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CONTENTS

Dear readers and authors!

In accordance with the Journal's tradition, the first issue of the year features an item by the Editor-in-Chief. In it, the Editorial Board and Council sum up the past year's activities and present the Journal's key objectives for the year ahead. The past year proved to be extremely hard for the humanity. It brought an enormous number of difficulties and suffering. The pandemic took many lives. It created significant problems for the development of industry, science and education. That affected the number of papers submitted to the Journal for publication. Nevertheless, the Editorial Council not only maintained, but also improved the quality of the paper review process, which contributed to the Journal's higher rating and prospects of its inclusion into Scopus and Web of Science. The applications have been made and are being considered. A favourable decision is furthered by the provision of free access to the electronic version of the Journal, double reviewing of papers, significant extension of the scope of the covered matters of science and technology.

In the current year, it is proposed to engage into a wider discussion of the dependability-related terminology, e.g., in the area of functional dependability, including the matters of reliability of specialist training. In the past year, the contributors showed great interest in this subject matter. Safety-related discussion is to start as well. A great deal of attention will be given to the terminology of functional, industrial, fire, environmental safety, as well as information security in transportation.

The Journal's focus of attention, as always, is the analysis and synthesis of structural and functional dependability of technical and social systems, safety of fixed and mobile entities, risk management. Of special interest are the matters of risk assessment amidst incomplete and/or insufficiently reliable information.

This year, a significant attention is to be given to the application of methods and algorithms of artificial intelligence for the purpose of prediction and estimation of the state of dependability and safety of complex technical and social systems. Priority will be given to papers dedicated to big data processing using Data Sciences technologies as part of solving the above problems.

We are hoping for a strong partnership with the readers and authors. We wish you further creative success.

Editor-in-Chief, Dependability Journal
I.B. Shubinsky

A method of accounting for censored items as part of fatigue testing of composite materials

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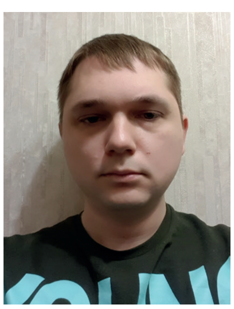

Sergey A. Smelov

Yulia V. Suslova

Abstract. *The* **Aim** *of the paper is to create a method for including information on censorship for the purpose of adjusting the estimates of the S-N diagram of composite materials. Censored items are such items that did not fail by the end of testing, for which a certain operation time has been registered. It must be noted that, currently, researchers often ignore the operation time data of the items that did not fail by the end of testing, which does not appear to be justified in terms of cost saving and reliability of statistical conclusions. Censorship information is very important in terms of assessing durability. It only needs the right tool to use it. The proposed* **Method** *consists in bootstrapping-based simulation, a method from the group of computer-intensive methods. In the process of the method's development, the previously used approaches (for instance, as regards metals) were considered. In the examined example of the method's application, the data was taken from literary sources.* **Results.** *The paper shows an example of fatigue testing conducted by the authors that produced a large number of censored items. The results obtained using the method were compared with real data. It is shown that the quality of statistical estimation improves with the use of the method. The paper sets forth certain observations regarding the mechanical testing tool for quality control. The source of data dispersion associated with fatigue testing is discussed.* **Conclusions.** *The application of the method will help include the information on censored items in the estimation of the S-N diagram. For scientists who are involved in the experimental research of the fatigue resistance of composite materials, the suggested method might prove to be quite useful. It takes into consideration the characteristic features of the strength analysis of composite materials (large properties dispersion and absence of unlimited fatigue range). The method will allow taking onto account an important, but not always so far used information on the items that operated a certain number of cycles, but did not fail.*

Keywords: *polymer composite, properties dispersion, fatigue, censored samples, bootstrapping.*

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1. Introduction

The research of the mechanical properties of polymer composite materials (PCM) shows that they have serious advantages over the conventional structural metals and alloys that are mainly due to high specific characteristics of static strength. A polymer composite is a multiphase material, in which the reinforcement fillers are integrated with a polymer matrix, which causes synergistic mechanical properties that cannot be achieved by any of the individual components. At the same time, thanks to the scientific and technical progress, the cost of manufacture of various composite materials are on a continuous decline, while the quality is improving. Thus, this type of materials finds new applications. Due to the growing use of composite materials [1], currently, priority is given to quality requirements. Some advanced testing methods are successfully applied not only for technical state diagnostics but also for quality control [2, 3].

In [4, 5], the experience of application of advanced methods of nondestructive (NDI) and destructive inspection is described. Among other things, the items made of composite materials were submitted to Through Transmission Ultrasonic NDI (TTU) control that generated C-scans for quantitative estimation of flat damaged areas using image analysis software. Additional methods of inspection, e.g., microscopy and thermal imaging are also used in the research of damage resistance. Such extended capabilities may provide additional information on censored items [4]. In [6], the authors noted certain causes affecting the quality and reliability of the estimated values that do not allow obtaining stable and reliable physico-mechanical values. In [6], the focus is on the deformations of the manufactured items and type of their physico-mechanical failure.

Along with modern physical methods (see, e.g., [5]), of unchanging relevance in the context of quality analysis of composite materials is the research of the mechanical characteristics of entities, such as strength in static testing (tension, compression, shearing), stiffness (elasticity modulus). In [7], the shearing strength of carbon-reinforced composite materials was tested for the purpose of outlier analysis of the shearing strength values of items made of composite materials. Fig. 1 shows box-and-whisker diagrams [7, 8] for several batches of items. A significant dispersion can be observed even within a single batch. The aim of the research [7] was to develop a method of outlier removal. In this particular example, the indicator τ = 83.9 MPA was assumed to be an outlier, which meant that this value was subsequently removed and was not used for further analysis.

The fatigue strength characteristics stand apart. Despite the fact that composite materials are more and more frequently used in aircraft, spacecraft and other products exposed to repeated loads, there is still an opinion that the static strength of composite materials is a sufficient indicator of strength. That is partly due to the fact that, in reality, the slope of the S-N diagram m of items made of composite materials is indeed very high as compared with the similar value for metals. If for metals, the value m = 5 ... 9 (indicator of the slope of the S-N diagram) is typical, in composite materials an m = 15 can often be observed. Such a high value of m primarily implies a significant scatter of the fatigue properties, not surprisingly. For composite materials, a large dispersion is the case for static characteristics as well (see Fig. 1), and, as noted above, fatigue always increases dispersion [9]. Two important factors increase the dispersion of the fatigue characteristics of composite materials. First, even during static testing, the strength of composite materials demonstrates a large dispersion as compared with metals. Second, fatigue-related dispersion is always higher than during static testing.

This research involved compression tests on small-size items. Fig. 2a shows the initial item, 2b shows the item that failed as the result of fatigue testing. The items were made of carbon fiber and binding substance based on epoxy and phenolformaldehyde resins normally used in the manufacture of aircraft and spacecraft products and components. At the first stage, the items were submitted to static compression testing. Table 1 shows the summary of the static $\sigma_c^{\text{в}}$ compression testing. The variation coefficient is quite high: V = 0.25, which indicates low stability of properties.

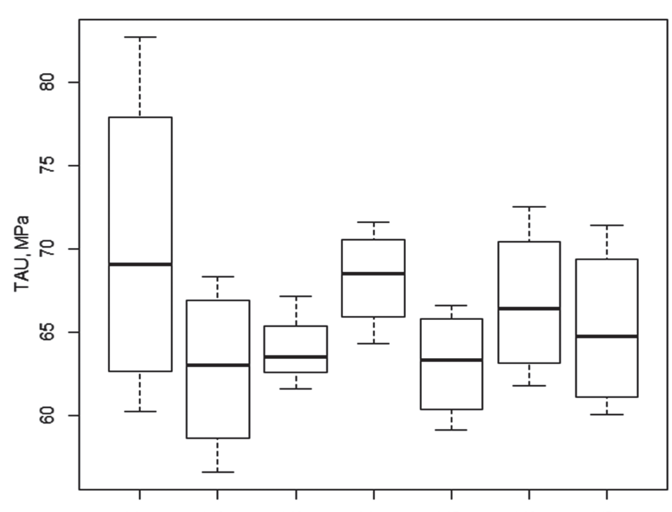
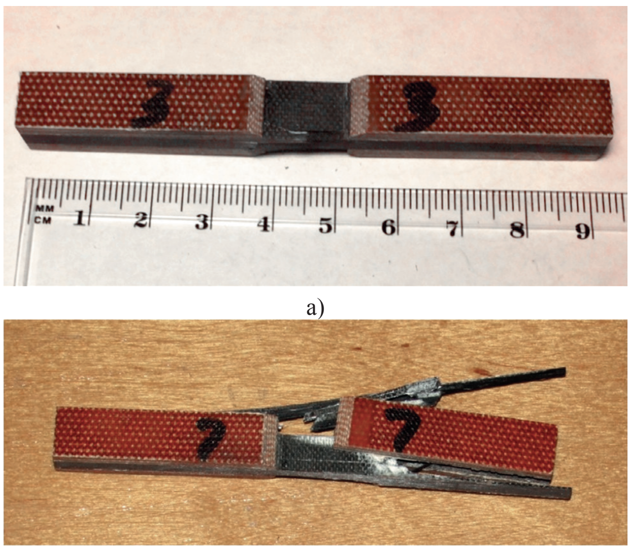


Fig. 1. Box-and-whisker diagrams for several batches of composite materials [7]

Table 1. Report on compression tests (static) $\sigma_c^{\text{в}}$

Mean $\sigma_c^{\text{в}}$	701.3	MPA
MSD	175.0	MPA
Variation V	0.25	



a)

b)

Fig. 2. Small-size item made of carbon fiber for compression testing. a) before testing; b) after fatigue failure

The item after fatigue failure, is shown in Figure 2b. It demonstrates a destruction with disrupted connections between fibers. The fiberboard pieces also show partial destruction. As such failure of the tested items is quite common, this result in terms of fatigue (specifically, item no. 7, figure 2b) was included in the general table.

Fig. 3 shows preliminary fatigue testing data:

The results shown in Fig. 3 demonstrate not only a large dispersion, but also an extremely high rate of censorship, i.e., the presence of a large number of items that did not fail by the end of testing. This figure can, very conditionally, be called an S-N diagram. It is more of agglomerated data that remotely indicate the presence of a dependence between the number of cycles and the range of stress. The high dispersion may be associated with: a) small size of the items that does not ensure the averaging of the properties with respect to the width; b) deformation of fibers; c) uneven compression at the stage of fabrication.

Conclusion: special methods are required in order to account for the censorship while constructing S-N diagrams of items made of composite materials.

2. Accounting for information on censorship (interruptions)

Fatigue testing of composite materials of various types, as well as the behaviour of materials under cyclic loads is the focus of attention of many researchers [10 – 14]. As it was noted above and based on common sense, it can be concluded that the information on the interruptions (censorship) should be somehow included into statistical conclusions. That would improve the statistical data on fatigue. Indeed, we know that a specific item (that did not fail by the end of the test cycle) has endured a certain (large!) number of cycles without breaking. It probably did not break before

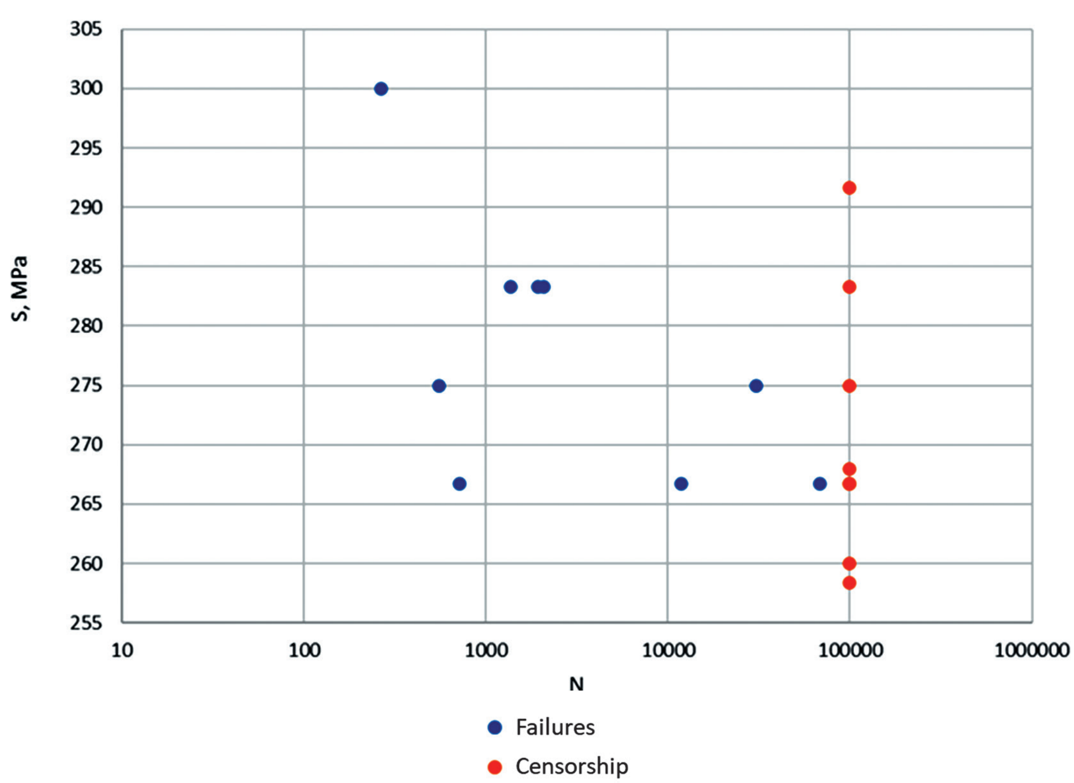


Fig. 3. Results of fatigue testing involving compression of small-size samples made of carbon fiber

the target number of cycles due to 1) a combination of individual positive strength characteristics of the item; or 2) unreasonably low selected stress amplitude σ_a. The normally recommended stress range for the first fatigue test is $\sigma_a = 2^{-1}$ (0.75… 0.85) $\sigma_c^в$, where $\sigma_c^в$ is the average value of the limiting compression stress evaluated based on 6 or 5 items. It can be stated that in the process of evaluation of $\sigma_c^в$ also an error is quite possible (see Table 1).

