Standardization of the capacity utilization factor of urban public transport fleet

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Abstract. The article describes the task of determining the standard for transport fleet when working on regular urban routes, analyzes the dependence of the capacity utilization factor on the passenger traffic parameters, the average operating time of the transport fleet on the route and the speed fluctuation during public transport operation. The accounting of the transportation speed fluctuation during the operation of urban public transport is suggested to be measured through the transportation speed fluctuation factor.

1. Introduction
One of the most important indicators determining the public transport service quality is the capacity utilization factor of transport fleet. This parameter also determines the economic efficiency of transport: it is desirable for the carrier that the value of the capacity utilization factor takes on the greatest value. On the contrary, for a passenger it is preferable not to overfull the capacity of transport vehicle. In this regard, when analyzing the performed traffic parameters, the average operating time of the transport fleet on the route and the speed fluctuation during public transport operation. The accounting of the transportation speed fluctuation during the operation of urban public transport is suggested to be measured through the transportation speed fluctuation factor.

The vehicle capacity utilization factor is also used for determining travel fares [3]. Nowadays, in order to obtain capacity utilization parameters, it is recommended to conduct surveys of passenger flows, which imply a significant resource expenditure.

It is considered [2] that the capacity utilization factor during peak periods for the most intense parts of the route should be in the range from 0.7 to 0.8, and no more than 0.3 (30% of the vehicle capacity utilization) on average per day of transport operation. However, these conclusions do not have a sufficiently serious substantiation and do not take into account the dependence of the capacity utilization factor on the parameters of the transport process and passenger flows. The task of determining the capacity utilization factor was reviewed in the research [6]. In this article, in order to develop the regulations, set forth in [6], recommendations are given on the standardization of the transport fleet’s capacity utilization factor.

2. Problem Statement
It is required to determine the standard value of the transport fleet’s capacity utilization factor of urban public transport that would ensure movement without exceeding the established limits for the passenger cabin filling of a vehicle.
3. Meeting the challenge

The limit of the capacity utilization factor standard value will be determined based on the condition: on the most intense part of the route during peak periods, the number of passengers in the vehicle does not exceed its capacity. It is known [1] that the passenger traffic is non-stationary: it varies along the route and the time of public transport movement. Therefore, the average filling of the vehicle cabin for a certain period of movement is significantly less than its capacity. However, in the process of movement, there are sections of the route where the capacity utilization of transport vehicle approaches the limit value that are specified by the vehicle manufacturer. In these most stressful areas, capacity utilization is determined by the static capacity utilization factor, which is calculated as the percentage of the actual number of passengers in the vehicle to its nominal capacity. It is clear that:

$$\gamma_{\text{max}} = q_{\text{max}} / q_n \leq 1,$$

(1)

where $q_{\text{max}}$ – the number of passengers in the cabin of the vehicle on the most intense part of the route (pass.) and $q_n$ – vehicle nominal capacity (pass.).

On average, for a journey, round trip or period of movement, the capacity utilization of transport vehicle is estimated by the factor of dynamic capacity utilization [1]:

$$\gamma'_{d} = P_f / P_{\text{max}},$$

(2)

where $P_f$ – actual transport operation (pass-km) and $P_{\text{max}}$ – transport operation with the full capacity utilization of transport vehicle (pass-km).

The equation (2) can be written:

$$\gamma'_{d} = \bar{q} / q_n,$$

(3)

where $\bar{q}$ – average number of passengers in a vehicle per journey, round trip or period of movement (pass.);

$$\bar{q} = P_f / L,$$

(4)

where $L$ – vehicle travelled kilometers on the route for the studying period (journey, round trip or period of movement), km.

As mentioned above, the intensity of passenger traffic is non-stationary through time. Determination of passenger traffic parameters (e.g. according to the results of passenger traffic survey) is usually carried out differentially by the hour of the day (Figure 3). To prevent vehicles overfilling in calculations based on hourly intensities during peak periods, intra-hour fluctuations in passenger traffic should be taken into account. Fluctuations of passenger traffic within periods’ hours are estimated by the factor of intra-hour irregularity of passenger traffic, which is calculated as follows [1]. An hour is divided into several calculation periods ($\tau$), the number of passengers is determined in each of these periods. The factor of intra-hour irregularity is the percentage of the largest number of passengers to the average for the studied hour:

$$k_h = q^\text{max}_{\tau} / \bar{q}_h,$$

(5)

where $q^\text{max}_{\tau}$ – the highest number of passengers for $\tau$ and $\bar{q}_h$ – average number of passengers for the studied hour.

Therefore, the average number of passengers in a vehicle on the most intense part of the route per peak hour of movement can be defined as:

$$q_h = q_n / k_h,$$

(6)

where $q_n$ – vehicle nominal capacity (pass.).

The average number of passengers in a vehicle per round trip can be defined as:

$$q_o = P_o / l_o,$$

(7)

where $P_o$ – transport operation per round trip (pass-km) and $l_o$ – round trip length (km).
The following relationship should be performed between the largest number of passengers (in the most intense part of the route) and the average number of passengers per journey [1]:

$$k_m = q_h / q_r,$$  \hspace{1cm} (8)

where $q_r$ – the average number of passengers in the vehicle per journey (pass.) and $k_m$ – the factor of irregularity distribution of the traffic load along the route.

