Consideration of the influence of the reliability of elements of the urban electric transport system on its bandwidth

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Abstract. The article proposes an approach to assessing the capacity of urban electric transport, which is one of the criteria for a stable resource supply of electric traction, taking into account the reliability of the elements of its infrastructure. By introducing the operational readiness factor as an indicator of reliability, the researcher has the opportunity to assess the impact of failures of these components on the efficiency of the electric traction process, as well as to compare the compliance of the transport line infrastructure with the characteristics of the rolling stock used.

Introduction

Capacity is one of the criteria for a stable and reliable resource support of the electric traction process in the urban electric transport system (UETS). For example, the task of guaranteed energy supply of passenger traffic is solved even at the design stage of a traction power supply system, while providing a reserve for increasing the size of traffic, and, therefore, sets the maximum capacity, taking into account the characteristics of the UET traction electrical equipment [1, 2].

The analysis of the existing scientific and methodological apparatus for estimating the throughput of the UET, and its comparison with the methodology for calculating the throughput of railways [3], allows us to make a number of observations:

1. The existing methods for calculating the capacity of route transport lines are rather outdated and do not take into account the current state of the elements of the urban electric transport system (UETS). Publications on this issue refer to the 60-80s of the last century. Studies of the throughput of railways, in contrast to the UET, were updated in the early 2000s, in particular, in 2010, the Instruction on the calculation of the available throughput of railways was approved [3].

2. As a temporary unit of measurement of the throughput capacity of UET transport lines, hours are taken, and the carrying capacity is respectively the transported number of passengers per hour. Since the passenger traffic in the UET S networks varies by the hour of the day, days of the week, months and seasons of the year, taking one hour as a time interval is not correct. It is necessary to evaluate these indicators at least for the daily period in order to increase the accuracy and reliability of the results obtained.
3. Studies carried out in VNIIZhT in the 60-70s of the last century showed that the level of reliability of technical equipment (locomotives, cars, track devices, signaling systems, etc.) influences the use of railway capacity. The growth of failures led to the fact that they began to be taken into account when calculating the carrying capacity of the corresponding reliability factor $\alpha_n$ [3, 4]

$$N_{nal} = \frac{(1440-t_{tec})\alpha_n}{I},$$

where $t_{tec}$ – the duration of the free time from the train, provided for the work on the current maintenance of the track, devices, structures, etc.; $I$ – travel interval.

Similar to rail transport, the failures of the elements of the ETS and the infrastructure of the transport line have a significant impact on the efficiency of passenger traffic of [5, 6], so there is an objective need to take into account the effect of reliability on the throughput of the GETS. Consideration of this issue should be carried out in a complex, taking into account the interaction and mutual influence of all components of the passenger transportation process.

**Approach to estimating the throughput of the elements of the UETS taking into account reliability.**

Approach to estimating the throughput of the elements of the UETS taking into account reliability. Since the reliability of stopping points and intermediate stations of transport lines, as engineering structures, with proper maintenance does not have a significant impact on the efficiency $\alpha_n$ of electric transport, the reliability factor in assessing the throughput of such transport infrastructure elements may not be taken into account. The components of the contact network and the track that are located within the stations (points) must be taken into account when forming the reliability coefficient of the corresponding span.

The expressions for estimating the throughput of the elements of the transport infrastructure of the UETS in the daily time interval, taking into account the influence of failures, with the exception of stopping points and intermediate stations, take the following form

**UET ground line carrying capacity**

$$P_p = \frac{3600V(24-t_{tec})\alpha_n}{t_pV+b+l+l_0};$$

where $V$ - movement speed on the stretch, m / sec;

$t_p$ – driver response time, sec;

$b$ – deceleration during emergency braking, m / sec²;

$l$ – length of electric rolling stock (EPS), m;

$l_0$ – safety clearance between successive transport units, m

**the capacity of the stopping points of the land line UET**

$$P_{o,p} = \frac{3600(24-t_{tec})}{t_1+t_2+t_3+t_4};$$

where $t_1$ – permissible time spent by EPS for approaching the stopping point, sec;

$t_2$ – duration of disembarking and landing of passengers, sec;

$t_3$ – duration of the announcement of the driver about stopping the landing and closing the doors;

$t_4$ – the duration of the release of the stopping point, s.