The problem of censored items also exists in the context of processing of fatigue testing results of metals. In [15 – 17], the problem of censored welded metal items is examined. The authors believe that their items have an unlimited fatigue endurance σ_∞. That complicated the problem even further. They try to estimate the fatigue endurance σ_∞ based on the information on the samples that did not fail before the target number of cycles. In order to solve the problem, they use the maximum likelihood method (MLM) (the method of estimation of population parameters, e.g., regression coefficients) for the purpose of estimating the values with the highest probability of obtaining the observed data.

There is a basic linear relationship between lg σ_a and lg N in the form of Basquin's equation:

$$\lg N = \lg A - m \cdot \lg \sigma_a, \tag{1}$$

where m is the indicator of fatigue (slope), while lg A is the point of intersection. Here, σ_a is the stress range, normally [MPA], while N is the number of cycles to failure (or another failure criterion in case of composite materials testing).

The most detailed research of the fatigue durability of composite materials used in aircraft can be found in [4]. Following the conclusions of an earlier work [17], the authors [4] use the Weibull distribution not only for the purpose of analyzing dispersion, but also for complementing information on the items broken in the process of cyclic loading with information on 1) static testing; 2) censored items. The concept of Load Enhancement (consisting in increasing the maximum allowed loading by taking into account the information on censored items) is widely used in [4]. Fig. 4 shows the S-N diagram from [4]. The information in Fig. 4 will be further used in the appraisal of the developing method.

Earlier there were no research aimed at directly estimating σ_∞ in composite materials (e.g., through ladder method) [10]. Fortunately, the times have changed; new testing methods appeared, and researchers started delving into gigacycle fatigue, i.e. $N > 10^8$ cycles [18]. In order to speed up the testing, special ultrasound machines have been developed [19]. This novel approach to testing allowed (although not without certain doubts) shedding light on whether σ_∞ exists in composite materials.

Fig. 5 shows the test results [19] of carbon fiber reinforced composite materials (CFRP) that are widely used in the aerospace industry. The tests were conducted with the asymmetry of R = 0.2 and (please note) frequency of 965 Hz. For that testing method, a special cooling system was developed. Fig. 5 shows that the curve $\sigma_a - N$ goes down even when the number of loading cycles is above 10^6. In Fig. 5, a plateau may be seen between 10^7 and 10^8. When the number of cycles is above 10^8, the fatigue strength continues to decline. The authors conclude that the S-N diagram $\sigma_a - N$ does not have an unlimited fatigue endurance σ_∞ similar to the one that can be observed in metals.

3. Method

The method was developed for improving the quality of linear regression of the S-N diagram (1) through special accounting for censorship. The assumptions underlying the developed method: 1) there is no unlimited fatigue endurance for composite materials; 2) equation (1) is correct if lg(σ_a)

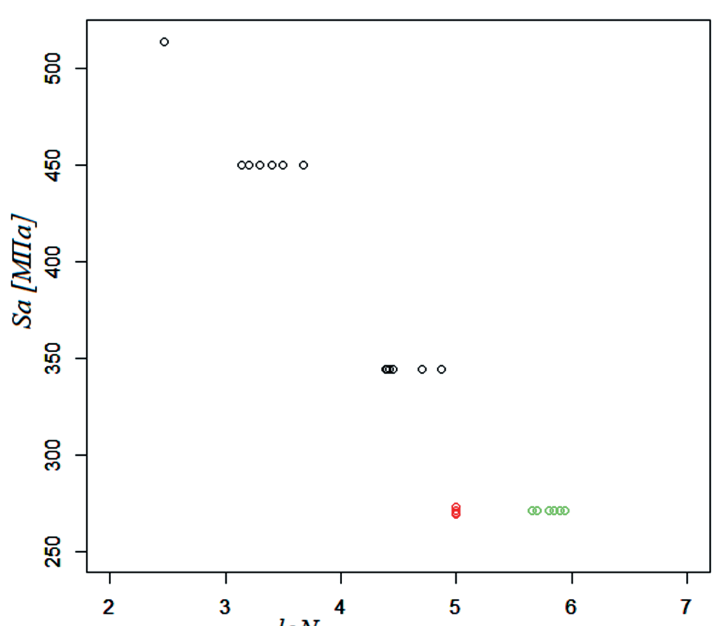


Fig. 4. S-N diagram of the AS4-PW composite material (according to [4]) (failures are marked in black and green, the red dots mark the conditionally censored samples; details below)

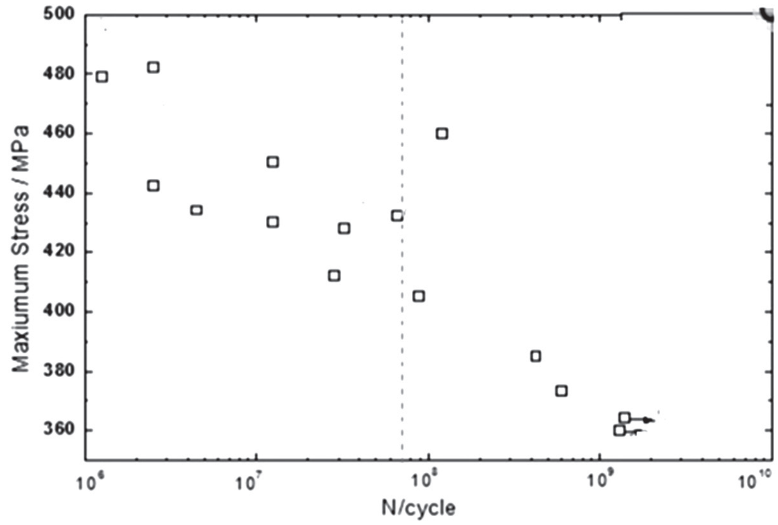


Fig. 5. Gigacycle fatigue of a composite material carbon fiber / epoxy resin [19]

is adopted as an independent variable (factor) and lg (N) as the function (dependent variable, normal distribution). As a reminder, historically, the S-N diagram is always mapped alternatively: the horizontal axis for lg(N) and vertical axis for lg(σ_a). Similarly, in this paper, the S-N diagrams are mapped in this way on graphs. During the estimation of regression coefficients, correctness is reestablished, i.e.: $y \to \lg(N)$ and $x \to \lg(\sigma_a)$.

Let us assume that there are p pairs of values σ_a, N, that are recorded failures during fatigue tests. We also have q censored tests at the lower level of σ_a*, for which only the number of tested items and their times to censoring are known.

As the limit number of cycles to completion of testing, the conventional $N_b = 10^5$ (target number of cycles of fatigue tests) was preliminary adopted. This type of data limitation is called single right censoring. This type of censorship takes place when a subject is removed from the research before an event occurred or when the research concludes before an event occurred. Unlike in operational dependability tests in service, when the times to censorship differ [20], in fatigue tests, all the censored elements usually have the same life, namely the target number of test cycles N_b.

In order to recover the lost data on the potential durability of non-failed q items in accordance with the developed method, it was proposed to create the bootstrap samples [20, 21]. Each bootstrap sample consists of p elements selected in a special random order. Based on the original sample, it appears to be possible estimating the regression equation of the form (1) using the least square method. The bootstrap sample consists of the same number of pairs (lgσ_a, lg$N$) and from the same pairs, but with a different probability of occurrence. The j-th bootstrap sample is generated through a random selection with replacement. Table 2 shows an example of selection of six possible combinations from 10 pairs in the original sample for bootstrap samples per the method's rules, according to which the random selection is done with replacement [21]:

The indices in Table 2 are related to the information on lg σ_a and lg$N$. For each j-th sample, a regression equation is derived. In this example, we have 6 equations with unique coefficients lg A and m in equation (1). Using those 6 equations, we can obtain 6 extrapolated values of N_i, i = 1… 6 for σ_a*, and all of them will be different. Believing those values to be relevant, at the next stage we include them in the adjusted estimate of the S-N diagram and obtain improved statistical parameters of the S-N diagram.

The method is further explained using an example.

The data for this example are taken from [4]. In Fig. 4, some points are shown in black (failures), p = 13, while some are shown in red (censored, q = 6). The green points in the figure show the "as though unknown failures" if the operation time $N > 10^5$. They were conditionally deemed unknown, as for the purpose of method appraisal it was initially deemed that testing was conducted for up to 10^5 cycles. Using the failure data and the least square method, the S-N diagram equation was estimated based on 13 points (Fig. 4, black points):

Table 2. An example of selection of six random indices for bootstrap samples based on the original sample.

j	1	2	3	4	5	6	7	8	9	10
1	6	7	7	8	4	7	6	3	9	1
2	4	2	4	4	2	8	3	5	9	4
3	1	8	7	3	5	3	10	2	2	10
4	6	1	2	7	9	2	1	10	9	2
5	7	10	8	10	6	2	8	2	5	1
6	3	6	3	7	3	5	1	3	9	6

$$\lg N = 39.49 - 16.94 \lg \sigma_a \quad (2)$$

After a bootstrap simulation, we obtained 6 additional breaking points N_i , $i = 1\ldots6N_i$, $i = 1\ldots6$ if $\sigma_a^* = 112$ MPA.

4. Analysis of the results

In Fig. 6, the normal probability graph (the "qqplot" function [22]) shows two distributions of the random durability values lg N for the items tested at σ_a*=112 MPA. One distribution (shown in blue) was obtained for real values obtained in [4]. Let us reveal a secret. In reality, the experiment was conducted up to $N_{b=}10^6$ cycles, and the cluster of points marked in red in Fig. 4 was adopted in the censored form for the purpose of method appraisal. Marked in red are those obtained using the above method, i.e. the bootstrapping distribution. As we can see, the distributions match well. The measures of distributions shown in Table 3 also demonstrate good concordance.

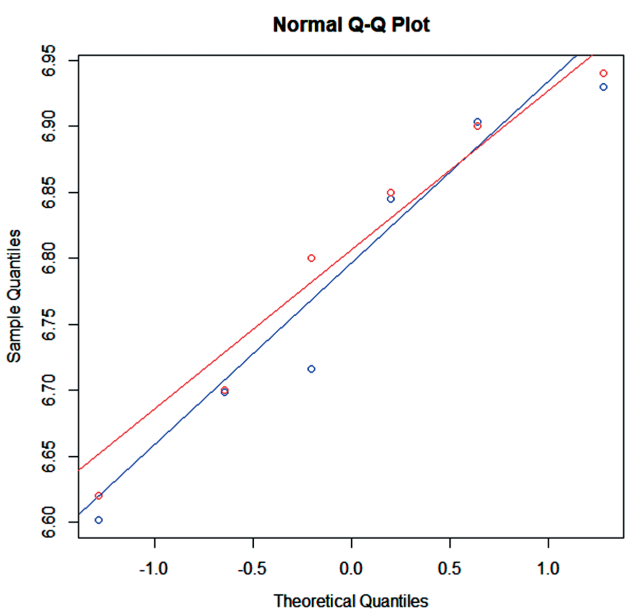


Fig. 6. Distribution of random value lg(N). Marked in blue is the natural distribution; marked in red is the one simulated for those tested under the range of $\sigma_a = 112$ [MPA]

Table 3. The parameters of experimental and model samples for random value lg N (σ_a) for those tested under the rate of σ_a = 112 [MPA]

	Experimental sample	Simulated sample
mean	6.78244	6.801667
RMS	0.129617	0.122052

Upon the acquisition of 6 additional points, the S-N diagram's equation was updated:

$$\lg N = 39.23 - 15.82 \cdot \lg \sigma_a \quad (3)$$

The quality of the regression equation can be characterized by the coefficient of determination R^2:

$$R^2 = D((y))\hat{}\,/\,D(y) = 1 - D(e)\,/\,D\,(y) \quad (4)$$

where D (y) is the total sum of squares; D (e) is the dispersion of the model predictions.

Based on (4), the coefficient of determination for original curve (2) is: $R^2 = 0.909$, while for the adjusted curve (3) it is: $R^2 = 0.941$, therefore, it can be stated that an improvement was made.

5. Conclusions

The paper discussed the causes and methods of dispersion analysis of strength tests of composite materials, both under statistic, and fatigue loading. Based on the recent years' research, both in the area of metal, and composite materials fatigue, a method of regression equation improvement was developed. Using the developed model, the method takes into consideration the censorship results. The simulation ~~is~~ was based on statistical bootstrapping. Using the example of actual testing quoted in literature, the applicability of the proposed method was shown.

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The authors' contribution

Gadolina I.V. conducted the experiment, ensured the repeatability of the fatigue tests.

Maydanov I.S. conducted the research literary sources, defined the problem.

Smelov S.A. prepared tests specimens, supervised the quality of their manufacture, verified the geometrical parameters.

Suslova Yu.V. processed the results, prepared the article.

Conflict of interests

The authors declare the absence of a conflict of interests.

