SERVICE RATE AS AN INDICATOR OF STREET AND ROAD NETWORK RELIABILITY

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ABSTRACT

The article assesses understanding and interpretation of scientific categories «reliability», «refusal», «congestion». The possibility of using the service level indicator as a criterion of reliability of functioning of street- road network is substantiated, bearing in mind that it reflects in a complex the data on economy, convenience and traffic safety, and through this, the state of a transport flow. Different approaches are given to determine the level of service, to classify features and signs of the work performed. Further directions for improving reliability of highways, searching for the most variable indicator of reliability of the urban transport network are formulated.

Keywords: *street-road network, reliability, congestion, flow, failure, service level, time buffer, buffer index.*

Background. *In conditions of high loading of public roads and street-road networks by traffic, the task of ensuring reliability of their functioning becomes particularly urgent, which in turn requires development of appropriate quantitative criteria for assessing reliability.*

In the Russian Federation, interpretation of the term «reliability» in technology is defined in GOST [state standard] 27.002–2015, which establishes the basic concepts in this field. The scope of GOST can be applied to an assembly unit, a part, a component, an element, a device, a functional unit, equipment, an article, a system, a structure [2].

Reliability, according to GOST, is a «property of an object to preserve in time the ability to perform the required functions in given modes and conditions of application, maintenance, storage and transportation». Also, a note is made that reliability is a complex property that, depending on the purpose of the object, can include reliability, maintainability, recoverability, durability, maintainability, availability or certain combinations of these properties [7].

Objective. *The objective of the authors is to consider service level as an indicator of street-road network reliability.*

Methods. *The authors use general scientific methods, comparative analysis, evaluation approach, mathematical methods.*

Results. *Let's consider reliability of a road from these positions. According to GOST a system is an object that is a set of interrelated elements considered in a certain context as a single whole and separated from the environment, therefore within the framework of the study we will proceed from such systemic properties.*

A road, according to [1], is an object of transport infrastructure intended for movement of vehicles, and includes land plots within the boundaries of a right-of-way and structural elements (roadbed, road surface and similar elements) located on them or under them, and road structures that are its technological part – protective structures, artificial road structures, production facilities, road construction elements.

There are a number of normative documents that define the requirements for motor roads [3, 4, 6]. The standards and rules envisaged in them concern not only the structural features of the road surface, materials, but also set requirements for operation of roads.

Based on the above formulation, the main function of the road as a system is to provide an opportunity for vehicles to move along it. It would be logical to assume that movement should be carried out with certain parameters, the occurrence of failures (for example, congestion) means a failure to perform a given function, that is, a property of non-failure is violated. And according to GOST failure-free operation is a property of an object to continuously maintain an ability to perform the required functions for some time or operating time in the prescribed modes and conditions of application [2].

A failure, in this case, is an event consisting in violation of working capacity of an object. In foreign literature, for such situations, a term «congestion» is used, which refers to the state of loading of a street-road network (SRN) when traffic volumes approach or exceed the capacity. Congestion can be recurrent or non-recurrent [9].

Let's add that a failure can be considered as a resource failure if an object reaches the limiting state, that is, congestion, as already mentioned, arises precisely because of insufficient road capacity, below the calculated flow. Sudden failure is characterized by an abrupt transition of the object into an inoperative state, a sharp increase in the risk of a road traffic accident [2].

From the point of view of users, public roads, urban streets and highways provide comfort, speed and road safety. These three indicators should be maximized as much as possible. For example, traffic may become different: movement of cars with an average speed of not more than 5 km/h is also movement, but it will no longer meet the usual criteria from the user's position and can be considered as a failure.

As the conditions for displacement deteriorate, the road passes into a pre-failure state characterized by an increased risk. Such a state can arise both as a result of internal processes and external influences on the object in the process of its functioning. Changing any parameters of the road network, reducing speed, increasing traffic intensity will certainly contribute to deterioration of the situation. A road-traffic accident, which severely limits the capacity of the road, also leads it to a pre-failure state. A failure will occur in case if the consequences of an accident are not eliminated as soon as possible or, for example, in case of deterioration in weather conditions (snowfall, flooding as a result of torrential rains, ice); the danger of emergencies is great [2].

The pre-failure state can persist indefinitely for a long time, or it can either go into a failure state or into a working state. In case the detected failure is eliminated with time, it is called a malfunction.

To determine a pre-failure state, GOST assumes the use of a criterion reflecting certain real features or a set of features of the object's pre-failure state [2].

In future, if the nature of traffic continues not to meet the requirements, the motor road passes into an inoperative state in which it cannot perform at least one prescribed function.

