Modeling of assessment of reliability transport systems

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Abstract: This article presents results of a study based on the analysis of the development of the theory of reliability whose indicators are formulated indicators of transport systems reliability and contributed to building a system of factors determining their reliability. It is established that the formation of the theory of reliability of transport systems today is not completed. Based on the specifics of the systems, new reliability indicators were proposed and substantiated such as emergency downtime and reliability of emergency downtime. On the basis of the performed studies, it was found that the specifics of the transport process require the introduction of emergency downtime close to the recovery time and the reliability of emergency downtime. It is necessary to introduce two close parameters such as the average recovery time and the average emergency idle time. They are associated with the need to distinguish between the idle time of a technological system, or a separate element when a failure occurs, and the idle time that is needed. For the technological links of the transport system, the main purpose of which is to ensure efficient operation transport process, the probability of emergency downtime can serve as a criterion for assessing their reliability.

Keywords: reliability, emergency downtime, probability of emergency downtime.

1. Introduction

The problem of reliability of transport systems is one of the main ensuring and improving the efficiency of their functioning. The reliability parameter of the transport system is one of the main indicators of the quality and efficiency of its operation, it manifests itself in time and reflects changes occurring in the system during the whole period of its operation. To date, the situation with the assessment and ensuring of the reliability of transport by road significantly impedes the achievement of the transport system indicators of transport strategy indicated in the Transport Strategy. The quality indicator in transport offered by scientists today is reliability taking into account mainly only the reliability of technical means, while reliability of performed services is practically not considered. There is also no standardization of reliability in road transport and in reports of motor transport enterprises

there are no criteria characterizing reliability and efficiency of their work. The formation of the theory of reliability of transport systems is not completed to date. Therefore, the bulk of organizational and technological decisions to reduce the number of failures is based on the knowledge of the methodology for solving traffic safety problems, technical maintenance of vehicles, situational management of motor transport, the theory of reliability of technical systems, risk management, supply chain management and other scientific fields. The coexistence of people and the world of machines depends not only on technical possibilities, costs of technology implementation, legal regulations, but also on social acceptance and people's ability to coexist with technologies [18, 19].

The problem of reliability in transport has significant features and is not limited to the reliability of technical means. It also determined the conditions and laws of all elements of the transport process [15]. The main problems of the theory of reliability are to establish patterns of occurrence of failures and their recovery; determining the quantitative characteristics, methods of calculation of reliability. The most studied in this it is considered theory of reliability technical systems. Principles of reliability of technical objects are adapted to the conditions of reliability of supply chains [5], [17]. Reliability transport systems and road transport process has methodological connection with the reliability of technical systems since to improve the quality of delivery of cargo and passengers as well as in technique applied reservation. There are structural [11] and functional reservation [10], [12]. In reliability theory, in particular, processes occurrence of failures, recovery of production systems elements are described by methods of probability theory [16].

Pronnikov A.S., Druzhynin G.V. consider the reliability of the system based on determining the function of readiness system that consists of n subsystems. In this case the function of readiness system describes the probability of finding the system in working condition at any time [13], [7].

The problem of reliability is complex both in terms of its characteristics and measurements, and its cause-effect displays. Thus the reliability of vehicles is based on the classic approach to reliability that investigates the reliability of all systems and mechanisms that in recent works called "mechanical reliability" [8], and the reliability of the technical maintenance and repair and reliability in the process of commercial exploitation also take into account organizational and economic factors. In reliability theory, considerable attention is given to the impact of damages from insufficient of reliability machines as an economic expression of technogenic risk [14]. Aulin V.V., Golub D.V engaged in issues of legal regulation to provide reliability of functioning transport systems in Ukraine [1], also they have investigated methods for assessing and analyzing the reliability of automobile transport systems [2], [3], [4].

Classical methods of quantitative assessment of indicators of reliability of complex systems [9] applied to systems for which the notion of failure is clearly identified, that system is in one of two states: in a state working or in a state of recovery.

The proposed in the article recommendations are based on the definitions of probability reliability indicators of transport systems.

2. Materials and Methods

The main tasks of reliability theory are the establishment of patterns of occurrence of failures and their recovery, determination of quantitative characteristics, development of methods of evaluation and calculation of reliability. There are two approaches to solving these problems. The first approach is to study statistical the patterns of failure of the same type of technical means in certain operating conditions and is the basis for the establishment of distribution laws of the investigated parameters and obtaining of their numerical characteristics operational reliability.

Found in this way specifications which are used for calculating the reliability of technological systems consist of the types of technical means for which they are identified.