Original article
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A method of using the transitive graph of a Markovian process as part of ranking of heterogeneous items

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Abstract. *Hierarchy analysis developed by Thomas Saaty is a closed logical structure that uses simple and well-substantiated rules that allow solving multicriterial problems that include both quantitative, and qualitative factors, whereby the quantitative factors can differ in terms of their dimensionality. The method is based on problem decomposition and its representation as a hierarchical arrangement, which allows including into such hierarchy all the knowledge the decision-maker has regarding the problem at hand and subsequent processing of decision-makers' judgements. As the result, the relative degree of the interaction between the elements of such hierarchy can be identified and later quantified. Hierarchy analysis includes the procedure of multiple judgement synthesis, criteria priority definition and rating of the compared alternatives. The method's significant limitation consists in the requirement of coherence of pairwise comparison matrices for correct definition of the weights of compared alternatives. The* **Aim** *of the paper is to examine a non-conventional method of solving the problem of alternative ratings estimation based on their pairwise comparisons that arises in the process of expert preference analysis in various fields of research. Approaches are discussed to the generation of pairwise comparison matrices taking into consideration the problem of coherence of such matrices and expert competence estimation.* **Method.** *The methods of hierarchy analysis, models and methods of the Markovian process theory were used.* **Result.** *The paper suggested a method of using the transitive graph of a Markovian process as part of expert ranking of items of a certain parent entity subject to the competence and qualification of the experts involved in the pairwise comparison. It is proposed to use steady-state probabilities of a Markovian process as the correlation of priorities (weights) of the compared items. The paper sets forth an algorithm for constructing the final scale of comparison taking into consideration the experts' level of competence.* **Conclusion.** *The decision procedures, in which the experts are expected to choose the best alternatives out of the allowable set, are quite frequently used in a variety of fields for the purpose of estimation and objective priority definition, etc. The described method can be applied not only for comparing items, but also for solving more complicated problems of expert group estimation, i.e., planning and management, prediction, etc. The use of the method contributes to the objectivity of analysis, when comparing alternatives, taking into consideration various aspects of their consequences, as well as the decision-maker's attitude to such consequences. The suggested model-based approach allows the decision-maker identifying and adjusting his/her preferences and, consequently, choosing the decisions according to such preferences, avoiding logical errors in long and complex reasoning chains. This approach can be used in group decision-making, description of the procedures that compensate a specific expert's insufficient knowledge by using information provided by the other experts.*

Keywords: *Markovian process, expert assessment, transitive graph, ranking, incomplete comparisons.*

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Introduction

In many cases, problems that require expert evaluation imply the involvement of many experts, which, in turn, imposes special requirements on the procedure of integration of estimates and their reliability. In most decision-making tasks there are procedures that allow combining the opinions of several experts regarding the alternatives presented to them [1, 2, 3]. As each expert has a unique experience, the opinions of various experts may significantly differ (indeed, there are many factors that affect an expert's preferences). This variety of expert assessments may cause a situation where some of them are unable to adequately express any degrees of preference by comparing two or more available alternatives. Additionally, the need arises to use the opinions of various experts, which causes another serious source of estimate inconsistency, i.e., the effect of disagreement between the experts' opinions. Sometimes, in a bid to ensure the agreement of comparison, estimates that significantly differ from average are discarded, but Little and Millet [4, 5], as well as Nogin [6] have shown that eventually that may cause the loss of influential common factors. In some cases, the expert polling procedure can be modified [10, 11]. The applicability and efficiency of individual approaches, in principle, depends on the number of gaps in data and reasons of their occurrence [12]. However, Carmone et al. [13], using a specific example, have shown that a "random removal of up to 50 percent of comparisons provides good results with no loss of accuracy". In this case, generalizing the results is incorrect; they rely on a priori knowledge of the complete matrix of pairwise comparison, which is practically impossible. There are approaches that, provided the availability of an incomplete matrix of pairwise comparison, enable methods that allow completing the matrix, which is confirmed by a number of researchers [14]. A system that helps build fuzzy preference relations was suggested in [15, 16]; a similar method is also described in Russian sources [17]. Group decision-making, description of procedures that correct the absence of knowledge in a specific expert using information provided by the other experts, along with some aggregation procedures can be found in [18 – 20].

1. Problem definition

The complexity of comparative estimation (ranking) of heterogeneous items of a certain set consists in the fact that each item is normally characterized by not one indicator (process-specific characteristics, certain intrinsic attributes, factors, pricing parameters, etc.), but several ones, whereby such indicators often vary in their nature.

In the general case, it is required to arrange all the items x_k (k=1, …, n) of a certain set G or define the rank (weight) of such items in set G, i.e., define preference correlations between the items $x^1 \succ x^2 \succ ... \succ x^n$.

Due to the insufficient amount of information on the compared items, the ranking problem is often solved with the involvement of experts that, upon a meticulous informal analysis, specify an order of preference for such items.

In this case, when the number of comparison parameters is high, it is very difficult for an expert to analyze them, which causes the requirement for item ranking methods that do not require significant calculations and are based on much simpler expert estimates. Such methods are to allow "combining" often contradictory pairwise comparative estimates of experts.

2. Method of solution

Let us briefly describe the essence of the suggested method of processing of expert estimates. A pairwise comparison matrix can be represented in the form of a connected graph with N nodes and two edges between a pair of nodes, with one characterizing the transition from the i-th state into the j-th state at the rate of ε_{ij}, while the other one characterizing the transition from the j-th state into the i-th at the rate of ε_{ji}. For instance, if two items compared, and the weights of items no. 1 and no. 2, in the first expert's opinion, are equal to 1 and 2, respectively, the Markovian network constructed for such case is shown in Fig. 1.

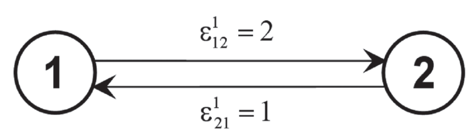

Fig. 1. Markovian process of comparing two items

The final state probabilities are equal to, respectively, $p_1^1 = \dfrac{\varepsilon_{21}^1}{\varepsilon_{12}^1 + \varepsilon_{21}^1} = \dfrac{1}{3}$ and $p_2^1 = \dfrac{\varepsilon_{12}^1}{\varepsilon_{12}^1 + \varepsilon_{21}^1} = \dfrac{2}{3}$, while their correlation is 1:2. This simple reasoning allows us, out of a paired preference, finding the transition rates for such graphs: $\dfrac{p_1^1}{p_1^2} = \dfrac{\varepsilon_{21}^1}{\varepsilon_{12}^1}$. The values of ε_{ij} are chosen subject to condition $\sum_{i,j=1}^{n} \varepsilon_{ij} + \varepsilon_{ji} = 1$.

Let us continue our reasoning. Let us assume that the second expert estimated the rates for the same pair of items at ε_{21}^2 = 3 and ε_{12}^2 = 1 respectively. If both experts have identical "confidence coefficients" ("weights"), i.e., $\omega^1=\omega^2=\omega=0{,}5$, then, obviously, the "compromise" rates will equal $\varepsilon_{21}^* = \omega^1 \cdot \varepsilon_{21}^1 + \omega^2 \cdot \varepsilon_{21}^2 = 0{,}5 \cdot \varepsilon_{21}^1 + 0{,}5 \cdot \varepsilon_{21}^2$ and $\varepsilon_{12}^* = 0{,}5 \cdot \varepsilon_{12}^1 + 0{,}5 \cdot \varepsilon_{12}^2$. Generalizing the above reasoning for a larger number of experts and accounting for their "weights" is trivial.

After the design has been constructed, a standard final probabilities calculation is conducted for process states [21, p. 404].

In order to calculate the final probabilities, Kolmogorov-Chapman equations can be used as well:

$$\begin{cases} \dfrac{dp_1}{dt} = \left(\varepsilon_{12}p_2 + \ldots + \varepsilon_{1n}p_n\right) - \left(\varepsilon_{21}p_1 + \ldots + \varepsilon_{n1}p_1\right), \\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots, \\ \dfrac{dp_n}{dt} = \left(\varepsilon_{n1}p_1 + \ldots + \varepsilon_{nn-1}p_{n-1}\right) - \left(\varepsilon_{1n}p_n + \ldots + \varepsilon_{n-1n}p_n\right). \end{cases}$$

Let us note that, provided all pairwise estimates are available, comparing N items (i.e., ranking on the number axis) only requires compliance with the requirement of the transitive nature of the transition graph of the Markovian process. An example of such graph is sown in Fig. 2.

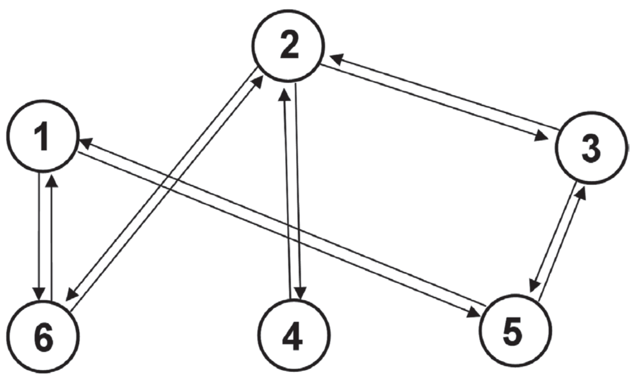

Fig. 2. Transitive graph of a Markovian process for the case of six items estimation

For the sake of specificity, let us examine the case of ranking of six items. Three experts were polled. Let each expert do all the possible pairwise comparisons of items. For each expert, according to the above method, a complete graph of a Markovian process can be constructed and all steady-state probabilities of states can be calculated. Let us assume that such probabilities will be the "weights" of the items defined by the experts. Then, the final probabilities are calculated for the "integral" graph, where the transition rates are just the average of all the rates (the "weights" of experts are assumed to be $1/N$, N being the number of experts).

3. Estimation of the degree of expert incompetence

Thus, let us examine a case of estimation of six items (i=1, …, 6) by three experts (k=1, 2, 3). The results of estimation (final probabilities p_i^k) are shown in Table 1.

Table 1. Estimation of six items by a group of three experts

Name of item	Experts		
	1	2	3
Item no. 1	1	2	3
Item no. 2	2	1	1
Item no. 3	5	4	5
Item no. 4	4	5	4
Item no. 5	3	3	6
Item no. 6	6	6	3

Calculating the corresponding average values of expert estimates:

$$\overline{p}^k = \frac{1}{6}\sum_{i=1}^{6} p_i^k. \tag{1}$$

The dispersion of expert estimates is, respectively:

$$\begin{aligned} D^1 &= \frac{1}{6}\sum_{i=1}^{6}\left(\frac{p_i^1 - \overline{p}^1}{\overline{p}^1}\right)^2, \\ D^2 &= \frac{1}{6}\sum_{i=1}^{6}\left(\frac{p_i^2 - \overline{p}^2}{\overline{p}^2}\right)^2, \\ D^3 &= \frac{1}{6}\sum_{i=1}^{6}\left(\frac{p_i^3 - \overline{p}^3}{\overline{p}^3}\right)^2. \end{aligned} \tag{2}$$

As the experts use different scales for the purpose of estimation, some relative values are allowable. The object of further research is the estimate of the measure of spread for non-significant and significant items, as the experts may have the corresponding "specialism". In other words, the confidence in the experts (their final "weights") may depend on the item category.

The following procedure is suggested:

a) for each expert, individual "coordinated[1] weights" of items are found from the graph with specified rates (p_i^k);

b) the same operation is repeated for a model, where all transition rates are equal to the average values of the respective rates for all experts ($\overline{p}^k$);

c) for each expert, the following value is calculated:

$$\delta^k = \sum_{1\le k\le n} (p_i^k - \overline{p}^k)^2. \tag{3}$$

The higher is the value, the lower is the confidence in the expert's opinion.

4. Definition of expert weights

Given (3), the adjusted "weights" of experts can be found according to formula

$$w^k = \frac{1-\delta^k}{6 - \sum\limits_{1\le j\le n}\delta^j}. \tag{4}$$

Let us plot a random graph with rates on the edges of, respectively

$$\overline{\varepsilon}_{ij} = \sum_{1\le k\le 6} w^k \varepsilon_{ij}^k. \tag{5}$$

[1] The weights are called coordinated, as the same expert may provide contradictory pairwise estimates, e.g., $A > B$, $B > C$, but $C > A$.

Table 2. Item estimates

Name of item	Experts			Final weight of items	Rank of items
	1	2	3		
Item no. 1	1	2	3	2.0865	2
Item no. 2	2	1	1	1.4398	1
Item no. 3	5	4	5	4.9662	5
Item no. 4	4	5	4	4.6429	4
Item no. 5	3	3	6	4.1729	3
Item no. 6	6	6	3	5.4361	6
Average estimate	3.50	3.50	3.67		
Dispersion	0.2380952	0.2380952	0.1900826		
Sigma	17.50	17.50	15.33		
Weight of expert	0.3721805	0.3721805	0.3233083		

The results of calculations per formulas (1) to (5) are shown in Table 2.

Further, the above algorithm repeats: the state probabilities, dispersions and new "weights" of experts are calculated. At the same time, a procedure should be provided to eliminate the experts that show a dispersion of estimates above a certain threshold (in other words, incompetent in the subject matter).

5. Final scale construction

For the purpose of building the final scale, let us use the procedure that is a modified algorithm of the Delphi method[1]. In general, the Delphi algorithm is a process, as the result of which the group members (independent experts) come to a consensus in relation to certain events with no face-to-face discussions. This contributes to independent thinking on part of the group members, prevents direct confrontation between the participants and does not allow them defending their opinion by imposing their views upon other experts of the group. Importantly, looking for a solution using this method allows taking into consideration minority opinion, whereby in individual cases it may play a decisive role.

