ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)

Наука та прогрес транспорту. Вісник Дніпропетровського національного університету залізничного транспорту, 2016, № 5 (65)



**UDC 629.45/.46-049.6**

L. A. MURADIAN[1*]

[1*]Dep. «Cars and Rolling Stock», Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St., 2, Dnipro, Ukraine, 49010, tel. +38 (056) 373 15 19, e-mail leon59@bk.ru, ORCID 0000-0003-1781-4580

# PROBABILISTIC-PHYSICAL APPROACH TO DESCRIBE AND DETERMINE THE RELIABILITY OF CARS

**Purpose.** The article aims to develop an algorithm and a sequence of description and determination of car reliability to predict certain quantitative indicators of the studied elements, parts and units, or a car as a whole on the basis of probabilistic-physical approach. **Methodology**. For the calculation of the indicators of reliability, durability and safety of cars the probabilistic-physical method was used, which takes into account the resources consumption inevitable in the operation of cars. The methodology of quantifying the reliability is based on the study of the physical-mechanical and physical-chemical properties and parameters of various elements, with the identification of principles of the aging processes of the elements or parts (with operating time) to determine the analytical dependencies of these processes from the indicators of cars reliability. **Findings.** On the basis of probabilistic-physical approach it was developed a model to describe and determine the reliability of the cars. At this the method of calculation based on probabilistic-physical model is fundamentally different from all known rigorous probabilistic methods by the fact that it considers a continuous set of states of the elements, parts and systems of the car during continuous time. If there exists or (if it possible to find) the information parameter about the resource consumption of the car element with evaluation of its change speed, and knowing its limit, based on the built car reliability model with the involvement of probabilistic-physical approach, one can predict all the necessary quantitative indicators of reliability of the studied elements, parts and units or a car as a whole. **Originality.** The methodology of the reliability construction with the use of probabilistic-physical model with DN-distribution was further developed in the article. The specific physical interpretation of the constants of DN-distribution of failures makes it possible to evaluate them according to the results of the study of certain parameters characterizing the technical condition of the car. On the basis of probabilistic-physical approach the algorithm and the sequence of description and determination of cars reliability to predict certain quantitative reliability indicators of the studied elements, parts and units, or a car as a whole were developed. **Practical value.** The results make it possible to calculate in practice the quantitative indicators of reliability of cars or their individual elements for further prediction of the overall reliability during operation.

*Keywords*: probabilistic-physical approach; reliability; technical condition of cars; failure model; development

## Introduction

In the reliability theory coexist two directions related in ideology and general system of concepts, but different in approaches [5-8, 11, 13-16].

The first direction includes the systemacity, statistical character, i.e. mathematical theory of reliability, the second one can be called the physical theory of reliability. The object of the system (statistical, mathematical) theory of reliability is the system of elements interacting in terms of survival in logical schemes: graphs, fault trees, etc.

Background information in the system reliability theory usually form the indicators of elements reliability that are determined by statistical analysis of the test results and (or) operational data. The task of system reliability theory is solved within the framework of the probability theory and mathematical statistics, which is without involvement physical models of failures and the physical phenomena that cause and accompany the emergence of failures.

The origins of the physical theory of reliability can be found in earlier works on statistical interpretation of assurance factor when calculating engineering structures [3, 4]. A distinctive feature of the physical theory of reliability lies in the fact that the system survival and the possibility of failure initiation are considered as the result of interaction between the system and external influences (operational loads, environmental conditions, etc.), as well as mechanical, physical and chemical processes that occur in the system components during its operation. The models and methods of natural

doi 10.15802/stp2016/84082

and technical sciences in the physical theory of reliability are widely used together with the means of probability theory and mathematical statistics.

Physical reliability theory indicates that first of all the car reliability is provided by consistency or little change in physical-mechanical and physico-chemical properties (within the permissible limits) of each element. That is it should be provided the safety of the physical-mechanical and physical-chemical properties of each element of the car in the original (initial) form or with of minor change that will not lead to a significant deterioration in the internal state of element materials, parts and units. First of all, it concerns the safety of such properties as microstructure, chemical and phase composition of materials that directly influence the change in hardness, strength, plasticity, wear, corrosive, and erosive resistance and other properties. In turn constancy or a small change (within the permissible limits) in these properties provides long and reliable operation of the elements and the car as a whole, which is based on physical reliability.

## Purpose

The article aimes to develop an algorithm and a sequence of description and determination of car reliability to predict certain quantitative reliability indicators of the studied elements, parts and units, or a car as a whole on the basis of probabilistic-physical approach.

## Methodology

Physical reliability of various kinds of materials is the foundation of any reliability (operational, local, integrated, etc.) of certain elements, parts and units, and the car in general. However, if to the material of the elements, parts and units of the car one applies only the concept of physical reliability, to the construction of various cars along with the physical reliability the concepts of constructive and technological reliability can be applied.