The second approach is aimed at studying the physical nature and mechanism of failures. It serves as a basis for the development of measures to improve the reliability of existing and planned technological systems. This approach is more efficient in terms of identifying physical essence reasons which caused the deviations options below acceptable limits, which means rejection. This path is used where, despite specificity of operation is still possible to obtain the necessary input data, such as the study of the reliability of transport systems.

To obtain analytical expressions of reliability of a transport system, we assume that it operates according to the following scheme: subsystems and elements, which were rejected, begin to recover; there are no restrictions on the number of restorations; failure of one of the elements or subsystems will result in the refusal of the transport system as a whole.

To evaluate the reliability of the elements of transport systems used probabilistic parameters of reliability.

The reliability of the functioning of transport systems and processes of road transport is a complex feature that includes the ability of the system to fulfill the requirements for the number and condition of the cargo carried, the safety of passengers and their luggage, compliance with the schedule of the transport process, as well as support and restoration of a given level of transport service.

One of the parameters of reliability is the probability of failure operation work. Failures in the transport system may be caused by some emergency situations in the functioning of its elements. Multi-transport system can occur in three forms: while eliminating the consequences of the situation in the transport process, when combined parties of their functions, the redevelopment of activity of the participants of the transport process. Any emergency situation caused by the refusal arising in the performance of transportation usually leads to changes in the technology of work its members. Reliability of transport system depends on several factors (Fig. 1).

Some emergency situations in road transport are common, such as a traffic accident or technical malfunction of the vehicle on line [11].

The algorithm of actions and approximate duration of treatment elimination of consequences of the typical situations is standard and is known in advance. Work by the transport process in the mode of elimination of the accident is a reserve (auxiliary) function and work as usual is the main function. Multifunctionality is reflected in the form of performances and methods of solving problems for managing reservation reliability of the transport process and its components.

In this case, based on the fact that at any time t state of the element or subsystem is described by the random vector

$$x(t) = \left[x_1(t), x_2(t), \dots x_n(t) \right]$$

(1)

which can take two values always at the one-dimensional variable: $x(t) = 1$, if the system or component is in working condition, and $x(t) = 0$ in case of failure. The components of the vector $x(t)$ can be the values of various parameters of the system.

Random vector $x(t)$ is characterized by a probability distribution $F(x_1, \dots, x_2, x_n, t)$ i.e. the probability that the $x_1(t) \leq x_1, \dots, x_n(t) \leq x_n$.
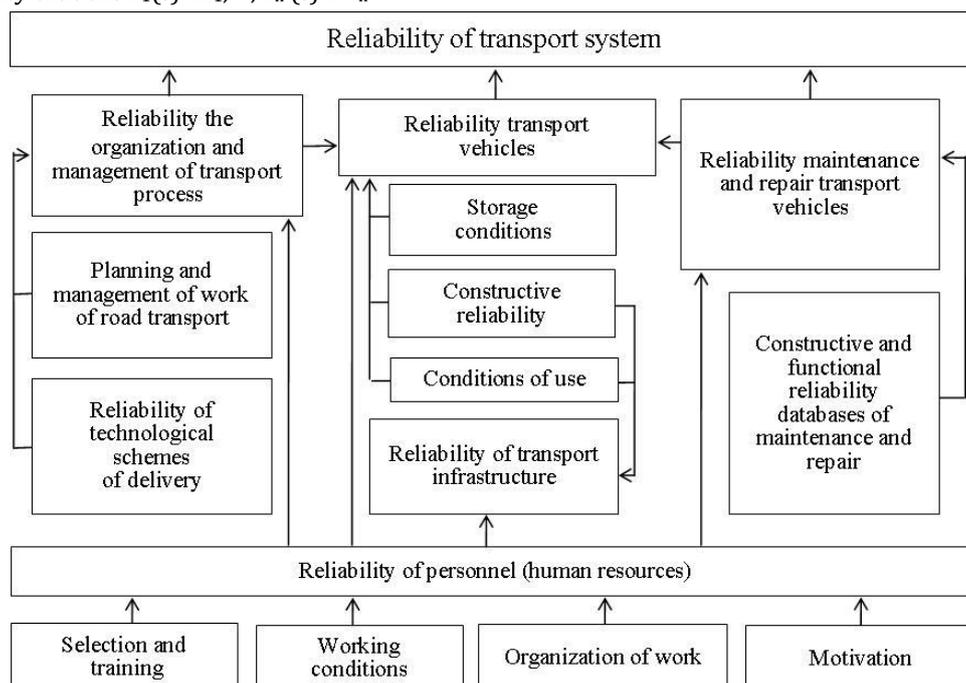
Figure 1. Factors that determine the reliability of transport system.

Each of the limit values that characterize the state of the system meets the mathematical expectation of the objective function *G(t)* at the interval of time $a \leq x \leq b$.