However, such a criterion for roads, in terms of their functionality, it must be acknowledged, is not normatively established. That is, it is not determined what size congestion is permissible, what average speed should be.

The next concept, which should concern a highway, is the operating time. The operating time is duration or volume of work of the object.

The road in the considered context can have an unlimited resource in time, and in some cases the value of the operating time indicator tends to infinity, and this despite the fact that the failure of the roadbed as a physical object can occur repeatedly for any foreseeable period. This situation is possible if timely repair of the road will not lead to congestion, otherwise, there is a dependent failure, when the impossibility of moving along it is associated with deterioration of the roadbed.

Nevertheless, if congestion occurs periodically, for example, daily in the peak hour, then a reverse picture occurs, when the roadbed is in good technical condition, but the road does not fulfill its functions. In case when this situation is regular, we can talk about the cycle of failures and equal intervals of the time between failures.

In any version of assessment and prediction of failures, their criteria and the causes should be determined. Since the technical documentation does not reflect the failure criteria for the potential throughput and, in essence, does not evaluate this parameter, this significantly affects organization of traffic.

When there are intermittent and other types of failures, the occurrence of which can be predicted using foreign terminology, we can talk about recurrent congestion, and with sudden refusals – about non-recurrent.

The actual values of parameters at a certain moment of time characterize the degree of readiness of an object to perform the given functions under the conditions considered.

GOST defines the classification of failures according to criticality:

1. Critical – a congestion when speed of movement is much lower than the forecasted (required) by users.

2. Noncritical – when traffic is difficult, but the flow of cars maintains speed close to the maximum allowed (optimal, comfortable).

Vehicles moving on the road are at the same time a part of the logistics system (chain). Failure of the road to perform its functions to let the cars move, leads to a failure in the logistics chain, which in turn affects the following links of the system. In this case, if such a failure occurs cyclically, then it is considered already as a systematic, unambiguously caused by a certain cause, which can be eliminated only by modification of the project or production process, the operation rules and the contents of the documentation.

From the point of view of elimination of failures the motor road can be referred to objects with the ability to self-repair, that is, as transport demand decreases, the congestion gradually disappears and normal functioning of the object is restored. Considering the motor road as such a system, we come to the conclusion that it acts as a technical object, to which the terminology on reliability in technology and all available and applicable relevant terms refer.

The criteria of failure (reliability) can be determined on the basis of a complex indicator representing a qualitative measure describing the operating conditions of vehicles in the flow. This indicator is present in the form of a scale having a gradation for the state of failure, pre-failure and operating states.

Requirements for reliability are formed mainly on the basis of user demand. Expected indicators are laid in the design standards and should be reflected in the technical documentation.

Decrease in speed of service or failure cause deterioration of a number of operational indicators: reduce the productivity of vehicles fleet, enhance the environmental impact, as the duration of the engine work increases, affect the psychophysical state of people for whom the time spent on movement caused by traffic jams increases.

For a long time in our country there was no need to evaluate such indicators because of the low level of motorization. Abroad, and especially in the US, this issue was forced to be dealt with since the middle of 20th century, when Highway Capacity Manual was prepared.

In recent years, to assess reliability of functioning of highways, it is proposed to use the level of service, calculated on the basis of the indicator of time index (TTi) [9].

Along with the indicator of time index, there are a number of other indicators that can be used for such an assessment: time buffer (T_b), buffer index (I_b), two-fluid Herman–Prigogine model (T_s, T_r) [8, 10–13], TOMTOM traffic index (I_{tt})) [15], INRIX Travel Time Index (I_{inrix}) [14].

TTi is defined as a ratio

$$TTi = \frac{Tp}{T_{15\%}}, \quad (1)$$

where T_p – time spent on movement during the peak period; $T_{15\%}$ – time spent on moving with regard to 15% capacity provision, observed during off-peak periods of the day.

$$T_b = T_n - \overline{T}, \quad (2)$$

where T_n – duration of movement of n % of capacity provision, $\overline{T}$ – average duration of movement.

$$I_b = \frac{T_b}{\overline{T}} \bullet 100\ \%, \quad (3)$$

$$T_r = T_m^{\frac{1}{1+n}} \bullet T^{\frac{n}{n+1}}, \quad (4)$$

$$T_s = T - T_m^{\frac{1}{1+n}} \bullet T^{\frac{n}{n+1}}, \quad (5)$$

where T_m – minimum specific time expenditure on movement in free conditions, min/km; n – an indicator characterizing the quality of functioning of SRN section in question; T_s – specific idle time, min/km; T_r – specific time of movement, min/km; T – specific time expenditure, min/km.

