

JUSTIFICATION OF THE CHOICE OF PUBLIC TRANSPORT SERVICE TYPE ON THE ROUTE

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Abstract. Problem. Currently, there exist two main types of service on public transport routes – headway-based and timetable-based. They differ by the frequency of service at the stops and by the information available for passengers. The required frequency of service significantly affects transport operator costs and passenger travel time which, in turn, influences the cost for a passenger. One of the ways to reduce costs for both parties of the transportation process is to make a reasonable choice of the type of service or switch between the types during the day depending on the passenger flow volume. **Goal.** In the paper, to justify the choice of between the types of service, the cost of public transport vehicles operation and the losses of passenger travel times are taken into account. **Methodology.** The developed way of making a choice about the type of service allows increasing the efficiency of urban public transport due to reducing the passenger waiting time by switching from the headway-based service in rush hours to timetable-based service in the periods of passenger flow volume decline. **Results.** The relationship allowing making a decision about the type of service on the route is developed. It allows to correctly introduce the type of service which will ensure the balance between the transport operator and passenger costs. **Originality.** The developed approach to make a decision on the type of service allows reducing the passenger waiting time by switching from headway-based service in rush hours to the timetable-based service in the periods of decline in passenger flow volume during the day. **Practical value.** The results of the research based on the survey data allowed estimating the numerical value of the headway at which it is expedient to switch to the timetable-based service.

Key words: passenger transportation, public transport, type of service, headway, waiting time.

Introduction

The main objective of the organization of urban public transport (UPT) operation is to provide passengers with high-quality service at a minimal cost. To improve the UPT efficiency, it is possible to change the type of public transport service on the route in order to reduce passenger travel time while maintaining the achieved level of service [1]. In this case, the task is to determine the number of public transport vehicles (or equally, the headway) required to handle existing passenger flows as well as to choose the type of service – timetable-based or headway-based. This task should be solved when transitioning from peak to off-peak periods and vice versa.

Literature review

Public transport operations can provide the urban population with services of different types. These types can be classified according to the way of stop servicing and the way of providing passengers with information about service frequency.

The first classification includes two main service types – conventional service and express service [2].

Conventional service means that public transport vehicle (PTV) will stop and pick up passengers at every stop on the route. Express service means that PTV will stop at a limited number of stops which is less than on a conventional route. This type of service needs to meet the prerequisites for putting into practice and allows increasing speed of the vehicles and, accordingly, reducing passenger travel times without changes in a fleet operating on the route [2].

The second classification also includes two types of services – headway-based and timetable-based [3-5]. Headway-based service means that passengers have only the information about the headway on the route. In this case, PTV usually operates at a relatively high frequency, and it allows passengers do not to plan their arrival at the origin stop – passengers just come to the stop and wait for some time for PTV. Many researchers usually consider waiting time as half of the headway [5].

Timetable-based service means that there exists a published timetable for a certain route, and this timetable is available for passengers. The timetable can be published online and placed at each stop of the route. At that, passengers can be supported with supplementary information about real-time information about public transport operation [6]. Under these conditions, public transport users can plan their arrival at the origin stop and therefore reduce their waiting time or even make it close to zero.

These types of services require attention because the right choice of a certain type can potentially achieve the balance between the cost of operator and passenger. For example, timetable-based service can allow an operator to reduce the number of vehicles on the route but in this case, passengers should be provided with the timetable to reduce their waiting time and, accordingly, travel time. On the other hand, headway-based service can attract passengers due to high service frequency but it requires higher operator costs [7, 8].

So, the well-grounded decision on when it is reasonable to use a certain type of service can positively affect the operator performance and passenger level of satisfaction with public transport use.

The aim and problem statement

To determine the moment when it is reasonable to change the type of service, it is proposed to use such criterion as the total cost which includes the losses caused by the decrease in passenger transportation volume, the losses of the passengers related to waiting for boarding to the PTV, the costs of the carrier caused by the used type of service (Z_T for the timetable-based service and Z_H for the headway-based service).