The technical literature and regulatory documents in principle does not contain such concepts as constructive and technological reliability. But the introduction of such terms is always dictated by production necessity, especially at the stage of designing and manufacturing of cars. Furthermore, it should be noted the existence of operational reliability of cars, which has a direct link with the physical reliability including with constructive and technological. Moreover, it should be noted the existence of operational reliability of cars, which has a direct communication with the physical reliability including the constructive and technological ones.

When designing cars, in accordance with the regulations [12], the constructive reliability includes the probability of reliable operation with certain (necessary) value. That is, at this stage a mathematical tool of reliability theory without taking into account possible (during manufacturing and operation) changes in physical-mechanical and physical-chemical properties of certain elements, parts, etc.

In the production process of cars (the initial time) parts and units are made of different materials, which have certain (projected) design, and which will operate in a car. Reliability and ultimately failure-free operation of this part will be determined not only by the initial properties of material, but also by the way in which, the assembly of elements and parts will influence the loss of the physical-mechanical and physical-chemical properties in the interaction of these elements during operation of cars. For example, if the element or part of the car is designed in the way that there are stress concentrators (sharp corners, irrationally located holes, etc.), then as a result of static and dynamic loadings during operation in the areas of stress concentration the cracks will be formed with subsequent destruction of the system of certain unit or car in general. If one projects the design of these elements or parts with fillets, the above mentioned destruction processes will not take place that is the overall reliability of the car assembly will be higher.

Another feature of constructive reliability of cars is the preservation of the initial (projected) design of the elements or parts during operation in its original form. For example, if during operation of different types of cars the assembly of elements, parts or units does not undergo significant changes, the survival and reliability of such system is guaranteed.

If during operation of car a random displacement of its elements in relation to the others beyond the permissible limits took place, or there was a loss of certain elements (due to prolonged

doi 10.15802/stp2016/84082

vibration there occurred screw detwisting, loss of bolts or certain elements, parts, their skewing took place, etc.), then ultimately such system will be unworkable and unreliable. Consequently, non-compliance of the original (initial) form preservation of the relative orientation of elements or parts of the system or the change of its completeness can cause failure. That such failure is a sign of low level of constructive reliability and, in some cases, of technological reliability of car.

Paramount importance of reliability is connected with the fact that its level largely determines the development of automation of production processes, intensification of working processes, materials and energy saving.

The urgency of reliability increases due to the complexity of modern machines and the importance of the functions they perform [4, 7, 10]. Modern hardware consists of many interacting mechanisms, machines and devices. Failure of even one element of a complex system leads to the failure of all system.

One of the problems of modern reliability theory based on classical probabilistic methods is the inability of adequate accurate prediction of the moment of failure emergence as a random event. Since, the moment of the object (especially durable one) failure usually preceded by the complex internal changes, these changes in freight cars may appear in different ways depending on the location and nature of the failure.

Recent studies of reliability, conducted for various products, machines and components [7, 8, 10-12] show that for the calculation of the values of reliability, durability and safety of cars one can apply probabilistic-physical method that takes into account resources consumption inevitable in the operation of cars.

The methodology of quantifying the reliability is based on the study of the physical-mechanical and physical-chemical properties and parameters of various types of technical means. On the basis of this study one can identify the principles of the aging processes of the elements or parts with operating time (during resource consumption), as well as determine the analytical dependencies of these processes with the indicators of reliability of cars. When studying the aging processes of cars, i.e. the degradation processes, one can apply the mathematical methods of studying the internal changes in the physical-mechanical and physical-chemical properties involving the theory of stochastic processes and using stochastic equations and physical modeling of the use of resource of the elements, parts and units of the car conducting the reliability tests.

The use of degradation models based on random processes and stochastic kinetic equations makes it possible to find dependences of the probability of reliable operation (or failure) and physical-mechanical and physical-chemical properties (or certain parameter) that led to the car failure. The obtained results of solutions of stochastic equations that describe the internal properties of the elements or parts of different technical means are repeatedly confirmed by long tests of the designed physical models that make it possible to make reliable adequate conclusions involving statistical tool [1, 2, 9]. This, in turn, opens the possibility to perform the calculations of physical reliability of different types of cars in the process of aging and using the resources, taking into account the degradation processes in materials of their elements and parts, in the case when the failure rate is acting as a function of operating time. This approach provides solution of many practical problems existing in the modern theory of reliability.

As it is known [7, 12], the state of reliability of cars during manufacture and maintenance of this reliability at a sufficient level during operation is greatly influenced by the processes of aging, fatigue and fracture of metals and alloys. The successful solution of these problems first of all lies in the development of new technology, methodology, physical theory of aging, fatigue and fracture of materials instead of outdated one. In the second place is the generalization of disaggregated experimental data on the mechanism of aging and fatigue in order to create a general physical theory of «aging-fatigue-destruction» of all sorts of materials from the beginning of their production to the total destruction. And then is the search and development of new technologies for production of parts, which reduce the level of fatigue and aging of materials at the stage of their processing.