**the throughput of regulated land crossings UET**

$$P_{reg} = \frac{3600(t_x-\Delta t)(24-t_{tec})\alpha_n}{T_c t_p};$$

where $t_x$ – duration of the green phase of the traffic light, sec;

$\Delta t$ - the time between turning on the permissive signal of the traffic light and crossing the stop line by the first vehicle;

$t_p = \frac{l_p+l_b}{V_y}$ - the estimated interval of passage of vehicles through the intersection, sec;

$V_y$ - set speed of EPS at intersection;
3

\( T_c \) - traffic light control cycle duration.

**Bandwidth intersection with a forced control system for a trolley bus**

\[ P_{pr.\text{reg}} = \frac{1200(t_z - \Delta t)(24 - t_{tech,h})a_n}{T_c t_p}; \]

**Crossing capacity with tram control system**

\[ P_{pr.\text{reg}} = \frac{3600k(24 - t_{tech,h})a_n}{T_c}; \]

**Tram traffic capacity**

\[ P_{Yz} = \frac{3600V(24 - t_{tech,h})a_n}{(t_p + t_k) + t_sV_{cp} + t_v^2}; \]

where \( l_k \) – distance between serial and shunt contacts;

\( t_v \) – driver response time and device response;

\( V_{cp} \) – the speed of passage of the section with a turnout.

**Underground driving capacity**

\[ P_u = \frac{3600(24 - t_{tech,h})a_n}{t_v + t_{ct} + t_{by} + t_{xy} + t_{cp} + t_p + t_{rez}}; \]

where \( t_p \) – interval between metro trains on the stretch;

\( t_v \) – time of signal perception by locomotive crew;

\( t_{ct} \) – time of service braking, during which the metro train travels the distance from the start of braking to the traffic lights, which changed the signal from prohibiting to allowing;

\( t_{by} \) – block time;

\( t_{xy} \) – transit time;

\( t_{cp} \) – the response time of the alarm, centralization and blocking devices (ACB) from the moment of the departure of the previous EPS from the protective area to the opening of the traffic light;

\( t_p \) – the time required for the entire composition to go beyond the site, equal to the length of the metro train;

\( t_{rez} \) – reserve (reserve) of the burning time of the traffic light permitting signal, taking into account the accuracy of the metro train.

**Bandwidth of an intermediate metro station**

\[ P_{ct} = \frac{3600(24 - t_{tech,h})}{t_v + t_{ct} + t_{pod.h} + t_{est} + t_{xy} + t_{cp} + t_p + t_{rez}}. \]

where \( t_{pod.h} \) – the time required for a metro train to go from the traffic light to its full stop at the platform;

\( t_{est} \) – train stop time on the main tracks of the station;

\( t_{xy} \) – time from the moment of starting the metro train after parking to leaving the security area behind the exit traffic lights.

To bring the hourly capacity to the daily interval, a multiplier \((24 - t_{tech})\) was introduced, where \( t_{tech} \) is the duration of the daily time budget allocated for the production of planned work on the current maintenance of the track, devices and facilities. As a rule, these activities are performed during a night break in the work of the UET and range from 4 to 6 hours. In contrast to the railway, to carry out these activities in the UET system, there is no need to look for the possibility of providing technological “windows” in the EPS schedule, which greatly facilitates the work of repair teams. At the same time, carrying out unplanned repairs to eliminate sudden failures of the UET infrastructure can lead to stopping the passenger transportation process at the site, while the railway transport can change the route in the case of freight traffic, or eliminate the backlog due to the subsequent increase in speed.