The average number of passengers per journey ($q_r$) is calculated as:

$$q_r = P_r / l_m,$$  \hspace{1cm} (9)

where $P_r$ – transport operation per journey (pass-km) and $l_m$ – trip length (km).

To determine the average value of the capacity utilization factor for round trip, it is necessary to take into account the factor of irregularity in the directions of the route:

$$k_o = q_r / q_o,$$  \hspace{1cm} (10)

where $q_r$ – the average number of passengers in a vehicle for the journey in the more intense direction.

Therefore, the average number of passengers in a vehicle per round trip can be determined:

$$q_o = q_r / k_o.$$  \hspace{1cm} (11)

Based on inequality (1), the average number of passengers in a vehicle per round trip should not exceed the following value:

$$q_o \leq \frac{q_m}{k_h k_m k_o}.$$  \hspace{1cm} (12)

The capacity utilization factor for the round trip for route can be calculated as:

$$\gamma_o = q_o / q_n.$$  \hspace{1cm} (13)

Thus:

$$\gamma_o \leq \frac{1}{k_h k_m k_o}.$$  \hspace{1cm} (14)

According to the surveys’ results of passenger traffic on public transport in Krasnoyarsk, Russia, the value of intra-hour irregularity factor ($k_h$) is 1.1, the factor of irregularity distribution of traffic load along the route ($k_m$) – 1.9, irregularity in the directions of the route ($k_o$) – 1.16. Consequently, the capacity utilization factor for one round trip on the route during the peak period while the highest passenger traffic intensity should not be higher than 0.41. Otherwise, in the most intense part of the route the vehicle cabin will be overfilled.

The factor of irregularity in traffic load along the route depends on the parameters of surveyed passenger traffic. Figure 1 shows the histogram of the routes distribution, depending on the factor of irregularity in traffic load. It can be seen from the figure that on most routes (84%) the factor of irregularity distribution traffic load is in the range of 1.6 to 2.0. Therefore, the maximum possible value of the capacity utilization factor during the peak period will be from 0.39 to 0.49 for most routes.

Apparently, the capacity utilization factor should be standardized for each route separately. Determination of the irregularity in traffic load factor can be carried out according to the results of a selective survey of passenger traffic, since this indicator is quite stable: during the transport operating time, its fluctuations for each route do not exceed 20%.
Figure 1. Histogram of public transport routes distribution in Krasnoyarsk according to the irregularity in traffic load factor; $k_{irr}$ – factor of irregularity distribution of the traffic load along the route.

The standard for factor capacity utilization of the vehicle in average for an operation day on the route must take into account the dynamics of passenger traffic by the hour. The dynamics of passenger traffic can be assessed by completed transport operations which there’s distribution by hours of the day is given in figure 3.

Let us determine the hourly transport operation fluctuation factor as follows [1]:

$$k_p = \frac{P_h}{\overline{P}_h},$$

(15)

where $P_h$ – the highest value of hourly transport operation for working day and $\overline{P}_h$ – the average value of hourly transport operation for working day.

Let us determine the smallest limit of capacity utilization factor. Apparently, the smallest transport operation for a unit of transport fleet will be obtained in case that the all vehicles will operate on the route for the entire period of transport operation. In this case, the average hourly transport operation for a unit of transport fleet will be:

$$\overline{P}_{hA} = \frac{P_h}{A},$$

(16)

where $A$ – quantity of s (units).

An average number of passengers in transport vehicle:

$$q_{min} = \frac{q_o}{k_p}.$$  

(17)

The factor of hourly fluctuation passenger traffic for public transport in Krasnoyarsk is about 1.8. Therefore, the minimum limit for capacity utilization factor will be 0.23.

Clearly, at different periods of the day there is a variable number of operated transport vehicles on routes. The number of transport fleet (fleet units) in each period depends on the intensity of passenger traffic and other factors, for example, established maximum movement range, transitional periods, restrictions on drivers’ working and resting schedules, etc. The completed transport activity of a transport vehicle unit can be defined by:

$$\overline{P}_A = q_A V_s T_u.$$  

(18)
where \( q_A \) – the average amount of passengers in the vehicle (pass); \( V_o \) – the transport vehicle operation speed (km / h) and \( T_m \) – average operating time for transport vehicle on the route (hour).

An average number of passengers in transport vehicle:

\[
q_A = \frac{q_m T}{T_m},
\]

(19)

where \( T \) – the time duration of transport vehicle movement (hour).

It is apparent that the following condition must be met:

\[
q_A \leq q_o.
\]

(20)

On this basis, we determined the smallest possible average working time for vehicle on the route:

\[
T_m = \frac{q T}{q_o k_p}.
\]

(21)

For public transport in the city of Krasnoyarsk with a value of average hourly passenger traffic fluctuation factor \((k_p)\), equal to 1.8 and a movement time for a transport vehicle of 18 hours, the average operating time of the transport fleet on routes should not be less than 10 hours. At the same time, during the period between peak times, the condition of compliance between the transport fleet capacity and the intensity of passenger traffic at the most loaded sections of the route will be observed.