This method is the most formal out of all methods of expert prediction and is most often used in technological forecasting, of which the data are later used in the planning of products manufacture and sales. This is a group method, whereas a group of experts is individually polled regarding their assumptions on future events in various areas, where discoveries or improvements are expected. Polling is done with the use of special questionnaires anonymously (personal contacts between experts and collective discussions are not allowed).

The obtained answers are summarized and the results are sent back to group members. For that purpose, the average and weighted average values of the examined parameter are calculated, the median is defined as the medium term of the general series of estimates obtained from the experts and the confidence area[2].

Based on that information, the group members (while remaining anonymous) express further assumptions, whereby this process may repeat several times as part of the so-called multi-tour polling procedure.

The experts can be conventionally divided into three categories:

– the "conservatives" who do not change their estimates;

– the "listeners" who start changing their estimate by bringing it closer to the average one;

– the "stubborn" who assign estimates that are further off the average one.

The results of expert polling are used as the prediction as the first matching opinions appear.

In general terms, the procedure of expert polling based on the Delphi method includes the following five stages.

Stage 1. Formation of the working group of analysts tasked with organizing expert polling.

Stage 2. Formation of the expert group. In accordance with the method's requirements, the group of experts is to include 10 to 15 subject matter experts. The experts' competence is defined by means of a questionnaire survey, referencing analysis (number of reference to the expert's publications), self-rating sheets.

Stage 3. Question definition. The wordings of the questions must be clear and unambiguous, imply clear-cut answers.

Stage 4. Expert evaluation. The method implies polling in a number of steps.

Stage 5. Conclusion.

The suggested algorithm of final scale construction is similar to the above algorithm of expert evaluation based on the Delphi method (Fig. 3).

[1] Another name of the method is the Delphian oracle method. Authors of the method: RAND mathematicians O. Helmer, T. Gordon T. and others (US), 1950s.

[2] The confidence area should be calculated through the quartile (term first used by Galton, 1882). There are three dividing points, i.e. the lower, medium and upper quartiles (also called quantiles 0.25; 0.5 and 0.75) that equal the 25-th, 50-th and 75-th percentiles of distribution (respectively). The 25-th percentile of a variable is such value, below which fall 25% of such variable's values. Similarly, the 75-th percentile is such value, below which fall 75% values of the variable. The medium quartile (50-th percentile) is called the median.

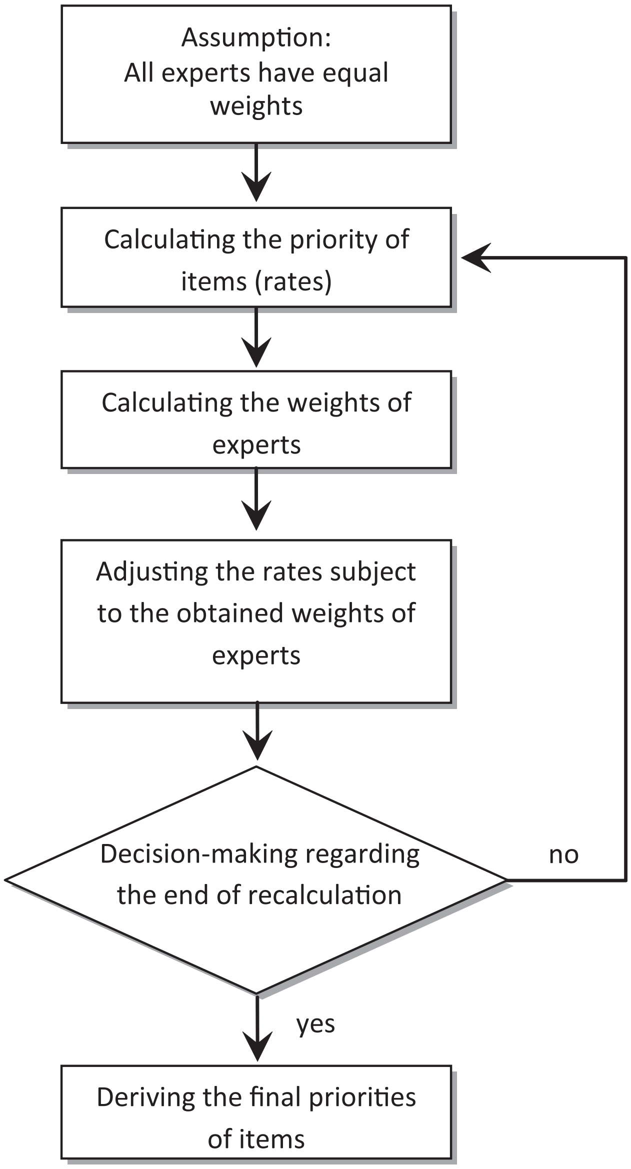

Fig. 3. Final scale construction algorithm

If the expert group is sufficiently large (more than 10 people), at the beginning of the procedure, the extreme values of item priority estimation can be discarded.

Conclusion

The above item ranking procedure that includes the algorithm of final scale construction and takes into consideration the experts' competence, may prove to be useful in solving the problem of defining the preferability of items based on certain features, the problem of estimation of potential hazard and risk of items as part of analysis of structurally complex systems, etc.

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The author's contribution

The author suggested a method of using the transitive graph of a Markovian process as part of expert ranking of items of a certain parent entity. It is proposed to use steady-state probabilities of a Markovian process as the correlation of priorities (weights) of the compared items. The paper sets forth an algorithm for constructing the final scale of comparison taking into consideration the experts' level of competence.

Conflict of interests

The author declares the absence of a conflict of interests

Original article
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An analysis of estimate bias of steady-state availability for various test plans

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Abstract. *Any process of technical product development may involve dependability testing. If in the course of operation, the recovery of an entity after a failure is the norm, then test plans of types NRect, NRecR, NNoRect и NNoRecR are normally used, where N is the number of tested same-type entities; t is the testing time of each of the N entities; R is the number of failures; Rec (NoRec) is the characteristic of the plan that indicates that the entity's operability after each failure within the testing time is recovered (not recovered). Normally, NRect and NRecR indicate that, in the process of testing, failures are recovered immediately. In order not to confuse plans NRect, NRecR, NNoRect and NNoRecR with test plans with long recovery times, let us denote the latter as NRec!t, NRec!R, NNoRec!t and NNoRec!R respectively. Let us simplify the problem description and require, for test plans of types NRec!t, NRec!R, NNoRec!t and NNoRec!R, the fulfilment of condition D = R, where D is the number of recoveries, i.e. after the conclusion of testing, at the moment of time t, the recovery of entities continues until the last of R failed entities is recovered. We will denote such test plans NRec!t(D=R), NRec!R(D=R), NNoRec!t(D=R) and NNoRec!R(D=R). As the dependability model, an exponential distribution is adopted. Steady-state availability is normally defined as the composite dependability indicator of recoverable entities. Finding efficient estimates is one of the primary goals of the dependability theory. Since the 1960s, Russian scientific literature has featured next to no research dedicated to the properties of steady-state availability estimates. The best known work in the steady-state availability estimates for a NRecR test plan is in the book: Beletsky B.R. [Dependability theory of radio engineering systems (mathematical foundations). Study guide for colleges]. Moscow: Sovetskoye radio; 1978. This paper makes up for this deficiency. In order to identify the efficient steady-state availability estimate out of infinite many, first, an estimate efficiency comparison criterion is to be constructed. The paper* **Aims** *to construct a simple criterion of steady-state availability estimation for test plans with long recovery times and identify the efficient estimate out of the available ones using the constructed criterion.* **Methods of research.** *The efficient estimate was found using integral numerical characteristics of the accuracy of estimate, i.e., the sum square of the displacement of the expected realization of an estimate from the considered parameters of the distribution laws.* **Conclusions.** *The authors constructed simple criteria of efficiency of steady-state availability estimation for test plans with long recovery time (case of N≥1). Estimate $G_3=(1+VR/S(R1))^{-1}$ is bias-efficient out of those available for test plans of types NRec!t(D=R) and NNoRec!t(D=R). Conventional estimate $G_1=(1+V/S)^{-1}$ is bias-efficient out of those available for test plans of types NRec!R(D=R) and NNoRec!R(D=R).*

Keywords: *estimation, efficient estimate, efficiency criterion, availability coefficient, steady-state availability.*

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Introduction

Any process of technical product development may involve dependability testing. If in the course of operation, the recovery of an entity after a failure is the norm, then test plans of types *NRect*, *NRecR, NNoRect* и *NNoRecR* are normally used, where N is the number of tested same-type entities; t is the testing time of each of the N entities; R is the number of failures; *Rec* (*NoRec*) is the characteristic of the plan that indicates that the entity's operability after each failure within the testing time is recovered (not recovered) [1–3]. Normally, *NRect* and *NRecR* indicate that, in the process of testing, failures are recovered immediately. In order not to confuse plans *NRect*, *NRecR, NNoRect* and *NNoRecR* with test plans with long recovery times, let us denote the latter as *NRec!t*, *NRec!R, NNoRec!t* and *NNoRec!R* respectively.

Let us simplify the problem description and require, for test plans of types *NRec!t*, *NRec!R, NNoRec!t* and *NNoRec!R*, the fulfilment of condition $D = R$, where D is the number of recoveries, i.e., after the conclusion of testing, at the moment of time t, the recovery of entities continues until the last of R failed entities is recovered. We will denote such test plans *NRec!t(D=R)*, *NRec!R(D=R), NNoRec!t(D=R)* and *NNoRec!R(D=R)*. As the dependability model, an exponential distribution is adopted.

Steady-state availability is normally defined as the composite dependability indicator of recoverable entities. Steady-state availability is defined as the probability that an entity will be in the up state at the given moment in time sufficiently remote from the start of the tests[1].

The formula for steady-state availability (C_a) used in practice is as [1–3]

$$C_a = T/(T+H) = 1/(1+H/T),$$

where $T = 1/\lambda$ is the mean time to failure of an entity, where λ is the failure rate of an entity, $H=1/h$ is the mean time to recovery (replacement) of an entity, where h is the renewal (replacement) rate of an entity. As the availability coefficient estimate, the following general formula is used

$$G = \check{T} / (\check{T} + \hat{H}) = 1 / (1 + \hat{H} / \check{T}),$$

where $\check{T}$ is the estimate of the mean time to failure based on the results of entities' testing, $\hat{H}$ is the estimate of the mean time to restoration based on the results of entities' testing. Out of the form of estimate G follows that there are infinite many estimates of steady-state availabilities C_a. For instance, for test plans of types *NRect* and *NRecR,* the estimate[2] $\check{T} = Nt / (R + 1)$, $R \geq 1$ and $\check{T} = Nt / R$, $R \geq 1$ [1–4] respectively can be chosen as $\check{T}$. As the formula for $\hat{H}$, $\hat{H} = V/D = R$ is normally chosen, where $R \geq 1$, V is the total recovery time. Finding efficient estimates is one of the primary goals of the dependability theory. Since the 1960s, Russian scientific literature has featured next to no research dedicated to the properties of steady-state availability estimates. The best-known work in the steady-state availability estimates for a *NRecR* test plan is in [3]. This paper makes up for this deficiency.

In order to identify the efficient steady-state availability C_a out of infinite many, first, an estimate efficiency comparison criterion is to be constructed.

The Aim of the paper

The paper aims to construct a simple criterion of steady-state availability estimation for test plans with long recovery times ($N \geq 1$) and identify the efficient estimate out of the available ones using the constructed criterion.

Methods of research

The efficient estimate was found using integral numerical characteristics of the accuracy of estimate, i.e. the sum square of the displacement of the expected realization of an estimate from the considered parameters of the distribution laws [4].

Constructing the efficient criterion of steady-state availability estimate for test plan of type *NRec!t(D=R)*

Let us examine the test plan of type *NRec!t(D=R)*. Such tests are primarily intended for steady-state availability estimation [1–3] (determinative tests). Let there be a certain number of entities undergoing tests and, in the process of testing, the time to failure and restoration time of an entity are random values and follow the exponential probability distribution [1–3]. In the course of testing, an entity may be in either of two states: up and down. In case of failure, an entity is recovered. Its operation time is restored in full (through replacement or repairs), which, in the process of testing, allows considering the parameters of the distribution law invariant.

Thus, an *NRec!t(D=R)* test can be represented as two sets of tests conducted according to classic plans *NRect* (recovery can be considered immediate) and *(N=R)Rec(D=R)* (we assume that failures occur immediately), i.e., a plan with limited testing time and a plan with a limited number of recoveries (is a random value) respectively.

In the process of *NRect* testing, a Poisson failure flow with the rate of $N\lambda$ can be observed [1–3]. Without violating the integrity of reasoning, we will denote the rate $N\lambda$ of the combined failure flow as λ, i.e., λ is equivalent to $N\lambda$, which should not cause confusion, then the set of independent tests is represented as the testing of one entity $N = 1$ characterized by the combined failure flow.

Let us introduce the following designations:

S, total operation time of entities;

V, total recovery time.

[1] GOST 27.002-2015. Dependability in technics. Terms and definitions. Moscow: Standartinform; 2016. (in Russ.)

[2] GOST R 50779.26-2007. Statistical methods. Point estimates, confidence intervals, prediction intervals and tolerance intervals for exponential distribution. Moscow: Standartinform; 2008. (in Russ.)

