SYSTEM ENGINEERING APPROACH TO OPERATIONAL RELIABILITY OF A RAILWAY

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ABSTRACT

The authors justify the use of system engineering approach to evaluation and tasks of improvement of railway line operational reliability. Particular emphasis is placed on interdependence of infrastructure capacity and overall operational readiness of the system «railway» in terms of compliance with criteria adopted in the theory of reliability. An own interpretation of the concept of «operational safety» and factors of maintenance of track in working order is given, as well as regularity in local situations, preventive and remedial actions are suggested.

Keywords: railway, infrastructure, operational reliability, track maintenance, transit capacity, system engineering, reliability theory.

Background. *It is known that the most important system engineering problems are found at joints of interacting systems. And it is here that the primary area of application of system engineering as a science of relationships and relationship management [1–3] can be found. In this context, study and improvement of reliability of the infrastructure of railways in terms of their transit capacity is not a simple system engineering task, in the course of its solution the very ability of functioning of the overall «railway» system is largely determined [4–5].*

In scientific literature reliability refers to properties of products and systems to perform their functions in a certain amount and under certain operating conditions [6–7]. Achievements, which are available in this area, include above all technical and cybernetic systems that control functioning of individual products and subsystems [8–10].

Objective. *The objective of the authors is to consider system engineering approach in relation to study of operational reliability of railway line.*

Methods. *The authors use general scientific and engineering methods, simulation, comparative analysis, mathematical method.*

Results. *During the construction of transport facilities, maintenance and repair of railway track cybernetic systems are used for the control over construction and track machines, machines for alignment, levelling and finishing of track and switches, diagnostic complexes, as well as over some of technological processes at construction industry enterprises.*

Significantly more complex is the situation with extension of reliability theory to operation of such a multi-tier system as «railway». It is a kind of organizational and technical systems that control manufacturing facilities and processes involving large labor groups and a variety of machines. These systems are companies within the holding company Russian Railways, including construction organizations JSC RZDstroy, enterprises, design and research establishments [11].

Similar structures operate under the constant influence of various random factors: meteorological, technical, technological, social and organizational. The cumulative impact of such factors, including geoextreme factors, on organizational and technical system «railway», in spite of their diverse nature and all kinds of combinations, result mainly in decrease of the main indicator of the functioning, traffic volume as a result of speed limits.

State standard «GOST 32192-2013. Reliability in railway engineering. Basic concepts. Terms and definitions» [12] considers a railway line as a set of technical subsystems and not as a complex organizational and technical system. In the document its reliability is identical to the ability to perform functions provided for by technical requirements for a certain period of service hours or operation.

Similarly, within the meaning such concepts are defined as «failure», «reliability», «resilience», «operational safety». Although GOST 32192-2013 regulates quite a wide range of parameters of reliability (single, comprehensive, current, experimental, operational), disadvantage of the list is genetic heterogeneity of concepts, which are designated by the terms listed. They characterize the reliability index in terms of the index itself, but not of the the reliability of which is studied. Therefore, definitions provided by GOST do not fully meet the needs that arise in discussion and evaluation of operational reliability of railways. They can be used only by recognizing the railway as a complex organizational and technical system, and besides, after adjustment of some interpretations.

There is, for example, such kind of failure as «partial». In reliability theory, partial failures are failures, after the occurrence of which the object can be used for its intended purpose, but with a lower efficiency, or if some values of output parameters (but not all of them) fall outside permissible limits. This is deeper interpretation than envisaged in GOST 32192-2013, where this kind of failures reflects «partially usable state of a railway track», which is characterized by deviations from norms and tolerances of its arrangement and maintenance, causing restriction of train movement.

It has been noted that for the railway line the main output parameter is traffic volume or net tonnage transported as production of industrial organizational and technical system of this type. Based on this, in fact, we try to determine rate of operational reliability, which is of interest for us.

We write the expression for the transported net tonnage as follows:

$$G_{net} = n_{pt} g_t, \quad (1)$$

where G_{net} is transported net tonnage;

n_{pt} is a number of pairs of trains;

g_t is average net train carrying capacity.