Table 1

Level of service under ODM 218.2.020–2012

Level of traffic service	z	c		Characteristics of the car flow	Flow state	Driver's emotional load	Driver's comfort	Economic efficiency of road operation
A	< 0,2	> 0,9	< 0,1	Cars move in free conditions, there is no interaction between cars	Free movement of single cars with high speed	Low	Convenient	Inefficient
B	0,2–0,45	0,7–0,9	0,1–0,3	Cars move in groups, many overtaking is made	Movement of cars in small groups (2–5 pcs). Overtaking is possible	Normal	Low convenience	Low efficiency
C	0,45–0,7	0,55–0,7	0,3–0,7	In the flow there are still large intervals between cars, overtaking is prohibited	Movement of cars in large groups (5–14 pcs). Overtaking is difficult	High	Inconvenient	Efficient
D	0,7–0,9	0,4–0,55	0,7–1,0	Continuous flow of cars moving at low speeds	Column traffic of cars with low speed. Overtaking is impossible	Very high	Very inconvenient	Inefficient
E	0,9–1,0	< 0,4	1,0	The flow moves with stops, jams occur, the regime of throughput	Dense	Very high	Very inconvenient	Inefficient
F	> 1,0	0,3	1,0	Full stop of traffic, congestion	Super dense	Extremely high	Extremely inconvenient	Inefficient

Source [5].

$$I_{tt} = \frac{\overline{T}}{T_{ff}} - 1, \qquad (6)$$

where $\overline{T}$ – average time of motion, s, T_{ff} – time of motion in free conditions, s.

$$I_{inrix} = \frac{T_p - T_{ff}}{T_{ff}}. \qquad (7)$$

In Russia, for assessment of functioning of roads, ODM 218.2.020–2012 «Methodical recommendations for assessing the carrying capacity of highways» were prepared [5]. The document contains instructions on calculations, including the level of service. The term «service level» in these recommendations means a comprehensive indicator of economy, convenience and traffic safety, characterizing the state of a transport flow.

To assess the level of service, it is offered to compare the actual traffic flow parameters with the calculated ones or the maximum possible ones.

$$z = \frac{N}{P}, \qquad (8)$$

where z – loading coefficient; N – traffic intensity, cars/h; P – practical throughput of the road section, cars/h.

$$c = \frac{v_z}{v_o}, \qquad (9)$$

where c – coefficient of speed of motion; v_z – average speed of motion at the level of convenience considered, km/h; v_o – speed of motion in free conditions at the level of convenience A, km/h.

$$\rho = \frac{q_z}{q_{\max}}, \qquad (10)$$

where ρ – coefficient of saturation of motion; q_z – average traffic density, cars/km; q_{max} – maximum traffic density, cars/km.

In Table 1, according to ODM, the indicators of compliance with a particular level of service are given.

Having considered the technique for assessing the level of service, it can be noted that, firstly, the parameters used (traffic intensity, speed and flow density) are interrelated, according to (11), that is, measuring three parameters for assessing the level of service is redundant.

$$q = \frac{N}{v}, \qquad (11)$$

where q – traffic density, cars/km; N – traffic intensity, cars/h; v – speed, km/h.

Secondly, carrying out measurement of density and (or) intensity is more expensive and laborious procedure than measurement of speed (time), since for its measurement the availability of ordinary watch or receipt of information from navigation equipment in a car (navigator, smartphone etc.), moving along a road, the parameters of which we want to measure, is sufficient.

Thirdly, there is a contradiction when the flow density is used in calculations and at the same time is a characteristic of the service level, which was given in column 6 of Table 1.

Fourthly, the parameter c is inverse of the time index: since measurements are made on the same section of the road, the length of this section remains unchanged (12).

$$c=\frac{v_z}{v_o}=\frac{\frac{S_z}{t_z}}{\frac{S_o}{t_o}}=\frac{S_z \bullet t_o}{S_o \bullet t_z},\ S_z=S_o \Rightarrow c=\frac{t_o}{t_z}=\frac{1}{TTi}, \qquad (12)$$

where S_z – length of the area at which measurements are made, km; t_z – duration of movement at the level of convenience considered, h; S_o – length of the area at which measurements are made in free conditions, km; t_o – duration of movement in free conditions, h.

The values of parameters z, c, p offered by ODM do not allow variations depending on various traffic parameters and SRN, although information is provided in [9] that the value of the service level indicator can vary depending on various factors, for example, the length of the route.

Proceeding from this, we exclude the indicators recommended by ODM from the number considered in our study.