Reliability of elements that make up the technological system, characterized probabilistic indicators (Table 1), the most important of which are the uptime and recovery time. These options are probabilistic in nature and describe the relevant laws of distribution.

Table 1. Indicators of reliability.

№	The name of indicator	Mathematical expression
Recoverable elements		

№	The name of indicator	Mathematical expression
1	Average uptime	$T_u = \int\limits_0^\infty P(t)dt$
2	Average recovery time	$T_{ar} = \int\limits_0^\infty \tau\, dv(\tau) = \int\limits_0^\infty G(\tau)d\tau$
3	Reliabilities	$P(t) = Bep(T \geq t)$
4	Failure rates	$\lambda(t) = \dfrac{f(t)}{P(t)} = \dfrac{d\ln P(t)}{dt}$
5	Reliabilities for the time $(0, \tau)$	$v(t) = Bep(T_B \langle \tau)$
6	The probability of no recovery time $(0, \tau)$	$G(\tau) = 1 - v(t) = Bep(T_B \geq \tau)$
7	The density of probability of recovery the time τ	$v(t) = V\langle \tau\rangle$
8	The intensity of recovery the time τ, τ_i – the duration of recovery of i-th failure, *n*- the number of failures	$\mu(\tau) = \dfrac{v(\tau)}{1 - V(\tau)}, \quad \mu = \dfrac{n}{\tau_i}$

Transport systems relating to renewable systems that are characterized by intervals periodically alternating correct operation and restore during the failure. Because of this indicators of reliability is selected in such a way that they can be would be to assess the reliability of individual elements, and generally renewable systems consisting of different types of elements.

Indicator of reliability which taking into account the uptime T_u and downtime τ_d is readiness coefficient:

$$K_R = \frac{T_u}{T_u + \tau_d}, \tag{2}$$

and the coefficient of failure:

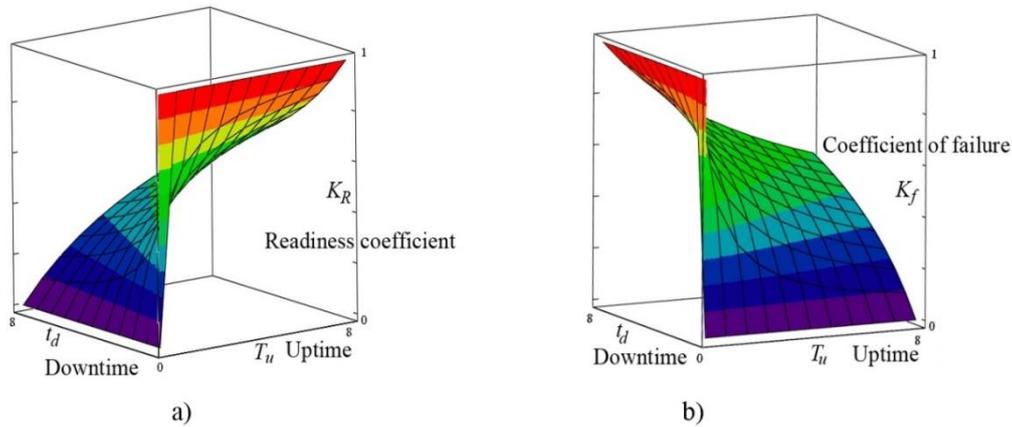$$K_f = 1 - K_R = \frac{\tau_d}{T_u + \tau_d}. \tag{3}$$

In Fig. 2 presented the dependence of the readiness coefficient and the coefficient of failure of uptime and downtime consumer.

In view of the data Table 1 we get

$$K_R = \frac{\int\limits_0^\infty t \cdot f(t)dt}{\int\limits_0^\infty t \cdot f(t)dt + \int\limits_0^\infty \tau \cdot dV(\tau)}, \tag{4}$$

$$K_f = \frac{\int\limits_0^\infty \tau \cdot dV(\tau)}{\int\limits_0^\infty t \cdot f(t)dt + \int\limits_0^\infty \tau \cdot dV(\tau)} \tag{5}$$

i.e. two parameters are characterized by distribution law uptime and recovery time and reflect the probability of finding components or systems in working order or in a state of failure, respectively.

Figure 2. Dependence of the readiness coefficient and the coefficient of failure of uptime and downtime: a) dependence of the readiness coefficient of uptime and downtime; b) dependence of the coefficient of failure of uptime and downtime.

The relative time of consumer's downtime by reason of failure of the system over a period of work.

$$\overline{P}(e) = \frac{t_D}{T_{co}} = \frac{t_D}{t_D + T_{UP}} \, , \qquad (6)$$

where: t_D is downtime of consumer for over a period of work; T_{UP} is uptime for a certain period.