The number of pairs of trains is found as follows:

$$n_{pt} = \frac{T\bar{v}}{2S}, \quad (2)$$

where T is accounting period;

$\bar{\upsilon}$ is average train speed on the railway section with the length S.

Substituting (2) in (1) and attributing the result to the duration of the calculation period, we obtain net tonnage as

$$G_{net} = \frac{g_t}{2S}\bar{v}. \quad (3)$$

Since the length of the railway line and the average net train carrying capacity are constant, the amount of «released» product by the line is determined by the average speed of trains.

If current technical parameters of the line fully meet the projected, the movement is carried out with the design average speed of $\bar{\upsilon}_0$. In case of partial failures average speed $\bar{\upsilon}$ will be reduced.

We introduce the technical readiness index K_{tr} of the railway line:

$$K_{tr} = 1 - \frac{\bar{v}_0 - \bar{v}}{\bar{v}_0}. \quad (4)$$

If the current average speed corresponds to the projected, then $K_{tr} = 1$. By reducing speed the coefficient of readiness will decrease. When $\bar{\upsilon} = 0$ $K_{tr} = 0$, that is, in case of movement stop, the technical readiness of the railway line is reduced to zero.

The average speed is defined as

$$\bar{v} = \frac{S}{t_x^0}, \quad (5)$$

where t_x^0 is project travel time on the section of line with the length of S.

Accordingly, we find the current average speed:

Table 1

Components of the duration of the technical maintenance

<table>
<tr><td colspan="8">Downtime</td></tr>
<tr><td colspan="6">Duration of technical maintenance</td><td colspan="2" rowspan="2">Recovery</td></tr>
<tr><td colspan="2">Duration of preventive maintenance (scheduled repair)</td><td colspan="4">Duration of unscheduled repair
Failure</td></tr>
<tr><td rowspan="3">Logistical delay</td><td rowspan="3">Operational length of service (repair)</td><td colspan="6">Time to recovery</td></tr>
<tr><td rowspan="2">Logistical delay</td><td colspan="4">Operative repair time</td><td rowspan="2">Administrative delay</td></tr>
<tr><td>Technical delay</td><td>Time of fault detection and localization</td><td>Troubleshooting time</td><td>Time of operation control</td></tr>
</table>

$$\overline{v} = \frac{S}{t_x^0 + \sum t_i}, \qquad (6)$$

where t_i is increase in travel time for a variety (i-th) of reasons.

In view of above mentioned steps the operational reliability of the railway line is a probability of maintenance of technical readiness coefficient at the level not lower than the set one:

$$H_{rl} = P(K_{tr} \geq K_x) = 1 - F(K_{tr}), \qquad (7)$$

where H_{rl} is operational reliability of the railway line;

$P(K_{tr} \geq K_x)$ is probability of the event at which K_{tr} is not below the specified level;

$F(K_{tr})$ is function of distribution of technical readiness coefficient.

This approach allows to take into account, while determining the index of operational reliability of line, effects of various factors on the transportation process. On quite a long section of the route decrease in average speed can be caused by operational factors (for example, delays in the process of train recollecting), as well as partial failures of the track on problem sections. There are three levels of reduction of technical readiness coefficient:

1st level – slight decrease (up to 90%);

2nd level – average decrease (up to 75%);

3rd level – significant decrease (up to 50%).

GOST 32192-2013 determines average time for recovery (for railway equipment) as a mathematical expectation of the time interval from the time of failure of equipment to recovery of its workable state. There it is also documented that repair time (see Table 1) consists of logistical, administrative and technical delays; time of detection and localization of the fault, its elimination and monitoring time of its functioning.

Conclusion. It is possible to predict confidently the duration of only the last two operations out of the enlisted. Logistical delay can be compensated for by the implementation of the plan of repair activities, which has been developed in advance. The same pre-treatment procedure is required for fault detection and localization. Such preparation will minimize technical and technological delays.

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