може покращити якість запланованих послуг зменшенням розриву між фактичним і запланованим часом у дорозі. Обговорено зазначену актуальність і на основі експериментальних даних вказується на користь використання досліджень середньої тривалості очікування пасажирів, особливо із врахуванням груп населення. Насправді, серед великої кількості чинників, що впливають на роботу громадського транспорту, більшість із них, як доведено попередніми дослідженнями, відповідають певній математичній методиці. Аналіз виконано з використанням натурних досліджень пасажиропотоку на зупинках автобусних маршрутів (Львів, Україна). Дослідження пасажиропотоків на зупинках дає можливість покращити якості послуг громадського транспорту (розрахувати точніше тривалість руху між зупинками та тривалість перебування на них). Встановлено тривалість простоїв автобусів на обраних зупинках залежно від кількості пасажирів. Також наведено результати дослідження тривалості очікування пасажирами громадського транспорту на зупинках. Отримано залежності тривалості очікування автобуса від груп населення. На основі цієї інформації оператори системи можуть проєктувати та налаштовувати графіки руху автобусів відповідно до орієнтовної тривалості подорожі.*

Ключові слова: *тривалість руху автобуса, пасажиропотік, пасажири, час очікування, зупинка громадського транспорту.*