Figure 2 shows the parameters illustration of the transport fleet capacity utilization. The \( P_{max} \) zone shows the amount of transport operations with full capacity utilization of the transport vehicle. The \( P_{min} \) zone shows the transport operation with the theoretically smallest possible capacity utilization (all the transport fleet are operated the entire period of traffic). \( P_o \) illustrates the actual process of routes operation, when the amount of transport fleet changes during a working day. At the same time, the average operation time on the route should not be less than \( T_m \), so the average number of passengers in the vehicle would not exceed the similar indicator for the round trip on the route in peak hour.

![Figure 2. Parameters of the capacity utilization for transport vehicle.](image)

Therefore, the limiting value of capacity utilization factor for transport fleet, depending on the working average time on the route, is calculated as:

\[
\bar{\gamma} \leq \frac{T}{T_m k_h k_m k_o}.
\]

(22)
Figure 3. Dynamics of transport operation by the hour of the day (Krasnoyarsk).

Apparently, the standard of capacity utilization factor is influenced by transport traffic, traffic congestion leads to a significant decrease in the public transport transfer speed during peak periods. To take into consideration the decrease in the transfer speed during peak periods, the factor of irregularity in transfer speed will be used, which is proposed to be calculated as follows:

$$k_v = \frac{V_p}{\bar{V}}$$

(23)

where \(V_p\) – transfer speed during peak hour and \(\bar{V}\) – public transport average transfer speed for the operation day.

As a result, the following equation is obtained to determine the standard of capacity utilization factor for the transport fleet:

$$\bar{\gamma} \leq \frac{T_k}{\bar{T}M_k k_m k_o}$$

(24)

The smallest average operating time for transport vehicle on the route should be also adjusted by the irregular transfer speed factor:

$$\bar{T}_w = \frac{T_k}{k_p}$$

(25)

In table 1 and figure 4 the dependence of the average capacity utilization factor for an operation day on the average vehicle operating time is shown. It is obtained from the results of a passenger traffic survey in Krasnoyarsk city. The table shows that the capacity utilization factor of transport vehicle depends significantly on the average operation time on the route and the fluctuation in transfer speed during the time of movement. The data in the table can be taken as the maximum allowed values. For example, with an average operating time on the route of 10 hours, the system will not have reserves of carrying capacity. During all periods of traffic, the utilization capacity for transport fleet will be at the limit of permissible values. In the case of failure of the transport process, for example, in the case of failure of a unit from transport fleet, there will be an excess in capacity of the remaining transport fleet or a passenger could deny the service.
Table 1. The dependence of standard capacity utilization factor for an operation day on the average vehicle operating time and fluctuation in transfer speed

| Time on the route, hour | Irregular transfer speed factor |
|------------------------|---------------------------------|
|                        | 0.75 | 0.80 | 0.85 | 0.90 | 0.95 |
| 10                     | 0.31 | 0.34 | 0.36 | 0.38 | 0.40 |
| 11                     | 0.29 | 0.30 | 0.32 | 0.34 | 0.36 |
| 12                     | 0.26 | 0.28 | 0.30 | 0.31 | 0.33 |
| 13                     | 0.24 | 0.26 | 0.27 | 0.29 | 0.31 |
| 14                     | 0.22 | 0.24 | 0.25 | 0.27 | 0.28 |
| 15                     | 0.21 | 0.22 | 0.24 | 0.25 | 0.27 |
| 16                     | 0.20 | 0.21 | 0.22 | 0.24 | 0.25 |
| 17                     | 0.18 | 0.20 | 0.21 | 0.22 | 0.23 |
| 18                     | 0.17 | 0.19 | 0.20 | 0.21 | 0.22 |

Figure 4. The dependence of standard capacity utilization factor for an operation day on the average vehicle operating time and fluctuation in transfer speed (Irregular transfer speed factor range : 0.75-0.95).

4. Conclusion
It is determined that standards of capacity utilization factor significantly depends on the parameters of passenger traffic, the average operating time of the transport fleet on the route and the fluctuation in transfer speed during the time of movement. The upper limit of the capacity utilization factor for the round trip along the route during peak periods is about 0.4, i.e. the average number of passengers in a vehicle for the round trip is significantly lower than the transport fleet’s nominal capacity.

The obtained dependences allow us to calculate the standards of capacity utilization factor taking into account the parameters of the planned transport process. As a result, the necessary level of transport process quality is ensured, and it also becomes possible to establish rational public transport fares taking into account the planned economic results.

Depending on the operating conditions, the standards of capacity utilization factor vary significantly from 0.2 to 0.4. The capacity utilization factor should be calculated separately for each route. Determination of the irregularity in traffic load factor can be carried out according to the results of a selective...
survey of passenger traffic, since this indicator is quite stable: during the transport operating time, its fluctuations for each route do not exceed 20%.

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