The equation allowing choosing a certain type of service on the route looks as follows:

$$Z_T \leq Z_H, \quad (1)$$

$$Z_T = Q_{pf} t_{wT} C_{ph} + \frac{A_T l_r}{t_o} S_{km} + A_T S_h + (A_e - A_T) S_{idle}, \quad (2)$$

$$Z_H = Q_{pf} t_{wH} C_{ph} + \frac{A_H l_r}{t_r} S_{km} + A_H S_h + (A_e - A_T) S_{idle} \quad (3)$$

where Q_{pf} is the passenger flow on the busiest section of the route, pas./h;

t_{wT}, t_{wH} is average passenger waiting time when the type of service is timetable-based and headway-based accordingly;

C_{ph} is the cost of passenger-hour spent for waiting for boarding, bel. rub/h;

A_T, A_H is the number of PTVs when the type of service is timetable-based and headway-based accordingly;

l_r is the length of the round trip, km;

A_e is the estimated number of PTVs required for the operation on a certain route (taking into account the reserve vehicles);

t_r is round trip time for a certain route, h;

S_{km} is the variable costs per 1 km covered by PTV on the route, bel. rub/km;

S_h is the fixed costs per 1 hour of PTV operation, bel. rub/h;

S_{idle} is the fixed costs per 1 hour of PTV idle time, bel. rub/h.

The number of PTVs required for the operation on a certain route can be calculated as follows:

$$A_e = \frac{Q_{pf} t_r}{q_{opt} \gamma} = \frac{t_r}{I} \quad (4)$$

where q_{opt} is the optimal PTV capacity, pas;

γ is the capacity ratio;

I is the headway on the route, h [1, 9].

When the type of service is timetable-based, the number of PTVs can be calculated using the formula

$$A_T = A_e K_{res}, \quad (5)$$

where K_{res} is the PTVs reservation ratio for the timetable-based service which is a percentage of the total number of PTVs operating on the route [10].

The optimal PTV capacity can be estimated as follows [11]:

$$q_{opt} = \sqrt{\frac{2Q_{pf}}{C_{ph}}} \times \sqrt{\frac{k_p [l_r a_{km} + a_h (l_r / v_t + t_{wt})]}{\eta_{to}}}, \quad (6)$$

where k_p is the ratio of passenger flow pulsation;

a_{km}, a_h are the coefficients of the relationship between vehicle capacity and the cost of passenger transportation;

v_t is the technical speed of the PTV, km/h;

t_{wt} is the idle time at the terminal stops, h;

η_{to} is the passenger turnover ratio [11].

For the headway-based service, the waiting time can be estimated as

$$t_{wH} = \frac{I}{2}. \quad (7)$$

For the timetable-based service, the waiting time t_{wT} can be determined based on a statistical analysis of the empirical data.

Substituting equations (5) and (6) into expressions (2) and (3) will result in the following formulas:

$$Z_T = Q_{pf} \left(t_{wT} C_{ph} + \frac{l_r}{q_T \gamma_T} S_{km} + \frac{t_r}{q_T \gamma_T} S_h \right) + \left(A_e K_{res} - \frac{Q_{pf} t_r}{q_T \gamma_T} \right) S_{idle}, \quad (8)$$

$$Z_H = Q_{pf} \left(\frac{I}{2} C_{ph} + \frac{l_r}{q_H \gamma_H} S_{km} + \frac{t_r}{q_H \gamma_H} S_h \right) + \left(A_e - \frac{Q_{pf} t_r}{q_H \gamma_H} \right) S_{idle}. \quad (9)$$

Equation (8) shows the sum of passenger costs related to their waiting for boarding and the carrier costs required to provide timetable-based service. Equation (9) represents the analogous sum of costs for the case of headway-based service. If Z_T is less than or equal to Z_H then it is reasonable to provide timetable-based service. Otherwise, the headway-based service will be more efficient. Thus, equations (8) and (9) allow deciding on the type of service on the route.

Development of the approach for choosing the type of service on the route

To develop the approach for choosing the type of service on the route, it is reasonable to graphically interpret formulas (8) and (9), Fig. 1.