Many estimates of $G(D = R, R, S = Nt, V)$ can be proposed. Comparing them efficiency-wise requires constructing an efficiency criterion of steady-state availability estimation. For that purpose, let use the experience of such construction presented in [4]. The estimate G is considered to be the most bias-efficient compared to other estimates if its expectation EG has the lowest bias from the true steady-state availability C_a that always depends on the parameters of the distribution laws λ, h. The bias (m) in most cases is defined as the square of deviation EG from the adopted availability values, namely:

$$m(G, C_a) = (EG - C_a)^2.$$

In principle, the form of estimates G of steady-state availability may have any functional form $G(N, S = Nt, V, D = R, R, \ldots)$, $N = 1$. In this paper, we should restrict ourselves to the simple form, namely ($S = Nt$):

$$G_1 = \frac{1}{1+\frac{V}{S}\cdot\frac{R}{D=R}} \text{ (conventional estimate)},$$

$$G_2 = \frac{1}{1+\frac{V}{S}\cdot\frac{R+1}{D=R}}, \quad G_3 = \frac{1}{1+\frac{V}{S}\cdot\frac{R}{R+1}}.$$

Then, assuming that $EG(V, R)$ is finite, $EG(V, R) = E_R(E_V(G|R))$ [6].

For each of the R failed entities, the density of the probability function for a sum of independent identically distributed random variables of recovery time τ_{vij} with distribution density $he^{-ht} - V$ has the form of a special Erlang distribution $F\left(D=R, R=r, H=10^j, T=10^i\right) = E\left(G - \frac{T}{T+H}\right)^2$ [1, 2, 5]. Conditional expectation E_V of estimate G of steady-state availability has the form:

$$E_V(G \mid R, D=R, h) = \int_0^\infty G\frac{h(hV)^{(D-1)}e^{-hV}}{(D-1)!}dV.$$

The failure flow is a Poisson flow with distribution function $L(r) = \sum_{k=0}^{r} e^{-\Delta}\frac{\Delta^k}{k!}$, ($\Delta = \lambda t$). The expectation EG is calculated according to formula [1–3]:

$$EG = E_R\left(E_V G\right) = \sum_{r=0}^{\infty}\left(E_V G\right)\cdot e^{-\Delta}\frac{\Delta^r}{r!}.$$

Bias $m(G)$, like C_a, also depends on the parameters of the chosen distribution laws (T, H). In order to construct the efficiency criterion of steady-state availability estimation, we should summarize the displacement per all parameters of the selected distribution laws (T, H) and test plan ($R=r$, t, $N=1$):

$$A(G) = \int_{10^3}^{10^5}\int_{10^1}^{10^4}\int_{10^4}^{10^7} m(G)dHdTdt. \tag{1}$$

Let us note that parameter N of the $NRec!t(D = R)$ test plan is not critical and, without violating the integrity of reasoning, is taken equal to one $N = 1$. If we do not restrict the summation, the value of the constructed functional $A(G)$ for most estimates will always be infinite. Therefore, the limits of summation (expressed in hours) are restricted by reasonable intervals of the values of parameters (T, H, t, V) and $R = 10$.

Among the estimates with minimal total bias $A(G)$, the one with the minimal total deviation is to be considered efficient. For that purpose, the functional is constructed:

$$B(G) = \int_{10^3}^{10^5}\int_{10^1}^{10^4}\int_{10^4}^{10^7} y(G)dHdTdt, \tag{2}$$

where $y(G) = E_R(E_V((G - K_r)^2|R))$ [4, 6],

$$E_V\left(\left(G-K_z\right)^2 \mid R, D=R, h\right) = \int_0^\infty \left(G-K_z\right)^2\frac{h(hV)^{(D-1)}e^{-hV}}{(D-1)!}dV.$$

Direct calculation of functionals $A(G)$ and $B(G)$ (formulas (1) and (2)) is quite complicated, as it requires significant computational powers. Therefore, formulas (1) and (2) should be simplified and given a more practical form according to ($R = r$)

$$A_1 = \sum_{k=3}^{5}\sum_{j=1}^{4}\sum_{i=4}^{7}(C)^2, \tag{3}$$

$$\text{where } C = \left[\begin{array}{l}\sum_{r=1}^{10} E_V G\left(D=r, R=r, H=10^j, t=10^k\right)\cdot \\ \cdot e^{-\frac{t=10^k}{T=10^i}}\frac{\left(-t=10^k\right)^r}{\left(T=10^i\right)^r r!}\end{array}\right] - \frac{10^i}{10^i+10^j},$$

$$B_1 = \sum_{k=3}^{5}\sum_{j=1}^{4}\sum_{i=4}^{7}\sum_{r=1}^{10} e^{-\frac{t=10^k}{T=10^i}}\frac{\left(-t=10^k\right)^r}{\left(T=10^i\right)^r r!}E_V F, \tag{4}$$

$$\text{where } F = \left[G\left(D=r, R=r, t=10^k\right) - \frac{10^i}{10^i+10^j}\right]^2.$$

The results of substitution into formulas (3) and (4) of the suggested estimates of steady-state availability for the $NRec!t(D = R)$ test plan are shown in Table 1.

Table 1. Results of substitution into formulas (1) and (2) of the suggested steady-state availability estimates for test plan of type $NRec!t(D = R)$

	G_1	G_2	G_3
$A1$	34.057	34.263	33.906
1 – 1000	114	170	93

Out of Table 1 follows that, for the test plan of type $NRec!t(D=R)$, estimate $G_3 = (1 + VR / S(R + 1))^{-1}$ is bias-efficient out of those available.

Example. Two items of complex equipment were submitted to trial operation for a period of three months (2190 h). As the dependability indicator, the specifications indicated the steady-state availability $C_a = 0.92$. In the course of trial operation, a failure was detected. Due to complicated logistics, the equipment spent 500 h under repairs.

Let us examine two solutions:

1) Conventional estimate

Based on the results of trail operation, the estimate of steady-state availability was

$G_1 = (1 + V / S)^{-1} = (1 + 500 / (2190 + 2190))^{-1} = 0.897$, which does not comply with the specifications.

2) Using the efficient estimate of steady-state availability $G_3 = (1 + VR / S(d + 1))^{-1}$.

Based on the results of trial operation, the estimate of steady-state availability was

$G_3 = (1+VR/S(R1))_{-1} = (1500/2(21902190))-1 = 0.946$, which does not comply with the specifications.

Constructing the efficient criterion of steady-state availability estimate for test plan of type *NNoRec!t(D=R)*

Let us examine the test plan of type *NNoRec!t(D=R)*. An *NNoRec!t(D=R)* test can be represented as two sets of tests conducted according to classic *NNoRect* plans (no recovery) and *(N = R)NoRec(D = R)* i.e., respectively, according to the binomial plan and a plan with a limited number of recoveries (a random value).

Let us examine the test plan of type *(N = R)NoRec(D = R)*. As in the previous section, for each of the *R* tested (or failed, in case of the *NNoRect*) entities, the density of the probability function for a sum of independent identically distributed random variables of recovery time τ_{vij} with distribution density $he^{-ht} – V$ has the form of a special Erlang distribution [1, 2, 5]. Then, the conditional expectation E_V of estimate G of steady-state availability is calculated according to formula:

$$E_V(G \mid R, D=R, h) = \int_0^\infty G \frac{h(hV)^{(D-1)} e^{-hV}}{(D-1)!} dV.$$

Let random value R have binomial distribution $p_N(R = r)$ [7, f. 1.4.55] with parameters N and $p,\ 0 \le p \le 1$, i.e., $R = r$ equal to the number of successes in a series of N independent experiments with the probability of success $p = 1 – e^{-\lambda t}$ assumes integer value 0, 1, 2, …, N with probabilities $p_N(r) = C_N^r p^r (1-p)^{N-r}$.

Then, expectation $EG(V, R) = E_R(E_V(G|R))$ has the form of

$$EG(V,R) = \sum_{r=0}^{N} p_N(r) E_V(G \mid R=r).$$

Similarly (see the previous section), the following expectation is constructed:

$$EG\left((G-K_г)^2\right) = \sum_{r=0}^{N} p_N(r) E_V\left((G-K_г)^2 \mid R=r\right).$$

In order to construct the efficiency criterion of steady-state availability estimation, we should summarize the displacement per all parameters of the selected distribution laws *(T, H)* and test plan ($R = r$, t, $N \le 10$):

$$A(G) = \sum_{N=1}^{10} \int_{1000}^{10^5} \int_{1}^{10^4} \int_{10^4}^{10^7} m(G)\, dHdTdt, \quad (5)$$

$$B(G) = \sum_{N=1}^{10} \int_{1000}^{10^5} \int_{1}^{10^4} \int_{10^4}^{10^7} y(G)\, dHdTdt. \quad (6)$$

Direct calculation of functionals *A(G)* and *B(G)* (formulas (5) and (6)) is quite complicated, as it requires significant computational powers. Therefore, formulas (5) and (6) transform as follows:

$$A_1 = \sum_{N=1}^{10} \sum_{k=3}^{5} \sum_{j=1}^{4} \sum_{i=4}^{7} (C)^2, \quad (7)$$

where

$$C = \begin{bmatrix} \sum_{r=1}^{N} E_V G\left(D=r, R=r, N, H=10^j, t=10^k\right) \\ \cdot C_N^r p^r (1-p)^{N-r} \end{bmatrix} - \frac{10^i}{10^i + 10^j},$$

$$B_1 = \sum_{N=1}^{10} \sum_{k=3}^{5} \sum_{j=1}^{4} \sum_{i=4}^{7} \sum_{r=1}^{N} C_N^r p^r (1-p)^{N-r} E_V F, \quad (8)$$

where $F = \left[G\left(D=r, R=r, N, t=10^k\right) - \frac{10^i}{10^i + 10^j} \right]^2$.

Let us note that total operation time S is calculated based on average $S = R \cdot t / 2 + (N – R) \cdot t$.

The results of substitution into formulas (7) and (8) of the suggested estimates of steady-state availability for the test plan of type *NNoRec!t(D=R)* are shown in Table 2.

Table 2. Results of substitution into formulas (1) and (8) of the suggested steady-state availability estimates for test plan of type *NNoRec!t(D = R)*

	G_1	G_2	G_3
*A*1	271	272	270
*B*1·*100*	240	272	239

Out of Table 1 follows that, for the *NNoRec!t(D = R)* test plan, estimate $G_3 = (1 + VR / S(R + 1))^{-1}$ is bias efficient out of those available.

Constructing the efficient criterion of steady-state availability estimate for test plan of type *NRec!R(D=R)* and *NNoRec!R(D=R)*

An *NNoRec!R(D=R)* test can be represented as two sets of tests conducted according to classic *NNoRecR* (no recovery) and *(N = R)NoRec(D = R)* plans, i.e., respectively, according to the binomial plan with a limited number of recoveries that, in this case, is not a random value. A similar *NRec!R(D = R)* test can be represented as two sets of tests conducted according to classic *NRecR* (with recovery) and *(N = R)Rec(D = R)* plans.

For any of R failed entities, the duration of recovery τ_{vij} and operation τ_{ij}, $i = 1, 2, \ldots, R$; $j = 1, 2, \ldots, N$ do not depend on each other and each one has its own distribution density he^{-ht} and $\lambda e^{-\lambda t}$ respectively. The dependence of the occurrence of failures and, consequently, recoveries does not affect the duration of recovery τ_{vij} and operation τ_{ij}. Consequently, the S, V are independent too. For the purpose of constructing expectation EG, the distribution function of the sums of S, V and number of failures R must be known. For each of the $R = r$ $(D = d = r)$ entities submitted to recovery, the density of the probability function for the sum of independent identically distributed random variables of recovery time τ_{vij} with distribution density $he^{-ht} - V$ has the form of a special Erlang distribution $\frac{h(hV)^{(d-1)}e^{-hV}}{(d-1)!}$ [1, 2, 5]. For each of the $R = r$ failed entities, the density of the probability function for the sum of independent identically distributed random times to failure with distribution density $\lambda e^{-\lambda t} - S$ also has the form of a special Erlang distribution $\frac{\lambda(\lambda S)^{(r-1)}e^{-\lambda S}}{(r-1)!}$. The same is true for the set R of failed entities [1, 2, 5].

Then, the expectation of estimate G of steady-state availability is calculated according to formula

$$E\left(G, D = d = r, R = r, \lambda, h\right) = \\ = \int_0^\infty\int_0^\infty G \frac{h(hV)^{(d-1)}e^{-hV}}{(d-1)!}\frac{\lambda(\lambda S)^{(r-1)}e^{-\lambda S}}{(r-1)!}dVdS.$$

Similarly,

$$E\left(\left(G - K_{\text{r}}\right)^2, D = d = r, R = r, \lambda, h\right) = \\ = \int_0^\infty\int_0^\infty \left(G - K_{\text{r}}\right)^2 \frac{h(hV)^{(d-1)}e^{-hV}}{(d-1)!}\frac{\lambda(\lambda S)^{(r-1)}e^{-\lambda S}}{(r-1)!}dVdS.$$

In order to construct the efficiency criterion of steady-state availability estimation, we should summarize the displacement per all parameters of the selected distribution laws *(T, H)* and (*R = 10*) test plan:

$$A(G) = \sum_{r=1}^{10}\int_1^{10^4}\int_{10^4}^{10^7} m(G)dTdH, \qquad (9)$$

$$B(G) = \sum_{r=1}^{10}\int_1^{10^4}\int_{10^4}^{10^7} E\left(G - K_{\text{г}}\right)^2 dHdT. \qquad (10)$$

Direct calculation of functionals *A(G)* and *B(G)* (formulas (9) and (10)) is quite complicated, as it requires significant computational powers. Therefore, formulas (9) and (10) should be simplified and given a more practical form respectively:

$$A_1 = 10^4 \sum_{j=1}^{4}\sum_{i=4}^{7}\sum_{r=1}^{10} C\left(D = R, R = r, H = 10^j, T = 10^i\right), \qquad (11)$$

where

$$C\left(D = R, R = r, H = 10^j, T = 10^i\right) = \left(EG - \frac{T}{T+H}\right)^2,$$

$$B_1 = 10^2 \sum_{j=1}^{4}\sum_{i=4}^{7}\sum_{r=1}^{10} F\left(D = R, R = r, H = 10^j, T = 10^i\right), \qquad (12)$$

where

$$F\left(D = R, R = r, H = 10^j, T = 10^i\right) = E\left(G - \frac{T}{T+H}\right)^2.$$

A normalizing factor is introduced into formulas (11) and (12), simplifying the form of the result. The results of substitution of the suggested steady-state availability estimates into formulas (11) and (12) for test plans of type *NRec!R(D=R)* and *NNoRec!R(D=R)* are shown in Table 3.