## Findings

Let us consider provision of the probabilistic-physical approach to the problems of reliability theory. The technical condition of cars depends on

doi 10.15802/stp2016/84082

the values of the internal parameters $D_i$, which will be unchanged during operation. With the accumulation of operating time and resource consumption these parameters that will determine the technical condition of the cars are changing (dropping from the reliability position), thereby approaching to the appropriate limit values: $D_i(t) \rightarrow D_{грi}$.

Initial technical condition of the car according to some information about the internal parameters will be determined by the following vector:

$$D_o = (D_{o1}, D_{o2}, ..., D_{oi}), \quad (1)$$

where $D_{oi}$ – is the value of defining parameter that was obtained for the *i*-th element in the initial moment of monitoring the technical condition of the car.

According to some information the following vector will correspond, to the limit condition respectively and, thus, to the working limit $T_{гр}$ of the car:

$$D_{гр} = (D_{гр1}, D_{гр2}, ..., D_{грi}). \quad (2)$$

Components of vectors of the obtained information (1) and (2) differ. This fact can be described by the parameter of changing the technical condition $\alpha$ for the *i*-th period of the operating time (mileage) of the car. According to its content this value is a random one and characterizes the change of determining parameter for the unit of operating hours (mileage), which can be defined as a unit of measurement of the technical state parameter divided by the unit of operating time of the car.

Similar to (1) and (2), the parameter of technical condition of the structural elements of the car for some operating moments can also be represented as vectors:

$$\alpha_1 = (\alpha_{11}, \alpha_{12}, ..., \alpha_{1i}); \quad (3)$$

$$\alpha_{гр} = (\alpha_{гр1}, \alpha_{гр2}, .., \alpha_{грi}), \quad (4)$$

where $\alpha_1, \alpha_{гр}$ – are correspondingly the parameters of changing the technical state of structural element of the car for the first and boundary periods of the operating time (mileage).

At the moment when the determining parameter of the components of the car structural elements achieves the boundary value there occurs its failure. The condition of the car failure can be written as follows:

$$\lim_{D_i(t) \to D_{гр}(t)} \left( \frac{D_i(t)}{D_{грi}} \right) = 1. \quad (5)$$

If we imagine that we can «observe» the degradations and «fix» the moments when the determining parameters $D_i$ achieve their boundary values $D_{грi}$, then we will obtain time interval to obtain an array of operating hours (mileage) $\{t_i\}$ in the time interval from $t_{\min}$ to $t_{\max}$ $\{t_i\}$. After we processed the array $\{t_i\}$ with the known method, that is, dividing the interval $t_{\min} \dots t_{\max}$ by $l$ of the intervals with the length $\Delta t$ and counted the number of failures $n(\Delta t)$ for each interval, we obtain the distribution density of failures in the specified interval of the operating hours (mileage). During mathematical modeling of the processes of degradation of «observation» and «fixing» are made on the basis of decision on the solution of (5) at the given initial and boundary conditions.

The obtained conditional $\omega(t, D)$ density of the implementation probability of one or another trajectory has simple relationship with the distribution density of operating hours (mileage) of the car to the failure:

$$f(t) = -\int_{-\infty}^{1} \frac{\partial \omega(D_o(t_o), D(t))}{\partial t} dD. \quad (6)$$

The degradation of properties of the structural elements of the car can have both monotonous and non-monotonous nature. Solution of the probability density equation (6) for monotonous and non-monotonous processes of degradation of structural elements of the car should differ only by different boundary conditions.

Changing the determining parameters of the car elements during operation is described by the stochastic Markov process, when the transition of physical parameters from the one value to another (from one state to another) has probabilistic nature, i.e. it is the Markov process of diffusion type.

At this the conditional probability density of transition from the one state to another $\omega(t, D)$ can be determined using the following equation in partial derivatives, which is similar to the diffusion

doi 10.15802/stp2016/84082

equation in the theory of mass transfer in the solid state physics:

$$\frac{\partial\omega(t,D)}{\partial t}+a\frac{\partial\omega(t,D)}{\partial D}-b^2\frac{\partial\omega(t,D)}{2\partial D^2}=0, \quad (7)$$

where $t$ – is the operating hours (mileage) of the car; $a$ – is the average rate of change of the determining parameter of structural element (in other way – drift coefficient); $D=D(t)$ – is the determining parameter of structural element that determines its technical condition; $b$ – is the flow coefficient of the probabilities of technical condition of the structural element, at that $b^2$ is the average speed of dispersion change of the determining parameter of the structural element.