The graphs in Fig. 1 testify that it is advisable to organize the timetable-based service when the frequency of the vehicles on the route is one vehicle in 10 to 20 minutes.

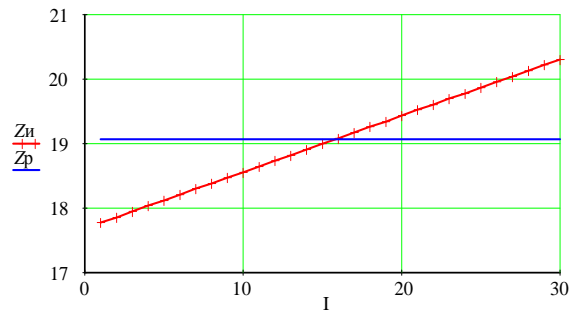


Fig. 1. The relationship between the total costs Z_T and Z_H and the headway on the route

To find the value of the headway at which it is reasonable to shift to the headway-based service, it is necessary to transform equations (8) and (9) with respect to I . Assuming that $q_T \gamma_T = q_H \gamma_H = q\gamma$, $q_H \gamma_H$ and $A_e = t_r / I$, we can get the following:

$$Z_p = Z_n, \quad (10)$$

$$Q_{pf} \left(t_{wT} C_{ph} + \frac{l_r}{q\gamma} S_{km} + \frac{t_r}{q\gamma} S_h \right) + \left(\frac{t_r}{I} K_{res} - \frac{Q_{pf} t_r}{q\gamma} \right) S_{idle} = Q_{pf} \left(\frac{I}{2} C_{ph} + \frac{l_r}{q\gamma} S_{km} + \frac{t_r}{q\gamma} S_h \right) + \left(A_e - \frac{Q_{pf} t_r}{q\gamma} \right) S_{idle}. \quad (11)$$

After transformations and under the assumption that $S_r = S_{idle} / Q_{pf}$, we can obtain

$$t_{wT} C_{ph} + \frac{t_r}{I} S_r (K_{res} - 1) - \frac{I}{2} C_{ph} = 0, \quad (12)$$

or

$$t_{wT} C_{ph} I + t_r S_r (K_{res} - 1) - \frac{I^2}{2} C_{ph} = 0. \quad (13)$$

where S_r is the specific reduced costs for the maintenance of reserve PTVs, bel. rub./pas.

Thus, the solution of the latter equation with respect to I will be as follows:

$$I = \frac{\sqrt{(t_{wT} C_{ph})^2 + 2C_{ph} t_r S_r (K_{res} - 1)}}{C_{ph}} + \frac{t_{wT} C_{ph}}{C_{ph}} \quad (14)$$

or

$$I = \sqrt{t_{wT}^2 + \frac{2t_r S_r (K_{res} - 1)}{C_{ph}}} + t_{wT}. \quad (15)$$

After the substitutions based on the research data from the papers [1, 9–11] as well as the existing cost indicators, it is possible to obtain

$$I = \sqrt{t_{wT}^2 + 0,0186} + t_{wT}. \quad (16)$$

To determine the values of t_{wT} when the type of service is timetable-based, a survey in the city of Gomel was conducted. In order to get the characteristic of the total population on the base of the sample, the sample units should correctly represent the population. Thus, the sample should cover all the quotas in the population, i.e. it should be representative.

According to the law of large numbers, it can be argued that the sample is representative if each sample unit is selected randomly from the population, and all objects have an equal probability to be selected. If the sample size is large and the sample is a small share of the population, the difference between repeated and non-repeated sample is nonsignificant. The total population is limited by the number of city inhabitants. The population of Gomel is approximately 526,9 thousand people, including 330 thousand working-age people. UPT in Gomel transports more than 250 thousand passengers per day [12]. Given the large total population, it is necessary to determine sufficient sample size. The size of the non-repeated sample can be determined using the formula

$$n \geq \frac{t^2 \delta^2 N_c}{\varepsilon^2 N_c + t^2 \delta^2}, \quad (17)$$

where t is the value of the normalized deviate at a certain confidence probability (for example, when the confidence probability $P = 0,95$ then $t = 1,96$ [13]);

δ – standard deviation;

N_c – city population;

ε – maximum permissible error (the recommended reference value is 0,05 [13]).

