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Effectiveness retention ratio and its standardization

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Abstract. Aim. *To promote a better understanding, a wider and more correct application of the effectiveness retention ratio. That is the measure that is best suited for assessing the dependability of complex technical systems, in which partial failures are possible that put a system into intermediate states between complete up and down ones.* **Methods.** *The paper uses the methods of the probability theory and comparative analysis of texts of interstate (Euro-Asian), Russian and international dependability-related standards.* **Results.** *The principal contribution of Russian researchers to the creation and development of methods for applying effectiveness indicators to estimating the dependability of complex systems is pointed out. Shortcomings were identified in the basic dependability-related standards as regards the effectiveness retention ratio and related concepts. Namely, in terminology standard GOST 27.002–2015, the phrases that require improvement are indicated. They relate to the concepts of partial failure, partial up state and partial down state. A broader and more accurate definition of partial failure is suggested. It is noted that the relationship between partially up and partially down states are to be discussed and clarified. GOST 27.003–2016 that establishes the content and general rules for specifying dependability requirements contains wording errors in the classification of items according to the number of possible (taken into consideration) states and in the examples of possible variants of the effectiveness retention ratio in various branches of technology that are probabilities of task completion, etc. The paper suggests corrections to the appropriate wordings. It has been established that although the effectiveness retention ratio is not referred to in the international dependability-related terminology standard (IEC 60050-192:2015), it implicitly appears in two IEC standards (IEC 61703:2016 and IEC 62673:2013), in which it is assigned to availability measures.* **Conclusion.** *The paper's findings will be useful to experts involved in the assessment and standardization of complex technical system dependability. Their implementation will help improve interstate, Russian and international dependability-related standards.*

Keywords: *complex system, dependability, partial failure, effectiveness retention ratio, output effect, interstate (Euro-Asian), Russian and international standards.*

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Introduction

Conventional dependability measures that characterize reliability and availability are defined on the assumption that a technical item can be in one of two states: up or down. However, many complex systems are characterized by partial failures that put the item into an intermediate state with reduced (partial) operability. The main dependability measure for such systems is the effectiveness retention ratio (ERR) that was covered in a number of publications referred to below.

The purpose of this paper is to promote a better understanding of the ERR, its broader and more correct application. It is intended for experts involved in the assessment and standardization of complex system dependability. The author analyses the degree and correctness of how ERR is captured in interstate, Russian and international standards adopted over the recent years. The concepts of partial failure and partially up and down states closely associated with ERR are also examined. The conducted analysis revealed the shortcomings present in those standards. Appropriate corrections are suggested.

Background

The need to consider systems with more than two levels of operability became clear as early as in 1960s. That was mentioned in the classic monograph [1]. In particular, it states that "the concept of failure associated with a complete or significant loss of operability of a [complex] system appears to be quite artificial. <…> In such cases, dependability of a system should be understood as the stability of efficiency subject to the dependability of the parts the system is composed of" [1, p. 84]. However, this idea was not further developed in this book. In the general mathematical model, the dependability measures were defined on the basis of the phase space where a set of down states was specified.

The credit for the initial systematic description of the effectiveness calculation methods is due to I.A. Ushakov [2]. He has also done a lot to popularize this area of research. The appropriate sections were included in the commonly-used guidebooks [3–6]. However, his publications dealt with absolute effectiveness values determined with regard to dependability, whereas the other factors that affect effectiveness were practically ignored. Later, I.A. Ushakov arrived to the conclusion that a non-dimensional indicator should be considered that shows the relative decrease in the operating effectiveness of a system as its elements fail [7, p. 131], i.e., the ERR .

The first book that thoroughly examined the ERR , was [8]. It is well complemented by [9] that describes the process of ERR evaluation using computational and experimental method. These books are still relevant these days and can be recommended to anyone interested in the topic. An overview of further findings as regards the ERR calculation and evaluation was presented in [10].

Definition and meaning of the ERR

The ERR can be found in Russian dependability-related terminology standards as early as 1983. The definition has not changed much ever since, and in the current standard [11] is as follows: the ratio of the value of the effectiveness indicator of an item's intended use over a certain period of operation to the nominal value of this indicator calculated under the assumption that the item is not affected by failures during the above period. In the international standards, this measure is not explicitly defined.

If we denote the item's application effectiveness indicator as E and its nominal value is E_0, then the ratio defining the ERR denoted as R_{ef} is as follows: $R_{ef} = E/E_0$. It should be emphasized that this formula defines what the ERR is, but does not provide the method for its practical calculation [8].

The effectiveness of an item's intended use is understood as its property to create a certain useful result (output effect) over the period of operation under certain conditions [12]. The output effect is defined as the useful result obtained in the course of the item's operation. It can be defined in a number of ways. For instance, the output effect can be the revenue generated by an item's operation and be expressed in monetary units. However, natural measures are more commonly used. Below are examples of the output effect for various types of systems:

- production systems, the quantity of released products (in pieces, tons, cubic meters, hectolitres, etc.);
- various service systems, the number of successfully served users or requests;
- transportation systems, the quantity of transported goods (in tons, cubic meters, etc.) or number of transported passengers;
- information and communication systems, the amount of transmitted, collected or processed information.