Then the expression for the law of distribution of the service life of the car to the failure, i.e. the mathematical model of failures, according to the fact that the change of the technical state of the car as a whole can be described by an exponential pattern will look like:

$$f(t)=\frac{1}{bt\sqrt{2\pi t}}\exp\left[-\frac{(1-at)^2}{2b^2t}\right]. \quad (8)$$

The equation (8) will represent the mathematical model of change of the car technical condition according to the determining parameters of structural elements or DN-model (DN-distribution) [2].

The above-mentioned distribution in the scientific literature [2, 4, 10] was named as the DN-distribution or diffusion non-monotonous distribution, because it results from the solution of the flow equation (diffusion) of probabilities.

In addition, the probability diffusion coefficient of the technical condition of the car $b$ will be equal to:

$$b=\frac{\sigma_a}{\sqrt{a}}=\frac{\sigma_a\sqrt{a}}{\sqrt{a}\sqrt{a}}=\frac{\sigma_a}{a}\sqrt{a}. \quad (9)$$

The ratio $\sigma_a/a$ acts as a coefficient of variation $V_з$ of the process of changing the technical condition of the car. In the DN-model of failures the variation coefficient of operating hours (mileage) to the failure $V$ of any element, part or unit of the car coincides with the variation coefficient of the speed of change taking place in the internal processes of changing the technical condition of the car $V_з$.

For the flow coefficient of probabilities of the technical condition of the car $b$ the following relationship can be written:

$$b=V\sqrt{a}. \quad (10)$$

Experience of theoretical estimates according to the specified mathematical model shows that it is more convenient to avoid the use of the average speed of technical state changing $a$, but to use the value reduced to it:

$$\mu=\frac{1}{a}. \quad (11)$$

Then, taking into account the above mentioned relationships, the distribution density (8) will take the following form:

$$f(t)=\frac{\sqrt{\mu}}{V_t t\sqrt{2\pi t}}\exp\left[-\frac{(\mu-t)^2}{2V_t^2\mu t}\right], \quad (12)$$

where $\mu$ – is a scale parameter of distributon; $V$ – is a variation coefficient of operating hours (mileage) to the failure – the parameter of the distribution form.

Let us find out the content of parameter of the scale distribution parameter $\mu$ from the standpoint of the reliability theory. To make this let us show that it nothing else but the average value of the operating time (mileage) of the car $t$, i.e. the mathematical expectation of the operating time to the failure.

According to the works [2, 10] – the mathematical expectation of a random variable $t$ is the first initial statistical moment. Since the operating time (mileage) of the car $t$ is a continuous random variable in the range of definition $(0,\infty)$, then the expression for the mathematical expectation operating time (mileage) of the car to the failure $T_o$ will take the following form:

$$T_o=\int_0^\infty tf(t)\,dt. \quad (13)$$

Let us apply the expression (12) to the last expression (13) and, as a result, after simplifications, we obtain operating hours (mileage) to the failure in the following form:

doi 10.15802/stp2016/84082 

$$T_o = \frac{\sqrt{\mu}}{V_t\sqrt{2\pi}}\exp\left(V_t^{-2}\right)2\sqrt{\mu}\times$$

$$\times V_t\sqrt{\frac{\pi}{2}}\exp\left(-V_t^{-2}\right)=\mu\,. \quad (14)$$

Thus, in the DN-model of the scale parameter of failures distribution $\mu$ have physical meaning of the average operating hours (mileage) of car to the failure.

Using the results of the works [2, 4, 10] one can determine the statistical parameters of DN-model:

− operating hours (mileage) dispersion of the car *t* to the failure:

$$\sigma_t^2 = \sum_0^{\infty}\left(t-\mu\right)^2 f\left(t\right)dt\,, \quad (15)$$

− statistical moments of failures:

$$M_t = \mu\,;\ \sigma_t^2 = \mu^2 V_t^2\,;\ A_s = 3V_t\,;\ E_x = 15V_t^2\,. \quad (16)$$

On the basis of the constructed model let us provide an example of the DN-distribution for statistics on failures of the freight cars (Fig. 1).

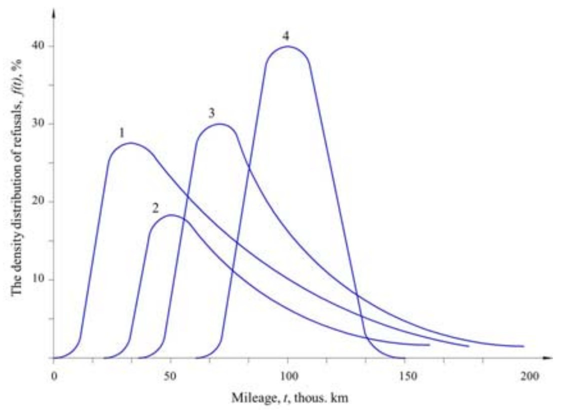


Fig. 1. DN-distribution of failures of structural elements of the freight cars at μ=const and μ=100 thous. km:
*1* – body structure; *2* – bogies and spring suspension;
*3* – braking equipment; *4* – wheel sets