For the repeated sampling, the sample size can be defined as

$$n \geq \frac{t^2 \sigma^2}{\varepsilon^2}. \quad (18)$$

Since there were no data about the waiting time, its mathematical expectation and standard deviation, it was necessary to conduct a pilot survey to estimate mentioned parameters. The survey was conducted during one day at the stop served by public transport route with a timetable-based service. Collected data were processed in “Statistica” software [14, 15], and the normal distribution [16] was fitted to the waiting time, Fig. 2.

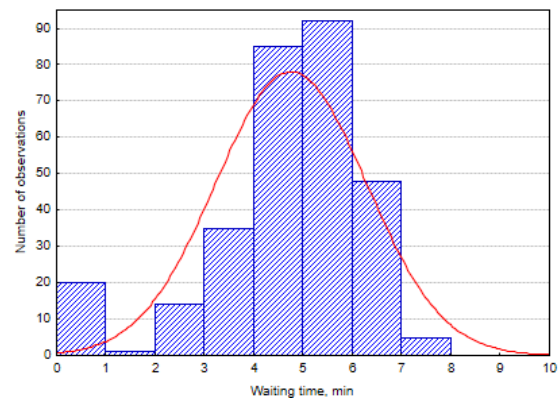


Fig. 2. Waiting time distribution when the type of service on the route is timetable-based

The main statistics calculated using the “Statistica” are given in Table 1.

Table 1 – The main statistical characteristics of the waiting time distribution when the type of service is timetable-based

Number of observations	Expectation, min	Minimum, min	Maximum, min	Standard deviation, min
300	4.76	0.50	8.00	1.53

Based on the received statistics, the size of the repeated sample according to formula (17) will be

$$n \geq \frac{1,96^2 \cdot 1,53^2}{0,05^2} = 3614 \text{ passengers.}$$

Thus, to analyze the waiting time variable for the case when the type of service is timetable-based, it is necessary to obtain a sample of more than 3614 values. These data were collected during the corresponding survey and then processed using “Statistica”. Statistical processing allowed confirming that the random waiting time values can be well-described by the normal distribution

[16], Fig. 3.

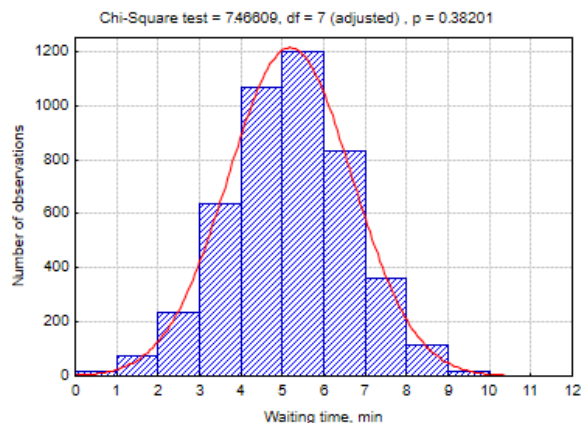


Fig. 3. The result of the analysis performed in module “Distribution Fitting”

The main distribution statistics calculated using “Statistica” are in Table 2.

Table 2 – The characteristics of the waiting time distribution when the type of service is timetable-based

Number of observations	Expectation, min	Minimum, min	Maximum, min	Standard deviation, min	Standard error
4562	5.19	0.10	10.20	1.50	0.02

In general, the figure shows that the distribution of the analyzed variable corresponds to the normal one. This conclusion based on visual conformity has a more strict confirmation by the results of the χ -square test (see the top of the graph). The χ -square tests the null hypothesis that the observed distribution does not differ from the theoretical normal distribution. Since the confidence level P appeared to be more than 0.05 (namely, $P = 0,38201$) and the tabulated value $\chi_{0.05;8}^2 = 15.51$ (8 is the number of degrees of freedom that equals to the difference between the number of distribution bins and the number of estimated statistical characteristics [17]) appeared to be greater than calculated, the hypothesis was considered confirmed.