Usually, the mathematical expectation (average value) of the output effect is used as the effectiveness indicator. The meaning of the ERR is quite simple. For instance, let output effect be income, while R_{ef}= 0.98. This means that, due to failures, the income generated by the item decreases on average by 2%.

Additionally, the probability of task completion can be taken as the effectiveness indicator. That is justified for intermittently operating and single use items [12]. The probability of task completion can also be represented as the mathematical expectation of the output effect. Indeed, if we set the output effect to 1 in the case the task has been completed , and 0 if otherwise, the mathematical expectation of such random value is equal to the probability that it takes the value of 1, i.e., the probability of task completion . In such situation, the ERR takes a direct probabilistic meaning. It is equal to the probability that the task completion will not be disrupted by failures [8].

The ERR can also apply to items all of whose states can be clearly divided into up and down. That being said, it usually comes down to such conventional dependability measures as availability, reliability, interval reliability [8]. In such situations, the ERR-based approach facilitates the correct selection of standardized measures .

Partial failure, partially up and partially down states

As noted above, the ERR is primarily required for systems that might be affected by partial failures. This concept is introduced in [11] in the note to the term "failure", where it is stated that a partial failure is characterized by the transition of an item into a partially down state. Unfortunately, [11] provides no explanation of what that means, yet sets forth the concept of "partially up state", i.e., a state of an item, in which it is capable of performing some functions, but at the same time is unable to perform some others. That definition is given in the note to the terms "up state" and "down state". Thus, there is an inconsistency.

The question regarding the relationship between the partially up and partially down states can be answered in different ways. In the author's opinion, those are essentially the same thing. For example, if, in a certain state, the output effect is 70% of the maximum value, then such state is 70% (partially) up and 30% (partially) down. That can be interpreted as the fuzzification of the failure criterion, i.e., the division of the whole set of states of an item into two complementary fuzzy subsets of up and down states (for the first time this idea was expressed in [13]). At the same time, some authors distinguish between the partially up and partially down states, believing that the former is closer to up state, and the latter is closer to down state [14, p. 53]. The issue therefore requires discussion and clarification.

Additionally, the definitions of partial failure and partially up/down state in [11] trace to the international terminology standard [15] and are only applicable to multifunctional items. However, those concepts should be considered for single-function items as well. For example, a process system may operate at reduced performance. Therefore, the associated wordings should be adjusted. In particular, a partially up/down state is to be defined as a state of an item with a reduced ability to function as required that is characterized by the loss of the ability to perform some, but not all, required functions or a reduced output effect. That will be close to the definition of the term "degraded state" in [15].

GOST 27.003-2016

The contents and general rules for specifying dependability requirements are set out in standard [12]. The ERR is among the dependability measures used in it. This standard was adopted to replace [16] and largely repeats its basic provisions. Unfortunately, among the modifications made to [12] some are positive, but some are erroneous.

Let us start with the positive changes. While [16] refers to products, [12] uses the more general term "item" (although this replacement was not done throughout the text and the word "product" is still found in the text). The relationship between these two concepts was thoroughly analysed in [17], so this matter is not addressed herewith. In [12], a useful note was added that explains the meaning of effectiveness and defines output effect (those were given above).

On the other hand, a frustrating mistake was made in one of the paragraphs of [12] that is important for understanding the scope of the ERR application. It was briefly mentioned in [18]. The matter is that among the primary features, based on which items are classified as part of dependability requirements specification, is the number of possible (taken into consideration) states of an item in terms of operability in operation. Based on that feature, [16] identified products of type I that, in the course of operation, can be in two states, i.e., up or down, and type II that, aside from the two above states, can be in a number of partially up/down states initiated by partial failure. Standard [12] dropped the nondescript types designated by Roman numerals, but the corresponding paragraph of the standard (6.3.2) contains a nonsensical wording stating that items are subdivided into those that are in up state and those in down state.

The correct wording of this paragraph is as follows: in terms of the number of possible (taken into consideration) states (operability-wise), items are classified as: items that, in the course of operation, can be in two states, i.e., up or down, and items that, apart from the two above states, can be in a number of partially up/down states initiated by partial failure.

Additional explanations concerning the ERR are given in Annex A that is identical to that in [16]. It states that the ERR is a generalized term denoting a group of measures used in a number of industries with their own names, designations and definitions. Unfortunately, several probabilistic measures are erroneously listed among the examples: "probability of specified output of a certain quality per work shift (month, quarter, year)" for process systems, "probability of mission program completion" by a spacecraft, "probability of typical mission (flight mission) performance within a given time" by a plane. The error is that dependability and ability to perform a task (program, mission, etc.) must be distinguished. That matter was discussed in detail in [19]. Indeed, an item's ability to perform a task may depend on factors that are not related to its dependability. For example, a completely operable aircraft may fail to complete a task (flight mission) due to adverse weather conditions or improper actions by ground services. However, as noted above, the probability of task (program, mission, etc.) completion may be an effectiveness indicator used for determining the ERR .