Consider what physical meaning is embedded in the concept of reliability coefficient \( \alpha_n \). In the Instructions for calculating the available capacity of railways, the reliability coefficient \( \alpha_n \) is a coefficient taking into account the reliability of technical equipment (infrastructure and rolling stock), and given fixed values depending on the number of main tracks (single-track or double-track lines) on
a stretch and type of traction (electric or diesel traction). The author “7” as the indicator of reliability $\mathcal{R}_t$ of technical means of railway transport uses the following expression:

$$\mathcal{R}_t = K_g \mathcal{P}(t),$$  \hspace{0.5cm} (1)

where $K_g$ - availability factor (the probability that at any time the technical system is operational and ready to work);

$\mathcal{P}(t)$ – probability of failure-free operation of the technical system;

$t$ – duration of a given time interval.

In terms of the theory of reliability of technology, there is no such indicator as the reliability coefficient, but based on formula (1) and GOST [8], it can be concluded that the coefficient of operational readiness is used as an indicator of reliability of technical means of railway transport, since under certain conditions it is a product of availability and probability of trouble-free operation. Under the coefficient of operational readiness of equipment [8], refers to the probability that the product at a given time $t_1$ is in working condition and, from this moment, perform the desired function under the given conditions in the interval $(t_1, t_2)$. In connection with the above, the reliability coefficient $\alpha_n$ used in estimating the throughput capacity of the GET transport line will be understood as operational availability $K_{o.g}(t_1, t_2)$ factors corresponding to the elements of the GETS transport infrastructure.

In [5, 6, 9, 10] it was proposed to consider the UETS from the standpoint of a systematic approach as a complex technical system consisting of a large number of elements combined into the following subsystems directly involved in the transmission and conversion of electrical equipment into mechanical work of rolling stock environmental conditions:

- traction rolling stock subsystem (fleet of traction units (TU));
- path subsystem;
- traction power supply subsystem (traction substations and contact network).

The proposed systematic approach to the consideration of the UETS makes it possible to solve problems of improving the functioning with regard to the interaction of its components, since, improving only the elements of traction rolling stock without upgrading the supporting transport infrastructure, it will not be possible to achieve an increase in any quantitative indicators of road traffic. It should be noted that some increase in the efficiency of the UETS is possible by increasing the qualification level of full-time specialists [11].

The figure shows a variant of the UETS decomposition using tramcars as traction units for the purpose of subsequent analysis of its reliability and assuming four levels in the structure of the system: the UETS as a whole is located at the initial level, the subsystems of the electric rolling stock, power supply and rail network; the second level is represented by electrical and engineering systems that are part of the subsystems of the 1st level; on the third (lower) level there are elements of the complexes (traction electrical equipment and mechanical equipment).
Figure 1. - Decomposition of the urban electric transport system
(option when equipping trams with cars)

Taking into account these provisions, and in order to take into account the influence of the level of
reliability of various components of the transport infrastructure on the throughput capacity of the
UETS transport line, the formulas for determining the reliability coefficient for various types of UET
will take the following form

For trolleybus line

$$\alpha_n^{troll}(t_1, t_2) = K_{o.g.}^{troll} = \prod_{i=1}^{2} K_{o.g.i}(t_1, t_2),$$

For tramway line

$$\alpha_n^{tram}(t_1, t_2) = K_{o.g.}^{tram} = \prod_{i=1}^{4} K_{o.g.i}(t_1, t_2),$$

For subway

$$\alpha_n^{metro}(t_1, t_2) = K_{o.g.}^{metro} = \prod_{i=1}^{5} K_{o.g.i}(t_1, t_2),$$

where

- $K_{o.g.i}(t_1, t_2)$ - coefficient of operational readiness of traction substations;
- $K_{o.g.2}(t_1, t_2)$ - coefficient of operational readiness of the contact network section;
- $K_{o.g.3}(t_1, t_2)$ - the operational readiness ratio of the rail line section;
- $K_{o.g.4}(t_1, t_2)$ - the operational readiness ratio of the area under the rail base;
- $K_{o.g.5}(t_1, t_2)$ - the operational readiness ratio of the used signaling systems.