Table 3. Results of substitution of the suggested steady-state availability estimates into formulas (11) and (12) for test plan of type *NRec!R(D=R)* and *NNoRec!R(D=R)*

	G_1	G_2	G_3
*A*1	202	1199	325
1	49	66	42

Out of Table 3 follows that estimate $G_1 = (1 + V / S)^{-1}$ is the bias-efficient out of those available ones.

Conclusions

1) The authors constructed simple criteria of efficiency of steady-state availability estimation for test plans with long recovery time (case of $N \geq 1$).

2) Estimate $G_3 = (1 + VR / S(R+1))^{-1}$ is the bias-efficient out of those available for test plans of types *NRec!t(D = R)* and *NNoRec!t(D = R)*.

3) Conventional estimate $G_1 = (1 + V/S)^{-1}$ is bias-efficient out of those available for test plans of types *NRec!R(D = R)* and *NNoRec!R(D = R)*.

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The authors' contribution

The authors constructed simple criteria of efficiency of steady-state availability estimation for test plans with long recovery time (case of $N \geq 1$). Efficient estimates were obtained out of those considered.

Dmitry M. Rudkovsky constructed the efficient criterion of steady-state availability estimate for test plans of type *NRec!R(D = R)* and *NNoRec!R(D = R)*.

Viktor S. Mikhailov constructed the efficient criterion of steady-state availability estimate for test plans of type *NRec!t(D = R)* and *NNoRec!t(D = R)*.

Conflict of interests

The authors declare the absence of a conflict of interests.

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Application of interval-valued triangular fuzzy numbers and their functional to the healthcare problems

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Abstract. Aim. *In healthcare field there exist different types of uncertainty due to medical error generated by human and technologies. In general the crisp value generate loss of precision and inaccuracy about result and therefore the available data is not sufficient to assessed clinical process up to desired degree of accuracy. Therefore fuzzy set theory play as an important and advance role in accuracy of results in healthcare related problems.* **Methods.** *Here for more accuracy of result, we use functional fuzzy numbers in this paper. This study uses a new fuzzy fault tree analysis for patient safety risk modelling in healthcare. In this paper we will use level (λ, ρ) interval-valued triangular fuzzy number, their functional, t-norm operation and centre of gravity defuzzification method to evaluate fuzzy failure probability and estimate reliability of system. The effectiveness of these methods is illustrated by an example related to healthcare problems and then we analyse the result obtained with the other existing techniques. Tanaka et al.'s approach has been used to give the rank of basic events of the considered problems. Also, we use functional of fuzzy numbers to analyse the change in fuzzy failure probability.* **Results.** *The paper examines the application of the failure tree, t-norm and functional fuzzy numbers in the context of interval-valued triangular fuzzy numbers. The research examined two types of healthcare-specific problems and the corresponding defuzzification techniques for the purpose of reliability analysis using the existing methods. The authors concluded that t-norm is not associated with significant accumulation and identified how a functional fuzzy number affects reliability. Similarly, using the V index method, the least critical events were found for each system.*

Keywords: *healthcare, fuzzy sets, t-norm, interval-valued triangular fuzzy numbers and their functional, fault tree analysis, defuzzification.*

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1. Introduction

In classical or traditional set theory, an element either belonging to the set or not, that is the answer of any element belongs to the set become yes or no rather than more or less. Fuzzy set theory [25] provide means of uncertainty, that is it explained about degree of belonging of any element in a set,

Since healthcare safety related problems are major concern for healthcare institutions around the world, so the healthcare institutions have to point out the main reasons of different kinds of medical errors and to find out the ways for reducing their frequency. In healthcare, more proactive risk analysis techniques should be applied for better and safe medication processes [3].Fault tree analysis (FTA) has been extensively used technique in health problems [1-5, 18-19].Hyman and Johnson [10] presents a FTA of the patient harm-related clinical alarms failures. Park and Lee [18] constructed a FTA of hand washing process. Chen [6] proposed a new and faster method to analyze fuzzy system reliability using fuzzy number arithmetic operations.

Lee has developed chromosomes image [11-12] by using fuzzy logic in blood leukocyte, Butnariu [4] developed a neuron model (Acoustico- vestibulary nerve) as a fuzzy automation describe with this help. Similarly Rocha has been used fuzzy logic in nervous system [20-21]. A classical approach was developed by Forden and Bezdek to diagnosis of renovascular-hypertension [7]. Adlassning and kolarz used fuzzy logic in a consultative system for rheumatology known as Cadiag-2 [2].

A fuzzy iterative diagnostic expert called "SPINX" which is used to design to deal with diagnosis [8], it consist a dialogue system where patient data is entered and response to request for additional information and a decision system, here fault tree searches match patient to diagnosis, similarly Lesmo, Saitta and Torasso have developed a system to learning production rules for medical decision making [13]. The automatic learning system based on fuzzy set theory and works on linguistic variables. One another example of fuzzy system in Ophthalmological fuzzy consultative system developed by Oguntade [17], he asses patient status pre and post therapy. It is clear that there is a good deal of fuzzy logic with medical system and fuzzy inference model have been suggested and tested successfully.

2. Fuzzy Sets

Fuzzy sets were introduced independently by Lotfi A. Jadeh [24] and Dieter Klaua in 1965 as an extension of classical notion of a set. In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent conditions that is an element either belong to set or not, fuzzy set theory give the membership of elements in a set belong to the unit interval [0, 1]. Fuzzy set is a generalization of classical theory.

A fuzzy set is defined by a membership function from the universal set to the interval [0, 1], as given below;

$$\mu_A(x): X \to [0,1]. \tag{1}$$

Here $\mu_A(x)$ gives the degree to x belonging in the set A. A fuzzy set A can be expressed as follows:

$$\tilde{A} = \{(x, \mu_A(x)) : x \in X\}. \tag{2}$$

Fuzziness can be found in many areas of daily life such as in engineering, medicine, manufacturing and others.

3. Fuzzification and interval-valued triangular fuzzy number

Fuzzification is the process of transformation crisp value to the fuzzy value with the help of fuzzy membership functions. There are a variety of fuzzy membership functions exist for performing fuzzification including triangular, trapezoidal, Cauchy and Gaussian, etc. [16]. For analysing safety and healthcare related problems, inter-valued triangular fuzzy membership functions or more simply inter-valued triangular fuzzy number (IVTFNs) are often utilized to provide more precise descriptions and to obtain more accurate solutions. Mathematically, an interval-valued fuzzy set $\tilde{A}(i-v\ fuzzy\ set)$ on R is derived by $\tilde{A} \equiv \{(x, [\mu_{\tilde{A}^L}(x), \mu_{\tilde{A}^u}(x)]) / x \in R\}$; $0 \le \mu_{\tilde{A}^L}(x) \le \mu_{\tilde{A}^u}(x) \le 1 \forall x \in R$, It is denoted by $\mu_{\tilde{A}}(x) = [\mu_{\tilde{A}^L}(x), \mu_{\tilde{A}^U}(x)] x \in R$ or $\tilde{A} = [\tilde{A}^L, \tilde{A}^U]$.

The i-v triangular fuzzy set $\tilde{A}$ indicates that, when the membership grade of x belongs to the interval $[\mu_{\tilde{A}^L}(x), \mu_{\tilde{A}^U}(x)]$ the largest grade is $\mu_{\tilde{A}^U}(x)$ and the smallest grade is $\mu_{\tilde{A}^L}(x)$. where

$$\mu_{\tilde{A}^L}(x) = \begin{cases} \dfrac{\lambda(x-a)}{b-a} & a \le x \le b \\ \dfrac{\lambda(c-x)}{c-b} & b \le x \le c \\ 0 & otherwise \end{cases} \tag{3}$$

Therefore, $\tilde{A}^U = (a, b, c, \rho)$, $a < b < c$ similarly,

$$\mu_{\tilde{A}^U}(x) = \begin{cases} \dfrac{\rho(x-a)}{b-a} & a \le x \le b \\ \dfrac{\rho(c-x)}{c-b} & b \le x \le c \\ 0 & otherwise \end{cases} \tag{4}$$

Therefore $\tilde{A}^U = (a, b, c, \rho)$, $a < b < c$. Consider the case in which $0 < \lambda \le \rho \le 1$. From (3) and (4) we obtain $\tilde{A} = [\tilde{A}^L, \tilde{A}^U]$, $[(a,b,c;\lambda),(a,b,c;\rho)]$, which is called the level $(\lambda,\rho)\, i-v$ triangular fuzzy number Fig. 1.

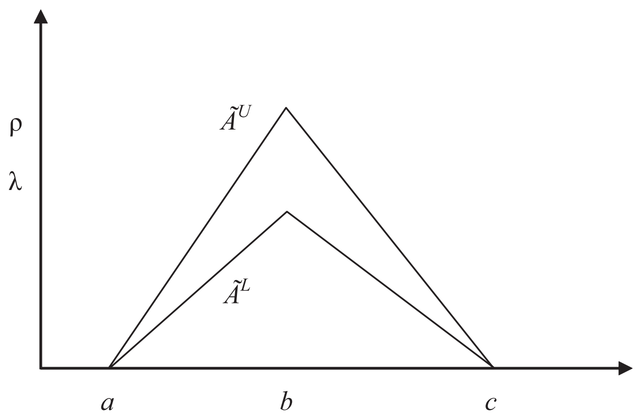

Fig. 1. i-v triangular fuzzy number

4. t-norm

Zadeh [24] suggest that the intersection of fuzzy set is minimum operator and algebraic product. The minimum product and bounded difference operator belong to so called triangular norm or t-norm. A t-norm is a binary function, t : [0, 1]×[0, 1]→[0, 1] which satisfies the axioms of (i) Commutativity, (ii) Associativity (iii) Monotonicity and (iv) Boundary condition. In literature there are various t-norms operation such as $t(\mu_{\tilde{A}}(x),\mu_{\tilde{B}}(x)) = \min\{\mu_{\tilde{A}}(x),\mu_{\tilde{B}}(x)\}$, $p < a < b < c < d < r$.

$$0 < \lambda \le \rho \le 1 \text{ and}$$

$$t(\mu_{\tilde{A}}(x),\mu_{\tilde{B}}(x)) = \begin{cases} \mu_{\tilde{A}}(x) & \text{where } \mu_{\tilde{B}}(x) = 1 \\ \mu_{\tilde{B}}(x) & \text{where } \mu_{\tilde{A}}(x) = 1\cdot \\ 0, & \text{otherwise} \end{cases}$$

Here the last t-norm operation was applied by Lin et al. [14] for triangular fuzzy numbers and we use this operation to find the failure probability of system. t–norm operation give smaller fuzzy accumulation which is the best advantage in fuzzy arithmetic operation.