Analyzing the main characteristics of the DN-distribution, the following facts should be noted:

− Skewness $A_s$ and kurtosis $E_x$ of thee obtained distribution are positive, and the mathematical expectation $M_t$ shifted to the right relative to the median, that is the DN-distribution density is asymmetric single-mode curve with extended right branch line (all the given curves 1-4 in the Fig. 1);

− at the fixed scale distribution parameter (expectation of operating hours (mileage) to the car failure $\mu=100$ thous. km) with the shift of the form parameter $V_t$ the maximum distribution density $f\left(t\right)$ is shifted to the right clockwise with the simultaneous decrease in the distribution amplitude (curves 1, 2, Fig. 1) and its subsequent increase (curves 3, 4, Fig. 1). At this, all the central statistical moments of distribution (dispersion, skewness and kurtosis) are decreased;

− at the fixed form parameter (variation coefficient $V_t$) with increasing in the scale parameter of distribution $\mu$, i.e. with the distribution shift to the right clockwise, it is deformed in a way that the dispersion increases and the coefficients of skewness and kurtosis are constant. The example of the given case is shown in the Fig. 2.

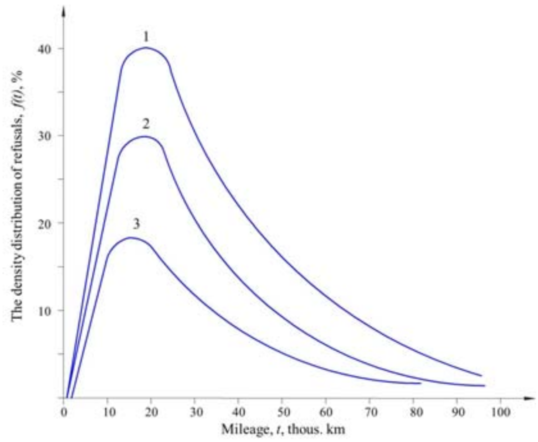


Fig. 2. DN-distribution of failures of structural elements of the freight cars at $V_t = \text{const}$ and $V_t = 1$:
*1* – wheel sets; *2* –braking equipment;
*3* – bogies and spring suspension

## Originality and practical value

The methodology of reliability construction with the use of the probabilistic-physical model with the DN-distribution was further developed in the paper. The specific physical interpretation of the constants of DN-distribution of failures makes it possible to evaluate them according to the results of the study of certain parameters describing the technical condition of the car.

Based on the probabilistic-physical approach it was developed the algorithm and the sequence of description and determination of the car reliability for predicting certain quantitative indicators of the

doi 10.15802/stp2016/84082

ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)

Наука та прогрес транспорту. Вісник Дніпропетровського національного університету залізничного транспорту, 2016, № 5 (65)



reliability of investigated elements, parts and units of the car in general.

The research results make possible practical calculation of the quantitative indicators of reliability of the cars or their elements for future forecasting of the general reliability during operation.

## Conclusions

The method of calculation based on the 6DN-distribution as the probabilistic-physical model is fundamentally different from all known rigorous probabilistic methods by the fact that it considers the continuous (continual) set of states of the elements, parts and systems of the car with continuous time. Undoubtedly, this is a high-quality representation of car elements behavior that consumes their resources over time – with operating hours increasing. Specific physical interpretation of the constants of probabilistic-physical models of failure distribution makes it possible to estimate them according to the research results of the determined parameters describing the technical condition of the car. If one can find the parameter that informs about the consumption of the car element resource, then after estimation of its change speed and knowing its limit value based on the constructed model of the freight car reliability involving the probabilistic-physical approach, one can predict the necessary quantitative reliability indicators of the investigated elements, parts and units and the car in general.