To support this conclusion, the other tests were applied [18]. The most preferable among them is the Shapiro-Wilk W -test (Fig. 4) since it has the greatest power compared to others (i.e. it often reveals differences between distributions when these differences really exist) [17, 18].

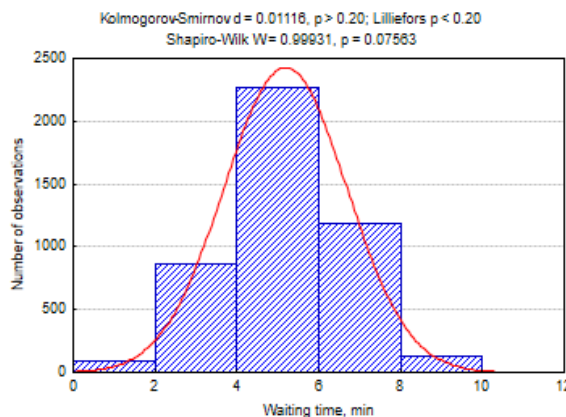


Fig. 4. The result of checking the waiting times' normality performed using module “Descriptive Statistics”

As in the previous case, the confidence level P appeared to be more than 0.05, and it approves that the analyzed distribution does not differ significantly from the normal one. Thus, the results of experimental studies allowed defining that when the type of service is timetable-based, the average waiting time is 5.2 min. The use of this value in formula (16) will result in

$$I = \sqrt{0.0867^2 + 0.0186} + 0.0867 = 0.25 \text{ hour.}$$

Conclusion

The result of the research allowed determining that the headway on the public transport route at which it is advisable to organize the provision of timetable-based service equals 0.25 hour or 15 minutes.

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Обґрунтування вибору форми надання послуг громадського транспорту на маршруті

Анотація. Проблема. На сьогодні існує два основних типи надання послуг пасажиром на маршрутах громадського транспорту – за інтервалом руху та за розкладом руху. Вони відрізняються частотою обслуговування зупинок та інформациєю, доступною пасажиром. Необхідна частота обслуговування громадським транспортом суттєво впливає на витрати транспортно-підприємства та час пересування пасажирів, що має вплив на вартісну оцінку витратеного пасажиром часу. Одним із способів зменшення витрат для обох сторін перевізного процесу є обґрунтований вибір форми обслуговування пасажирів або її зміна протягом дня залежно від величини пасажиропотоку. **Мета.** У статті для обґрунтування вибору між формами надання послуг пасажиром вразо-

вуються вартість експлуатації транспортних засобів громадського транспорту та втрати часу пасажирів на пересування. **Методологія.** Розроблений спосіб вибору форми надання послуг дозволяє підвищити ефективність міського громадського транспорту за рахунок скорочення часу очікування пасажирів шляхом переключення з обслуговування за інтервалом в години пік на обслуговування за розкладом в періоди спаду пасажиропотоку. **Результати.** Розроблена залежність, що дозволяє приймати рішення про форму надання послуг на маршруті громадського транспорту. Це дозволяє обґрунтовано запроваджувати форму обслуговування, що забезпечить баланс між витратами транспортного перевізника та пасажирів. **Оригінальність.** Розроблений підхід для прийняття рішення щодо форми обслуговування дозволяє скоротити час очікування пасажирів шляхом переключення з обслуговування за інтервалом у години пік на обслуговування за розкладом у періоди зменшення величини пасажиропотоку протягом доби. **Практичне значення.** Результати дослідження, основані на даних обстеження, дозволили оцінити чисельне значення інтервалу руху транспортних засобів громадського транспорту, коли доцільно перейти на обслуговування пасажирів за розкладом руху.

Ключові слова: пасажирські перевезення, громадський транспорт, форма обслуговування, інтервал руху, час очікування.

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