The reliability indicators used are currently regulated for railway transport and its infrastructure
[12-15], but, taking into account the peculiarities of operation, they can be used for UET. Thus, using
the operational availability factor as the reliability coefficient of the corresponding components
(contact network, traction substations, rail line and rail base) of the electric power exchange system
located within the transport line elements (spans, intersections, nodes, etc.) can be corrected the
amount of available capacity of passenger routes.
Similarly, to assess the impact of technical failures on the carrying capacity of the railway section at work [7], the allocation of five farms in the structure that ensure the functioning of the transportation process was proposed. Due to the specific features of the operation of the UET, the subsystems proposed by the authors of this article are somewhat different from the farms of railway transport described in [7], and their number varies depending on the type of EPS. Also, the author of [7] presented separately the locomotive and wagon economy combined into one to consider the reliability of the train's technical equipment. In the case of a UET, it is proposed to consider the impact of failures of the transport line infrastructure (power supply subsystems and rail network) on its carrying capacity, and the reliability (readiness) of the EPS substation from the standpoint of its impact on the carrying capacity of the UET in general.

Conclusions
Thus, by analyzing the impact of reliability of all subsystems in the composition of the UETS on throughput and carrying capacity, you can determine its place in the structure of urban passenger traffic. The proposed approach can be used to identify the least reliable elements, both traction EPS and transport infrastructure, affecting the process of passenger transportation UETS, and if necessary, take measures to improve their efficiency. When creating new passenger routes or upgrading old ones, the described method allows one to practically evaluate the predicted traffic indicators and the compliance of the elements of the infrastructure of the transport line with the capabilities of the EPS planned for use.

Literature
[1] Kisneeva L N, Auhadeev A E, Tukhbatullina D I nEgorova P V 2018 Energy supply of the electric traction process of the urban electric transport (Moscow: Modern Science) No 12-1pp 19-21
[2] Rylov Yu A, Aukhadeev A E, Babakuliev R Yu nFazylov S G Analysis of the motion modes of urban electric transport electric rolling stock (Moscow: Modern Science)No 1-1 pp 50-53
[3] Borodin AF 2011 Instructions for calculating the cash capacity of railways, (Moscow: Russian Railways) p 305
[4] Levin D Yu and Pavlov VL 2011 Calculation and use of the throughput capacity of railways (Moscow: Federal State Educational Institution "Training and Methodological Center for Education in Railway Transport") p 364
[5] Litvinenko RS, Aukhadeev A E and Filina OA 2017 Investigation of the technical reliability of the urban electric transport system (Moscow: Transport: science, technology, management) No 8 p 60-71
[6] Pavlov PP, Idiyatullin RG and Litvinenko RS 2017 On the issue of assessing the reliability of the electric transport system of the city (Moscow: Transport Information Bulletin) No 5 (263) p 23-26
[7] Ivnitsky VA 2008 Reliability of technical means of railway transport and its connection with the capacity of the directions. (Moscow: Bulletin of VNIIZhT) p 6-9
[8] GOSTR 53480 2009 Reliability in engineering. Terms and definitions (Moscow: Standardinform) p 33
[9] Kisneeva L N, Aukhadeev A E, Tukhbatullina D I nStaroverova U V 2017 Description of urban electric transce as a complex technical system (Moscow: Modern Science) No 11 pp 181-183
[10] Rylov Yu A, Aukhadeev A E, Egorova N Yu nUrzhumtsev P S 2017 Electric traction in urban electric transport system (Moscow: Modern Science) No 11 pp 195-197
[11] Khusnutdinova E M, Khaidullina G R, Pavlov P P, Aukhadeyev A E, Litvinenko R S and Khusnutdinov A N 2018 Training transport specialists based on a contemporary view of self-organization of sophisticated developing systems (IOP Conference Series: Materials Science and Engineering) 412(1) 012047
[12] GOST R 55444 2013 Railway power supply. The nomenclature of reliability and functional safety indicators (Moscow: Standardinform) p 14
[13] GOST R 55443 2013 *Railway track. The nomenclature of reliability and functional safety indicators* (Moscow: Standardinform) p 12

[14] GOST R 54461 2011 *Reliability of railway traction rolling stock. Terms and definitions* (Moscow: Standardinform) p 20

[15] GOST 32192 2013 *Reliability in railway engineering. Basic concepts. Terms and Definitions* (Moscow: Standardinform) p 32