GOST R 27.010-2019 (IEC 61703:2016) and IEC 62673:2013

Standard [20] is based on the IEC standard [21] and is its modified version. It contains item 6.1.2.4 entitled "Extending the concept of availability factor to items with multiple states". It examines systems whose states, as pointed out above, "cannot be classified as up and down only, and more accurate classification is required". It is noted that "this is especially common for the production of outputs, including oil, gas, electricity, water, etc." For such systems, a measure is defined that is described as "a generalization of the average availability factor and the mathematical expectation of performance often called the "production availability" of a system. More broadly, it is also called the item performance". A simple example is given for a production system, for which this measure is calculated along with the conventional availability factor.

In this case , the standard refers to monograph [22]. In its preface, the authors express their gratitude to their teacher and friend, I.A. Ushakov, but while presenting the basic concepts associated with multi-state systems, they use only one example out all his works, the one taken from [6].

In fact, the measure examined in the above item in [20, 21] is an ERR . Unfortunately, in [20], this fact is not even mentioned. It is clear that [20] is based on the IEC standard. However, that is a modified standard. The changes are that references to international standards are replaced with references to national standards. The above item 6.1.2.4 should also have been amended to indicate that it refers to ERR . The reference to [22] should be replaced with a reference to a Russian subject matter publication, preferably [8].

In general, the reference list in [20] should have been further modified. The American version of [1] in English should have been replaced with the original Russian version. A number of books on the list have been translated into Russian (by R. Barlow and F. Proschan, W. Feller, D.R. Cox). The Russian publications should have been referenced instead, which would be much more convenient for the Russian users of the standard.

As a side note, we would like to make another observation regarding many standards developed on the basis of international standards. We are talking about the discrepancy with other dependability-related standards in terms of terminology and notations. In particular, in [20], the availability factor is designated as *A*, although in Russia it is conventionally designated K_r, which is stipulated in standard [12]; for continuously operating item and intermittently operating item English abbreviations (COI and IOI) are used instead of Russian ones set in [12], etc. In such situations, one would want to follow suite of the authors of [23] and exclaim "What to believe?" It is clear that there is a conflict between the principles of continuity and proximity to international standards [24], but the standard developers must find a reasonable middle ground. For instance, the dependability measures and types of items could be designated according to both the international and Russian convention (as it is done for physical values in [25]).

Another IEC standard, in which the ERR is implied is [26] (you can learn about it in [27]). It is dedicated to the dependability of communication networks, the feasibility of the ERR's application to which was shown in [28–31]. In [26], it is recommended to use two measures, i.e., end-to-end network availability and full-end network availability designed to assess dependability from the point of view of the end users and network operator/service provider, respectively. The former is the availability factor of a node-to-node connection and the latter is the weighted sum of such availability factors for different pairs of nodes and actually turns out to be the ERR [27, 30, 31].

Conclusion

One of the achievements of the Russian school of dependability that should not be forgotten is the definition and development of the ERR calculation and evaluation methods. Our representatives in the IEC TC 56 should make efforts to incorporate this measure into international standards, especially since they already implicitly imply it. This challenge is motivated by one of the goals defined in Article 3 of the Federal Law FZ-162 "On Standardization", i.e., to promote the integration of the Russian Federation into international standardization systems as an equal partner.

Unfortunately, interstate standards contain inaccuracies as regards ERR . Specifically, in GOST 27.002-2015, the wording associated with the terms "partial failure" and "partially up/down state" are to be clarified. In GOST 27.003–2016, it is required to make corrections to the wordings in the classification of items in terms of the number of possible (taken into consideration) states and in the examples of possible ERR variants in various branches of technology that are probabilities of task completion, etc. The paper suggests the appropriate adjustments.

The Russian standard GOST R 27.010–2019 developed on the basis of an IEC standard does not fully comply with the above basic standards for dependability and ignores the Russian ERR developments. In general, speaking on the subject of Russian and interstate standards created on the basis of international ones, one should remember the words of I.A. Ushakov written by him while the draft of one of those documents was being discussed: "The basic idea of the domestic standard is not to follow blindly the letter of the IEC recommendations, but to ensure the most complete conformity to the spirit of these recommendations, yet be sure to capture the immense domestic experience in the theory and practice of dependability and over half a century of domestic technical documentation and scientific and technical literature." We would like to direct this message to all standard-makers.

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The author’s contribution

Netes V.A. analysed interstate, Russian and international dependability-related standards in terms of definitions and other wordings related to the effectiveness retention ratio and related concepts (partial failure, partially up and partially down states), identified existing shortcomings and suggested corrections.

Conflict of interests

The author declares the absence of a conflict of interests.