## LIST OF REFERNCE LINKS

1. Бочаров, П. П. Теория вероятностей. Математическая статистика / П. П. Бочаров, А. В. Печинкин. – Москва : Физматлит, 2005. – 296 с.
2. Булинский, А. В. Теория случайных процессов / А. В. Булинский, А. Н. Ширяев. – Москва : Физматлит, 2005. – 408 с.
3. Грибов, В. М. Основы теории надежности авиационной техники : конспект лекций / В. М. Грибов, В. В. Козарук. – Киев : КМУГА, 1994. – 268 с.
4. Далецкий, С. В. Проектирование систем технического обслуживания и ремонта ВС ГА / С. В. Далецкий. – Москва : МАИ, 2001. – 245 с.
5. Мурадян, Л. А. Відмови та безвідмовність вагонів як складові експлуатаційної надійності // Вісн. НТУ «ХПІ». Серія: Механіко-технолог. системи та комплекси. – Харків, 2015. – Т. 52 (1161). – С. 127–130.
6. Мямлін, С. В. Застосування основних законів розподілу випадкових величин для визначення показників надійності вагонів / С. В. Мямлін, Л. А. Мурадян // Зб. наук. пр. ДЕТУТ. Серія: «Трансп. системи і технології». – Київ, 2015. – Вип. 26–27. – С. 172–180.
7. Мямлін, С. В. Проблема визначення терміну «надійність». Методологія побудови та вивчення надійності вантажних вагонів / С. В. Мямлін, Л. А. Мурадян, Д. М. Барановський // Наука та прогрес транспорту. – 2015. – № 6 (60). – С. 110–117. doi: 10.15802/stp-2015/57034.
8. Мямлін, С. В. Розробка конструкцій та машинобудівних технологій створення вантажних вагонів нового покоління // С. В. Мямлін // Вагонний парк. – 2014. – № 10. – С. 4–9.
9. Павлов, И. В. Статистические методы оценки характеристик надежности и эффективности сложных систем по результатам испытаний / И. В. Павлов. – Москва : Сов. радио, 1978. – 36 с.
10. Техническая эксплуатация авиационного оборудования : учебник / под ред. В. Г. Воробьёва. – Москва : Транспорт, 1990. – 296 с.
11. Трощенко, В. Т. Роль науки в обеспечении надежности машин и сооружений / В. Т. Трощенко // Надежность и долговечность машин и сооружений. – 1985. – № 7. – С. 3–5.
12. Устич, П. А. Надежность рельсового нетягового подвижного состава / П. А. Устич, В. А. Карпычев, М. Н. Овечников. – Москва : Вариант, 1999. – 412 с.
13. Хрусталев, В. В. Необходим инженерный анализ надежности сложных систем / В. В. Хрусталев // Стандарты и качество. – 1989. – № 3. – С. 17–19.
14. Determination of the dynamic characteristics of freight wagons with various bogie / S. Myamlin, L. P. Lingaitis, S. Dailydka [et al.] // Transport. – 2015. – Vol. 30. – Iss. 1. – P. 88–92. doi: 10.3846/16484142.2015.1020565.
15. Myamlin, S. V. Investigation of dynamic characteristics of gondola cars on perspective bogies / S. V. Myamlin, V. M. Bubnov, Ye. O. Pysmennyi // Наука та прогрес транспорту. – 2014. – № 5 (53). – С. 126–137. doi: 10.15802/stp2014/30789.
16. Myamlin, S. V. The modeling of economic efficiency of products carriage-building plant in conditions of dynamic pricing / S. V. Myamlin, D. M. Baranovskiy // Проблеми економіки транспорту : зб. наук. пр. Дніпропетр. нац. ун-ту залізн. трансп. ім. акад. В. Лазаряна. – Дніпропетровськ, 2014. – Вип. 7. – С. 61–66.

doi 10.15802/stp2016/84082 

ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)

Наука та прогрес транспорту. Вісник Дніпропетровського
національного університету залізничного транспорту, 2016, № 5 (65)



Л. А. МУРАДЯН[1*]

[1*]Каф. «Вагони та вагонне господарство», Дніпропетровський національний університет залізничного транспорту імені академіка В. Лазаряна, вул. Лазаряна, 2, Дніпро, Україна, 49010, тел. +38 (056) 373 15 19, ел. пошта leon59@bk.ru, ORCID 0000-0003-1781-4580

# ЙМОВІРНІСНО-ФІЗИЧНИЙ ПІДХІД ДЛЯ ОПИСАННЯ ТА ВИЗНАЧЕННЯ НАДІЙНОСТІ ВАГОНІВ

**Мета.** У роботі передбачається на основі ймовірнісно-фізичного підходу розробити алгоритм і послідовність описання та визначення надійності вагонів для прогнозування окремих кількісних показників досліджуваних елементів, деталей та вузлів або вагона в цілому. **Методика.** Для розрахунку показників безвідмовності, довговічності й збережуваності вагонів застосовано ймовірнісно-фізичний метод, що враховує неминучі під час експлуатації вагонів витрати ресурсу. Методика встановлення кількісних показників надійності ґрунтується на вивченні фізико-механічних та фізико-хімічних властивостей і параметрів різних елементів, із виявленням закономірностей процесів старіння елементів чи деталей (з часом чи напрацюванням) для визначення аналітичних залежностей зазначених процесів від показників надійності вагонів. **Результати.** На основі ймовірнісно-фізичного підходу розроблено модель для описання та визначення надійності вагонів. При цьому метод розрахунку на основі ймовірнісно-фізичної моделі принципово відрізняється від усіх відомих строгих ймовірнісних методів тим, що він розглядає неперервну множину станів елементів, деталей і систем вагона впродовж неперервного часу. При існуванні (чи можливості знаходження) інформаційного параметра про витрату ресурсу елемента вагона з оцінкою швидкості його зміни і, знаючи його граничне значення, на основі побудованої моделі надійності вагона із залученням ймовірнісно-фізичного підходу можна прогнозувати всі необхідні кількісні показники надійності досліджуваних елементів, деталей та вузлів або вагона в цілому. **Наукова новизна.** У роботі набула подальшого розвитку методологія побудови надійності вагонів із використанням ймовірнісно-фізичної моделі з DN-розподілом. Конкретна фізична інтерпретація констант DN-розподілу відмов дає можливість оцінити їх за результатами дослідження окремих параметрів, що характеризують технічний стан вагона. На основі ймовірнісно-фізичного підходу розроблено алгоритм і послідовність описання та визначення надійності вагонів для прогнозування окремих кількісних показників досліджуваних елементів, деталей та вузлів і вагона в цілому. **Практична значимість.** Результати роботи дозволяють практично розрахувати кількісні показники надійності вагонів чи їх окремих елементів для подальшого прогнозування загальної надійності під час експлуатації.