5. Functional of fuzzy numbers

It is defined as a function of function of x that is, membership value have a membership degree also. It is defined as follow

$$\mu_{\tilde{A}}(x) : X \to [0,1],\ \mu\left(\mu_{\tilde{A}}(x)\right) : \mu_{\tilde{A}}(x) \to [0,1],$$

$$\tilde{A} = \left\{\left(\left(x, \mu_{\tilde{A}}(x)\right), \mu\left(\mu_{\tilde{A}}(x)\right)\right) : x \in X\right\}. \tag{5}$$

Here a interval-valued triangular functional fuzzy number shown in Fig. 2 here the lower interval-valued triangular fuzzy number membership is (1,2,3:0.5) and upper membership value is (1,2,3:1.0) the z coordinate can be calculated as $\mu\left(\mu_A(x)\right) = \dfrac{1}{x^2+1}$;

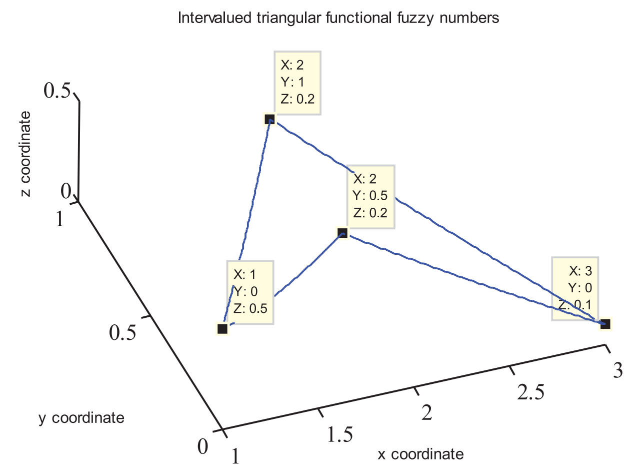

Fig. 2.Interval-valued Triangular Functional fuzzy numbers

Table 1. Gate Operation

Approach	Gate	Operation	Equation
Traditional FTA	OR	Conjunction	$P_{\text{OR}} = 1-[(1-q_1)\times(1-q_2)\times\ldots\times(1-q_n)]$
	AND	Intersection	$P_{\text{AND}} = q_1 \times q_2 \times \ldots. \times q_n$
Traditional FFTA	OR	Conjunction	$P_{\text{OR}} = \tilde{1}\Theta[(\tilde{1}\Theta\tilde{q}_1)\otimes(\tilde{1}\Theta\tilde{q}_2)\otimes\ldots.\otimes(\tilde{1}\Theta\tilde{q}_n)]$
	AND	Intersection	$P_{\text{AND}} = \tilde{q}_1 \otimes \tilde{q}_2 \otimes \ldots\ldots \otimes \tilde{q}_n$
t-norm FFTA	OR	Conjunction	$P_{\text{OR}} = \tilde{1}\Theta_t[(\tilde{1}\Theta_t\tilde{q}_1)\otimes_t(\tilde{1}\Theta_t\tilde{q}_2)\otimes_t\ldots.\otimes_t(\tilde{1}\Theta_t\tilde{q}_n)]$
	AND	Intersection	$P_{\text{AND}} = q_1 \otimes_t q_2 \otimes_t \ldots. \otimes_t q_n$

Table 2. Fuzzy operation of two interval-valued Triangular fuzzy numbers (TFN's)

Operation	Triangular fuzzy interval-valued numbers
Multiplication	$\begin{pmatrix} a_1,b_1,c_1:\rho \\ a_1,b_1,c_1:\lambda \end{pmatrix} \times \begin{pmatrix} a_2,b_2,c_2:\rho \\ a_2,b_2,c_2:\lambda \end{pmatrix} = \begin{pmatrix} a_1a_2,b_1b_2,c_1c_2:\rho \\ a_1a_2,b_1b_2,c_1c_2:\lambda \end{pmatrix}$
Complement	$1-\begin{pmatrix} a,b,c:\rho \\ a,b,c:\lambda \end{pmatrix} = \begin{pmatrix} 1-c,1-b,1-a:\rho \\ 1-c,1-b,1-a:\lambda \end{pmatrix}$

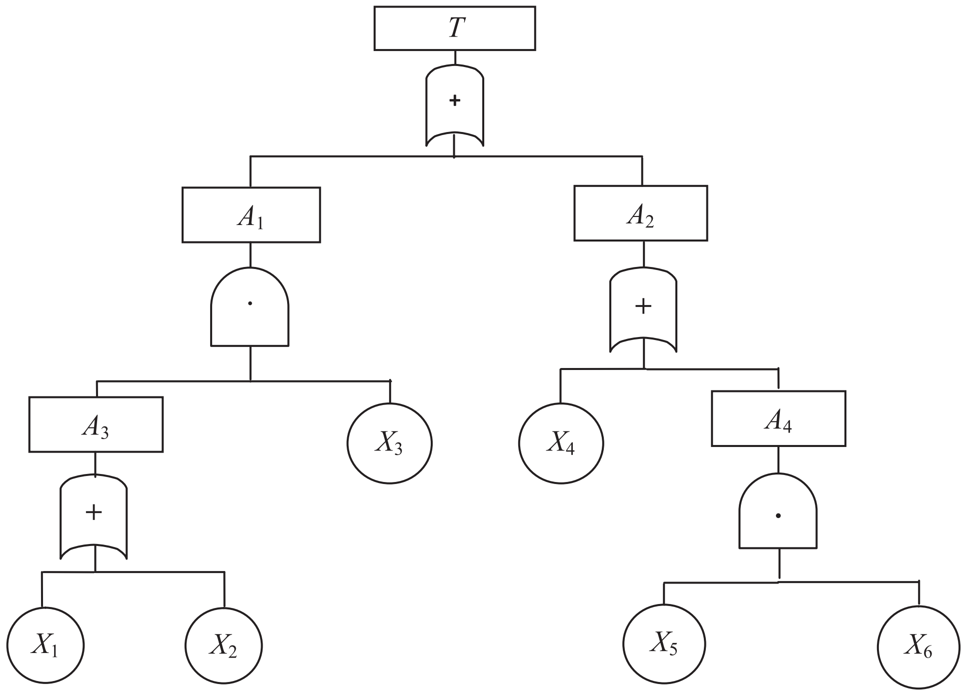

Fig. 3. Fault tree diagram

6. Fault tree analysis (FTA) and fuzzy probability

Fault-tree analysis (FTA) is a tree analysis in which undesired state of a system is analyzed using Boolean logic to combine a series of lower level basic events. Furthermore, if the failure probabilities of system components are known then the probability of the top event can be calculated. In fault tree diagram there are two gates are used one is "AND" and another is "OR". "AND" (conjunction) means the failure probability is depend on that entire event, and the event associated with OR gate means they are work independently to failure next event. The fuzzy failure probability can be calculated by following arithmetic operation on fuzzy numbers, here when we take probability in fuzzy sense the FTA is called FFTA (fuzzy fault tree analysis). In FTA operation we take crisp failure probability and in FFTA we use fuzzy failure probability.

The fault tree Fig. 3 associated with the basic events name as X_1, X_2, X_3, X_4, X_5 and X_6. The Top event is T and T can be expressed as the following equation;

$$T = A_1 \cup A_2,$$

$$T = (A_3 \cap X_3) \cup (X_4 \cup A_4),$$

$$T = \left[\left\{\left(X_1 \cup X_2\right) \cap X_3\right\} \cup \left\{X_4 \cup \left(X_5 \cap X_6\right)\right\}\right]. \quad (6)$$

7. Reliability

Reliability is defined to be the probability that a component or system will perform a required function for a given period of time, when used under stated operating conditions. It is the probability of a non failure over time. Reliability is a property of consistency, measurement, test or life of any system or accuracy of experiment. It's an estimation about how much the error is smaller and the value is around the true value .A high reliable system produce similar result under various conditions i.e. highly reliable score are accurate.

7.1. Computation of Reliability of a system

In analyzing a complex system, a particular failure law may be applied to the entire system. However, an alternative approach is to determine an appropriate reliability or reliability model for each component of the system and by applying the rules of probability according to the configurations of the components within the system. Compute a system reliability there are following configurations;

7.1.1. Serial (Series) Configuration

In series configuration all components must run for the system to function. Under this concept, if either of two serially related components fails, the system will fail. The series relationship is represented by the block diagram in Fig. 4.

Fig. 4.serial configuration

The failure probability of series system may be determined by 1 minus the probability that no component fail (i.e. the probability that the system operate). The component failure probabilities in the following way;

E1: the event that component 1 fail.

E_2: the event that component 2 fail.

Then let failure probability of component 1 is $P(E_1)=q_1$ and component 2 is $P(E_2)=q_2$, then non failure probability of components are $P(E_1^C)=1-q_1$ and $P(E_2^C)=1-q_2$.then non failure probability of system is equal to $(1-q_1)\cdot(1-q_2)$.

Therefore failure probability is $P_s=1-(1-q_1)\cdot(1-q_2)$.

Assuming that the two components are independent, Generalising to n mutually independent components in series;

$$P_S = 1-(1-q_1)\cdot(1-q_2)\cdot(1-q_3)\cdot(1-q_4)\cdot\ldots\cdot(1-q_n). \quad (7)$$

Now to determine reliability we take the complement of failure probability of system.

7.1.2. Parallel Configuration

Two or more components are in parallel or redundant configuration if all the units must fail for the system to fail, i.e. if one or more units operate the system continuous to operate. Parallel units are represented by block diagram in Fig. 5.

The failure probability for n parallel and independent components is found by the probability that all components fail, i.e.

$$P_S = q_1 \times q_2 \times q_3 \times \ldots \times q_n. \quad (8)$$

Now to determine reliability we take the complement of failure probability of system.

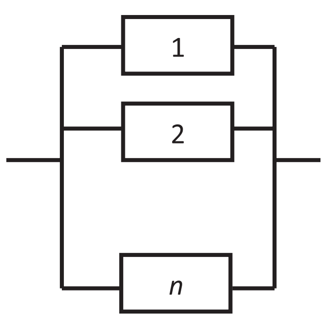

Fig. 5.Components in Parallel

8. V Index

Let $\tilde{q}_T$ denote the fuzzy failure probability of the system top event, which depends on its components whose fuzzy failure probabilities ($q_{i's}$) are interval-valued TFN's then the fuzzy Failure probability of system top event is given by the equations;

$$\tilde{q}_T = \tilde{q}_T(\tilde{q}_1, \tilde{q}_2 ......\tilde{q}_i....\tilde{q}_n) = \\ = \left[\left(\tilde{q}^L_{T_1}, \tilde{q}^L_{T_2}, \tilde{q}^L_{T_3} : \lambda\right), \left(\tilde{q}^L_{T_1}, \tilde{q}^L_{T_2}, \tilde{q}^L_{T_3} : \rho\right)\right], \quad (9)$$

where $\tilde{q}^L_T = \left[\left(\tilde{q}^L_{T_1}, \tilde{q}^L_{T_2}, \tilde{q}^L_{T_3} : \lambda\right), \left(\tilde{q}^L_{T_1}, \tilde{q}^L_{T_2}, \tilde{q}^L_{T_3} : \rho\right)\right]$ is a λ, ρ i-v TFNs.

Let $\tilde{q}_{T_i}$ be the fuzzy failure probability of system top event after preventing system i^th component failure (i.e. $\tilde{q}_i = \tilde{0}$) then the value of $\tilde{q}_{T_i}$ is given by the equation.

$$\tilde{q}_T = \tilde{q}_T(\tilde{q}_1, \tilde{q}_2, ..., \tilde{q}_i, ..., \tilde{q}_n) = \\ = \left[\left(\tilde{q}_{Ti_1}, \tilde{q}_{Ti_2}, \tilde{q}_{Ti_3} : \lambda\right), \left(\tilde{q}_{Ti_1}, \tilde{q}_{Ti_2}, \tilde{q}_{Ti_3} : \rho\right)\right], \quad (10)$$

where $\tilde{q}_T = \left[\left(\tilde{q}_{Ti_1}, \tilde{q}_{Ti_2}, \tilde{q}_{Ti_3} : \lambda\right), \left(\tilde{q}_{Ti_1}, \tilde{q}_{Ti_2}, \tilde{q}_{Ti_3} : \rho\right)\right]$ is λ, ρ i-v TFN.

Then the index V given by H. Tanaka [23], measure the difference between E_1 and $\tilde{q}_{E_1}$ is defined as;

$$V\left(\tilde{q}_T, \tilde{q}_{T_i}\right) = \left(\tilde{q}_{T_i} - \tilde{q}_{T_{i_1}}\right) + \left(\tilde{q}_{T_i} - \tilde{q}_{T_{i_2}}\right) + \left(\tilde{q}_{T_i} - \tilde{q}_{T_{i_3}}\right) > 0. \quad (11)$$

$V\left(\tilde{q}_T, \tilde{q}_{T_i}\right)$ Indicates the extent of improvement in eliminating the failure of the i^th component. If $V\left(\tilde{q}_T, \tilde{q}_{T_i}\right) > V\left(\tilde{q}_T, \tilde{q}_{T_j}\right)$ then preventing failure of i^th component is more effective than the preventing failure of j^th component of the system.

9. Definitions

9.1. Definition 1

Let $\tilde{A} = \left[(a_1, b_1, c_1 : \lambda), (a_1, b_1, c_1 : \rho)\right]$ and $\tilde{B} = \left[(a_2, b_2, c_2 : \lambda), (a_2, b_2, c_2 : \rho)\right]$ are two i-v triangular fuzzy numbers then the failure probability $P(\tilde{A} \cup \tilde{B})$ for $\tilde{A} > 0$ and $\tilde{B} > 0$ can be defined using OR operator [9, 25] as

$$P(\tilde{A} \cup \tilde{B}) = 1\Theta\left[\left(1\Theta P(\tilde{A})\right) \otimes \left(1\Theta P(\tilde{B})\right)\right]. \quad (12)$$

9.2. Definition 2

Let $\tilde{A} = \left[(a_1, b_1, c_1 : \lambda), (a_1, b_1, c_1 : \rho)\right]$ and $\tilde{B} = \left[(a_2, b_2, c_2 : \lambda), (a_2, b_2, c_2 : \rho)\right]$ be two i-v triangular fuzzy numbers then the failure probability $P(\tilde{A} \cap \tilde{B})$ for $\tilde{A} > 0$ and $\tilde{B} > 0$ can be defined using AND operator [9, 22] as;

$$P(\tilde{A} \cap \tilde{B}) = P(\tilde{A}) \otimes P(\tilde{B}). \quad (13)$$

10. Methodology

The following steps are performed for developing proposed FFTA.

Step 1. Construct a fault tree of any healthcare related problem associated with intermediate and basic events.

Step 2. Transform bottom events failure possibilities in the form of interval-valued triangular fuzzy numbers with the help of expert knowledge and discussion.

Step 3. Calculate top event fuzzy failure probability using simple arithmetic operation and t-norm based fuzzy arithmetic operations on interval-valued triangular fuzzy numbers using operations given in Table 2, and expressions given in Table 3 (third row) for 'OR' and 'AND' gates which are based on eq. (11) and (13), respectively.

Step 4. With the help of functional of fuzzy numbers we associate the membership function with its membership degree in the form of a continuous function and analyse the change in fuzzy failure probability of top event.

Step 5. We Compute system top event fuzzy reliability, which is equal to one minus the fuzzy failure probability of the top event.