Conclusions. *The analysis showed that there are many indicators that can be taken as a criterion for assessing reliability of functioning of highways (service level). The next task of the study is to identify the indicator that is best suited for determining reliability of SRN operation, that is, assessing the level of service in urban settings. To do this it is necessary to:*

1. Record GLONASS/GPS tracks on the surveyed areas.

2. Perform processing of tracks.

3. Download the characteristics of tracks.

4. Carry out calculations of all indicators based on the information collected.

5. Carry out statistical data processing (using statistical software packages) to identify the most variable indicator.

The fulfillment of this task will allow to determine the most variable indicator that can be used to assess reliability of SRN operation. Also, during the study, it will be possible to determine the minimum sample size (minimum number of tracks) sufficient for reliable assessment of the level of service in urban conditions. The collected data array can be used to determine the dependence of the service level on various parameters.

REFERENCES

1. Federal Law «On Roads and Road Activities in the Russian Federation and on Amending Certain Legislative Acts of the Russian Federation» dated 08.11.2007 No. 257-FZ [*Federal'niy zakon «Ob avtomobil'nyh dorogah i o dorozhnoi deyatel'nosti v Rossiiskoi Federatsii i o vnesenii izmenenii v otdel'nie zakonodatel'nye akty Rossiiskoi FEderatsii» ot 08.11.2007 No. 257-FZ*].

2. GOST 27.002-2015 Reliability in engineering. Terms and Definitions [*GOST 27.002-2015 Nadezhnost' v tehnike. Terminy i opredeleniya*].

3. GOST 33220-2015 Motor roads of general use. Requirements for operational status and other [*GOST 33220-2015 Dorogi avtomobil'nye obshchego pol'zovaniya. Trebovaniya k ekspluatatsionnomu sostoyaniyu i drugie*].

4. GOST R 50597-93. Roads and streets. Requirements for the operational status, permissible under conditions of ensuring road safety [*GOST R 50597-93. Avtomobil'nye dorogi i ulitsy. Trebovaniya k ekspluatatsionnomu sostoyaniyu, dopustimomu po usloviyam obespecheniya bezopasnosti dorozhnogo dvizheniya*].

5. ODM 218.2.020-2012 Methodological recommendations for assessing the carrying capacity of highways [*ODM 218.2.020-2012 Metodicheskie rekomendatsii po otsenke propusknoi sposobnosti avtomobil'nyh dorog*].

6. SP 34.13330.2012 Highways [*SP 34.13330.2012 Avtomobil'nye dorogi*].

7. Beridze, V. A., Kolchin, V. S., Kolchina, Z. V., Malomyzhev, O. L. Foundations of the theory of reliability: Study guide [*Osnovy teorii nadezhnosti: Uchebnoe posobie*]. Irkutsk, Publishing House of IrSTU, 2014, 124 p.

8. Blinkin, M. Ya., Tkachenko, B. A. System assessment of traffic conditions on the basis of the Herman–Prigogine [*Sistemnaya otsenka uslovii dvizheniya na baze modeli Hermana-Prigozhina*]. *Sotsial'no-ekonomicheskie problem razvitiya transportnyh system gorodov i zon ih vliyaniya*, 2009 [Electronic resource]: http://www.waksman.ru/Russian/Org&B/2008/blinkin1.htm. Last accessed: 18.06.2018.

9. Gorbunov, R. N., Mikhailov, A. Yu., Pirov, Zh. T. Assessment of the level of service on the basis of reliability criteria [*Otsenka urovnya obsluzhivaniya na osnove kriteriev nadezhnosti*]. *Vestnik of Irkutsk State Technical University*, 2017, Iss. 10, pp. 188–194.

10. Rumyantsev, E. A. Assessment of traffic conditions on the basis of the Herman criterion [*Otsenka uslovii dorozhnogo dvizheniya na osnove kriteriya Hermana*]. *Nauka. Technologies. Innovations: Collection of scientific works of All-Russian Scientific Conference of Students, Ph.D. students and young scientists*. Novosibirsk, NSTU publ., 2012, pp. 321–325.

11. A toolbox for alleviating traffic congestion and enhancing mobility. Institute of Transportation Engineers, Publication IR-054B, 1997, 119 p.

12. Herman, R., Ardekani, S. A. Characterizing traffic conditions in urban areas. *Transportation Science,* 1984, Vol 18, Iss. 2, pp. 101–140.

13. Herman, R., Prigogine, I. A two-fluid approach to town traffic. *Science*, 1979, Vol. 204, pp. 148–151.

14. INRIX Traffic Scorecard 2015 [Electronic resource]: http://www.inrix.com/wpcontent/uploads/2016/11/INRIX_2015_Traffic_Scorecard.pdf. Last accessed: 18.06.2018.

15. TomTomTraffic Index [Electronic resource]: https://www.tomtom.com/en_gb/trafficindex/about. Last accessed: 18.06.2018.

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