*Ключові слова*: ймовірнісно-фізичний підхід; надійність; технічний стан вагонів; модель відмов; напрацювання

Л. А. МУРАДЯН[1*]

[1*]Каф. «Вагоны и вагонное хозяйство», Днепропетровский национальный университет железнодорожного транспорта имени академика В. Лазаряна, ул. Лазаряна, 2, Днипро, Украина, 49010, тел. +38 (056) 373 15 19, эл. почта leon59@bk.ru, ORCID 0000-0003-1781-4580

# ВЕРОЯТНОСТНО-ФИЗИЧЕСКИЙ ПОДХОД ДЛЯ ОПИСАНИЯ И ОПРЕДЕЛЕНИЯ НАДЕЖНОСТИ ВАГОНОВ

**Цель.** В работе предполагается на основе вероятностно-физического подхода разработать алгоритм и последовательность описания и определения надежности вагонов для прогнозирования отдельных количественных показателей исследуемых элементов, деталей и узлов или вагона в целом**. Методика.** Для расчета показателей безотказности, долговечности и сохранности вагонов применен вероятностно-физический метод, учитывающий неизбежные при эксплуатации вагонов расходы ресурса. Методика установления количественных показателей надежности основывается на изучении физико-механических и физико-химических свойств и параметров различных элементов, с выявлением закономерностей процессов старения элементов или деталей (со временем или наработкой) для определения аналитических зависимостей указанных процессов от показателей надежности вагонов**. Результаты.** На основе вероятностно-физического подхода разра-

doi 10.15802/stp2016/84082 

ботана модель для описания и определения надежности вагонов. При этом метод расчета на основе вероятностно-физической модели принципиально отличается от всех известных строгих вероятностных методов тем, что он рассматривает непрерывное множество состояний элементов, деталей и систем вагона в течение непрерывного времени. При существовании (или возможности нахождения) информационного параметра о расходе ресурса элемента вагона с оценкой скорости его изменения и, зная его предельное значение, на основе построенной модели надежности вагона с привлечением вероятностно-физического подхода можно прогнозировать все необходимые количественные показатели надежности исследуемых элементов, деталей и узлов или вагона в целом**. Научная новизна.** В работе получила дальнейшее развитие методология построения надежности вагонов с использованием вероятностно-физической модели с DN-распределением. Конкретная физическая интерпретация констант DN-распределения отказов дает возможность оценить их по результатам исследования отдельных параметров, характеризующих техническое состояние вагона. На основе вероятностно-физического подхода разработан алгоритм и последовательность описания и определения надежности вагонов для прогнозирования отдельных количественных показателей исследуемых элементов, деталей, узлов и вагона в целом**. Практическая значимость.** Результаты работы позволяют практически рассчитать количественные показатели надежности вагонов или их отдельных элементов для дальнейшего прогнозирования общей надежности при эксплуатации**.**

*Ключевые слова*: вероятностно-физический подход; надежность; техническое состояние вагонов; модель отказов; наработка