Indicator $\overline{P}(e)$ of (6) is the probability of stimulated (emergency) downtime and form with a probability of a working state of complete group of events:

$$\overline{P}(e) + P(t) = 1 \qquad (7)$$

These terms define more precisely the probabilistic nature of the indicators of reliability. They take into account the frequency of occurrence of failure and downtime and represented more comfortable by using.

Any considered technological scheme can be represented as a system composed of a number of elements. If the i-th element of the system has been in operation for the time T_E then this value consists of alternating time intervals, correct operation t_{co} and recovery time T_r. However, the recovery failure T_r does not fully reflect the time of consumer in forced waiting for service. This specificity characteristic for the transport process requires the introduction of another indicator that comes close to recovery time, namely, time of emergency downtime t_{ed}. Significantly it affects the type of the distribution of the random variable on the accuracy of results in calculations for reliability.

For example, the exponential distribution law uptime element or some technological system indicates that the flow of failures can be adopted the simplest.

Be noted the basic properties of the simplest flow failures:

a) failure rate is constant (λ = const) and average uptime:

$$T_u = \frac{1}{\lambda} A \qquad (8)$$

b) density of probability of time intervals between the neighboring failures:

$$f(t) = \lambda \cdot exp(-\lambda t) \, , \quad f(t) = \lambda \cdot exp(-\lambda t) \qquad (9)$$

c) probability of getting n events in the time interval [$t, t + \Delta t$] gets according to Poisson:

$$P_n = \frac{1}{n!}(\lambda t)^n exp(-\lambda t)$$

(10)

where λt is the average number of failures in an interval of duration t;

d) the probability of absence of failures in the interval duration τ, which starts at a random time determined by the equation:

$$P_0 = exp(-\lambda t)$$.

(11)

3. Results

The simplest flow failures and recoveries in transport technological systems can be quite completely described by three numerical indicators of reliability, which are important to get to practical use. These characteristics are the average intensity of failures λ_{av}, average recovery time T_{ar} and the average emergency downtime t_{av}. The introduction of two close parameters: the average recovery time T_{ar} and the average emergency downtime t_{av} is associated with the necessity of the separation time finding in state of downtime technological system or a separate element with the appearance of failure and downtime of consumer.

Probability of emergency downtime defined by the formula:

$$\overline{P}(e) = \frac{t_{ME}}{t_{ME} + T_{co}},$$

(12)

where t_{ME} is the mathematical expectation of time of forced (emergency) downtime, $t_{ME} \approx t_{aed}$; T_{co} is the time of correct operation during the observation time; $T_{co} + t_{ME} = T_o$. is the observation time;

Or

$$\overline{P}(e) = \frac{n \cdot t_d}{N \cdot T_o} = \lambda \cdot t_d = \frac{t_d}{T_u},$$

(13)

where n is the number of failures of elements of the system during the observation time T_o.; N is the number of elements of the system which are under the observation.

From (13) implies that the probability of emergency downtime represents size of relative of time of emergency downtime and therefore can be used to determine the economic damage caused by interruptions in the functioning of technological systems.

The probability of emergency downtime linked to probability of faultless work with the following ratio. With exponential distribution law uptime

$$P(t) = exp(-\lambda t) = exp\left(\frac{t}{T_u}\right)$$

(14)

whence

$$\lambda = -\frac{\ln P(t)}{t}, \quad \overline{P}(e) = \lambda t_d$$

(15)

If the probability of faultless work P(t) is given, then $\overline{P}(e) = \lambda_{av} t_{ed}$.

4. Discussion

Thus, specificity which is typical for transport process requires the introduction time of emergency downtime t_{ed}, which is close to the time of recovery. This indicator can be attributed to one of the main numerical reliability features that characterize a simplest flow failures and recovery in transport technological systems. The introduction of two close parameters: the average recovery time T_{ar} and the average emergency downtime t_{aed} is associated with the necessity of the separation time finding in state of downtime technological system or a separate element with the appearance of failure and downtime of consumer.

For technological parts of the transport system, the main purpose of which consists in maintenance conditions for effective functioning of the transport process, the probability of emergency downtime can serve as a criterion for evaluating their reliability.

5. Conclusions

An important indicator to assess the reliability of renewable transport systems is the probability of an emergency downtime, which reflects both the frequency of failure and the idle time.

From the practical point of view, the above models allow us to determine the general probability of a forced idle or other reliability measure for virtually any scheme of the transport process, and on this basis to assess its reliability either in absolute value of the indicator, or with the help of economic expression of reliability in the form, for example, mathematical expectation of damage.

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