# REFERENCES

1. Bocharov P.P., Pechinkin A.V. *Teoriya veroyatnostey. Matematicheskaya statistika* [Theory of probability. Mathematical statistics]. Moscow, Fizmatlit Publ., 2005. 296 p.
2. Bulinskiy A.V., Shiryayev A.N. *Teoriya sluchaynykh protsessov* [Theory of stochastic processes]. Moscow, Fizmatlit Publ., 2005. 408 p.
3. Gribov V.M., Kozaruk V.V. *Osnovy teorii nadezhnosti aviatsionnoy tekhniki* [Fundamentals of reliability theory of aviation engineering]. Kyiv, KIUCA Publ., 1994. 268 p.
4. Daletskiy S.V. *Proyektirovaniye sistem tekhnicheskogo obsluzhivaniya i remonta VS GA* [Designing of systems of maintenance and repair of civil aircrafts]. Moscow, MAI Publ., 2001. 245 p.
5. Muradian L.A. Vidmovy ta bezvidmovnist vahoniv yak skladovi ekspluatatsiinoi nadiinosti [Failures and reliability of cars as components of operational reliability]. *Visnyk Natsionalnoho tekhnichnoho universytetu «Kharkivskyi politekhnichnyi instytut». Seriia: Mekhaniko-tekhnolohichni systemy ta kompleksy* [Bulletin of National Technical University «Kharkiv Polytechnical Institute». Series: Mechanical-technological systems and complexes], 2015, issue 52 (1161), pp. 127-130.
6. Miamlin S.V., Muradian L.A. Zastosuvannia osnovnykh zakoniv rozpodilu vypadkovykh velychyn dlia vyznachennia pokaznykiv nadiinosti vahoniv [The application of the basic laws of distribution of random variables to determine the reliability indicators of cars]. *Zbirnyk naukovykh prats Derzhavnoho ekonomiko-tekhnolohichnoho universytetu transportu. Seriia: «Transportni systemy i tekhnolohii»* [Proc. of State Economic-Technological University of Transport. Series: «Transport Systems and Technologies»], 2015, issue 26-27, pp. 172-180.
7. Miamlin S.V., Muradian L.A., Baranovskyi D.M. Problema vyznachennia terminu «nadiinist». Metodolohiia pobudovy ta vyvchennia nadiinosti vantazhnykh vahoniv [Problem of the definition the «reliability» term. Methodology of construction and study the reliability of freight cars]. *Nauka ta prohres transportu – Science and Transport Progress*, 2015, no. 6 (60), pp. 110-117. doi: 10.15802/stp2015/57034.
8. Miamlin S.V. Rozrobka konstruktsii ta mashynobudivnykh tekhnolohii stvorennia vantazhnykh vahoniv novoho pokolinnia [Development of structures and engineering technologies of creating the new generation freight cars]. *Vahonnyi park – Car Fleet*, 2014, no.10, pp. 4-9.
9. Pavlov I.V. *Statisticheskiye metody otsenki kharakteristik nadezhnosti i effektivnosti slozhnykh sistem po rezultatam ispytaniy* [Statistical methods for evaluating the reliability and efficiency of complex systems according to the test results]. Moscow, Sovetskoye radio Publ., 1978. 36 p.
10. Vorobyev V.G. *Tekhnicheskaya ekspluatatsiya aviatsionnogo oborudovaniya* [Technical maintenance of aviation equipment]. Moscow, Transport Publ., 1990. 296 p.
11. Troshchenko V.T. Rol nauki v obespechenii nadezhnosti mashin i sooruzheniy [The role of science in ensuring the reliability of the machines and installations]. *Nadezhnost i dolgovechnost mashin i sooruzheniy – The Reliability and Durability of Machines and Structures*, 1985, no. 7, pp. 3-5.

doi 10.15802/stp2016/84082

12. Ustich P.A., Karpychev V.A., Ovechnikov M.N. *Nadezhnost relsovogo netyagovogo podvizhnogo sostava* [Reliability of the rail non-tractive rolling stock]. Moscow, IG Variant Publ., 1999. 412 p.
13. Khrustalev V.V. Neobkhodim inzhenernyy analiz nadezhnosti slozhnykh system [Engineering analysis of reliability of complex systems]. *Standarty i kachestvo – Standards and Quality*, 1989, no. 3, pp. 17-19.
14. Myamlin S., Lingaitis L.P., Dailydka S., Vaičiūnas G., Bogdevičius M., Bureika G. Determination of the dynamic characteristics of freight wagons with various bogie. *Transport*, 2015, vol. 30, issue 1, pp. 88-92. doi: 10.3846/16484142.2015.1020565.
15. Myamlin S.V., Bubnov V.M., Pysmennyi Ye.O. Investigation of dynamic characteristics of gondola cars on perspective bogies. *Nauka ta prohres transportu – Science and Transport Progress*, 2014, no. 5 (53), pp. 126-137. doi: 10.15802/stp2014/30789.
16. Myamlin S.V., Baranovskiy D.M. The modeling of economic efficiency of products carriage-building plant in conditions of dynamic pricing. *Zbirnyk naukovykh prats Dnipropetrovskoho natsionalnoho universytetu zaliznychnoho transportu imeni akademika V. Lazariana «Problemy ekonomiky transportu»* [Proc. of Dnipropetrovsk National University named after Academician V. Lazaryan «Problems of Transport Economics»], 2014, no. 7, pp. 61-66.

*Prof. S. V. Myamlin, D. Sc. (Tech.) (Ukraine); Prof. I. E. Martynov, D. Sc. (Tech.) (Ukraine) recommended this article to be published*

Accessed: July 04, 2016
Received: Sep. 30, 2016

doi 10.15802/stp2016/84082 