Step 6. Find the most and least influential bottom events using the definition of index V given in eq. (11), calculate $V\left(\tilde{q}_T, \tilde{q}_{T_i}\right)\forall i$ by eliminating the ith bottom event in the fault-tree diagram, and find the most and least influential events by finding max $V\left(\tilde{q}_T, \tilde{q}_{T_i}\right)$ and min $V\left(\tilde{q}_T, \tilde{q}_{T_i}\right)$ values, respectively for the whole system.

Step 7. Defuzzified top event failure probability and can be easily computed with the help of COG defuzzification method and proposed COG method for functional of fuzzy number and then analyze the results and give suggestions based on it for improving the performance of system.

11. Defuzzification

Defuzzification is the process of converting the fuzzy value to crisp value. There are various methods to transform a number into a fuzzy set and then defuzzified [25]. The simplest method to defuzzification is chose to set the highest membership function, another a common and useful defuzzification technique is centre of gravity. For the interval valued triangular fuzzy number we will take the mean of the COG of upper and lower triangular fuzzy numbers. In this paper we also use COG method to Interval-valued triangular functional fuzzy numbers.

Table 3. t-norm operation in i-v triangular fuzzy numbers

Operation	Fuzzy expression t-norm definition
(1) Addition	$\tilde{A}\oplus_{T_w}\tilde{B}$ = (b_1+b_2-max(b_1-a_1, b_2-a_2), b_1+b_2, , c_1+c_2+max(c_1-b_1, c_2-b_2))
(2) Multiplication	$\tilde{A}\otimes_{T_w}\tilde{B}$ = (b_1b_2-max((b_1-a_1)c_2, (b_2-a_2)c_1), b_1b_2, c_1c_2+max((c_1-b_1)a_2, (c_2-b_2)a_1)
(3) Subtraction	$\tilde{A}\Theta_{T_w}\tilde{B}$ = (b_1-b_2-max(b_1-a_1, c_2-b_2), b_1-b_2, b_1-b_2+max(c_1-b_1, b_2-a_2))
(4) Compliment	$1\Theta_{T_w}\tilde{B}$ = (1-c_2, , 1-b_2, 1-a_2)

11.1. COG Method

The centre of gravity defuzzification method can be expressed as

$$x^* = \frac{\int x\cdot\mu_A(x)dx}{\int\mu_A(x)dx} \tag{14}$$

From Fig. 1 we evaluate COG of both of the membership function upper and lower as follow;

$$x^{U*} = \frac{\int_a^b x\cdot\rho\left(\frac{x-a}{b-a}\right)dx + \int_b^c x\cdot\rho\left(\frac{c-x}{c-b}\right)dx}{\int_a^b \rho\left(\frac{x-a}{b-a}\right)dx + \int_b^c \rho\left(\frac{c-x}{c-b}\right)dx},$$

$$x^{U*} = \frac{a+b+c}{3}; \tag{15}$$

$$x^{L*} = \frac{\int_a^b x\cdot\lambda\left(\frac{x-a}{b-a}\right)dx + \int_b^c x\cdot\lambda\left(\frac{c-x}{c-b}\right)dx}{\int_a^b \lambda\left(\frac{x-a}{b-a}\right)dx + \int_b^c \lambda\left(\frac{c-x}{c-b}\right)dx},$$

$$x^{L*} = \frac{a+b+c}{3}. \tag{16}$$

Then average of both of the value we can get;

$$x^* = \frac{1}{2}\left[x^{U^*} + x^{L^*}\right], \tag{17}$$

$$x^* = \frac{a+b+c}{3}. \tag{18}$$

11.2. Proposed COG Method

In proposed methods the membership function possesses a variable degree of membership. In this method the centre of gravity define as;

$$x^* = \frac{\int x\cdot\mu_A(x)\cdot\mu(\mu_A(x))dx}{\int\mu_A(x)\cdot\mu(\mu_A(x))dx} \tag{19}$$

Let $\mu(\mu_A(x)) = \frac{1}{x^2+1}$, and $0 < \frac{1}{x^2+1} \le 1$, for any real value of x then

We evaluate the defuzzified value of each lower and upper trapezoidal fuzzy numbers and then we take the mean value of both defuzzification values.

$$x^{U*} = \frac{\int_a^b x\cdot\rho\left(\frac{x-a}{b-a}\right)\cdot\frac{1}{x^2+1}dx + \int_b^c x\cdot\rho\left(\frac{c-x}{c-b}\right)\cdot\frac{1}{x^2+1}dx}{\int_a^b \rho\left(\frac{x-a}{b-a}\right)\cdot\frac{1}{x^2+1}dx + \int_b^c \rho\left(\frac{c-x}{c-b}\right)\cdot\frac{1}{x^2+1}dx}, \tag{20}$$

$$x^{L*} = \frac{\int_a^b x\cdot\lambda\left(\frac{x-a}{b-a}\right)\cdot\frac{1}{x^2+1}dx + \int_b^c x\cdot\lambda\left(\frac{c-x}{c-b}\right)\cdot\frac{1}{x^2+1}dx}{\int_a^b \lambda\left(\frac{x-a}{b-a}\right)\cdot\frac{1}{x^2+1}dx + \int_b^c \lambda\left(\frac{c-x}{c-b}\right)\cdot\frac{1}{x^2+1}dx}, \tag{21}$$

$$x^{*}=\frac{1}{2}\left[x^{U^{*}}+x^{L^{*}}\right], \qquad (22)$$

$$x^{U^{*}}=x^{L^{*}}=\frac{\left[\begin{array}{l}\frac{1}{b-a}\left\{b-a-\frac{a}{2}\ln\left(\frac{b^{2}+1}{a^{2}+1}\right)-\tan^{-1}\left(\frac{b-a}{1+ab}\right)\right\}-\\-\frac{1}{c-b}\left\{c-b-\frac{c}{2}\ln\left(\frac{c^{2}+1}{b^{2}+1}\right)-\tan^{-1}\left(\frac{c-b}{1+bc}\right)\right\}\end{array}\right]}{\left[\begin{array}{l}\frac{1}{b-a}\left\{\frac{1}{2}\ln\left(\frac{b^{2}+1}{a^{2}+1}\right)-a\tan^{-1}\left(\frac{b-a}{1+ab}\right)\right\}-\\-\frac{1}{c-b}\left\{\frac{1}{2}\ln\left(\frac{c^{2}+1}{b^{2}+1}\right)-c\tan^{-1}\left(\frac{c-b}{1+bc}\right)\right\}\end{array}\right]}, \qquad (23)$$

$$x^{*}=\frac{1}{2}\left[x^{U^{*}}+x^{L^{*}}\right]=x^{U^{*}}\ \textit{или}\ x^{L^{*}},\ \text{т.к.}\ x^{U^{*}}=x^{L^{*}}. \qquad (24)$$

12. Example

12.1. Fault Tree of medication Pump

The FTA Diagram of medication pump failure [15] is shown in Fig.6. In this example of Fault tree contain four combination of failures which lead to top event, i.e. top event is associated with 'OR' gate, that means all are each independently associated. Similarly the pump and the alarm work together associated with AND gate.

Marx and Slonim [15] considered the failure probability of basic events 0.001(column 3 of Table 4) However, this

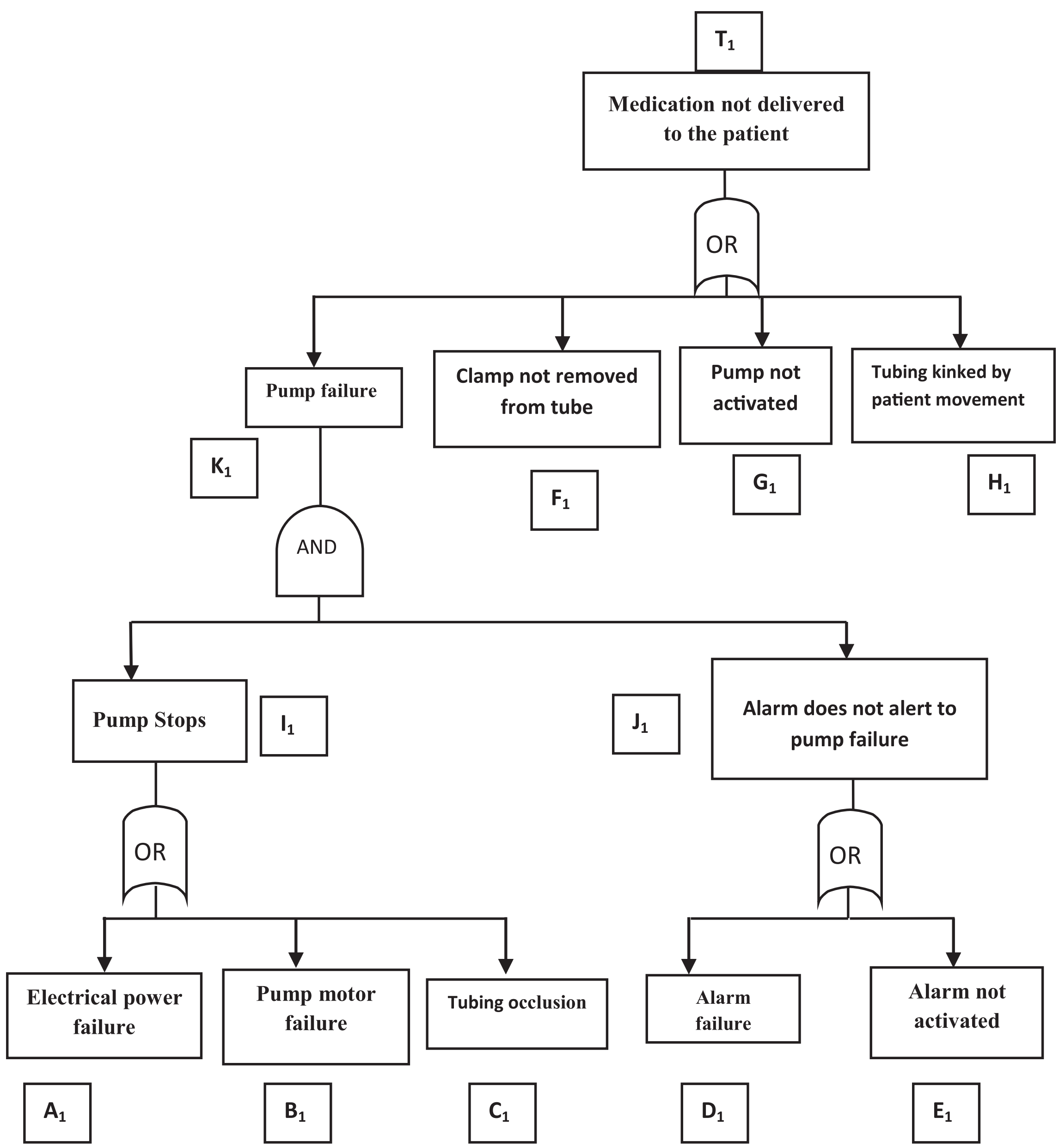

Fig. 6. Fault tree of medication pump

could not be possible for real system, and so we transform these values as different interval-valued TFNs (Triangular fuzzy numbers) as given in Table 4 (column 4).

Mathematical expression of event is given by;

$$T = K_1 \cup F_1 \cup G_1 \cup H_1 = (I_1 \cap J_1) \cup F_1 \cup G_1 \cup H_1 = \\ = ((A_1 \cup B_1 \cup C_1) \cap (D_1 \cup E_1)) \cup F_1 \cup G_1 \cup H_1. \quad (25)$$

By definition we can establish mathematical formula of this expression is given as:

$$q_{T_i} = 1 - \left[(1 - q_{K_1}) \times (1 - q_{F_1}) \times (1 - q_{G_1}) \times (1 - q_{H_1}) \right] = \\ = 1 - \left[(1 - q_{I_1} \times q_{J_1}) \times (1 - q_{F_1}) \times (1 - q_{G_1}) \times (1 - q_{H_1}) \right] = \\ = 1 - \Big[\Big(1 - \big(1 - (1 - q_{A_1}) \times (1 - q_{B_1}) \times (1 - q_{C_1})\big) \times \\ \times \big(1 - (1 - q_{D_1}) \times (1 - q_{E_1})\big)\Big) \times (1 - q_{F_1}) \times (1 - q_{G_1}) \times (1 - q_{H_1}) \Big]. \quad (26)$$

Now for calculating the output result for the crisp value, we use traditional method. For operate the fuzzy numbers, we use traditional fuzzy fault tree operation and in proposed method, we use the t-norm operation on interval-valued triangular fuzzy numbers. The operation between 'OR' gate and 'AND' gate in various method shown in Table 2 and Table 3.

13. Fuzzy Failure Probability and Reliability by various method

13.1. Max-Min Method

Huang et al. [9] max min method is applicable when the failure probability is extremely small. In this method we use maximum failure possibility among those events which are associated with 'OR' operation and minimum for which are associated with 'AND' operation. The crisp probability is in Table 4 (column 3)

$$P_{OSS}(I_1) = \max\left(P_{OSS}(A_1),\ P_{OSS}(B_1), P_{OSS}(C_1)\right) = \\ = \max(0.001, 0.001, 0.001) = 0.001,$$

$$P_{OSS}(J_1) = \max\left(P_{OSS}(D_1),\ P_{OSS}(E_1)\right) = \\ = \max(0.001, 0.001) = 0.001,$$

$$P_{OSS}(K_1) = \min\left(P_{OSS}(I_1),\ P_{OSS}(J_1)\right) = \\ = \min(0.001, 0.001) = 0.001.$$

Then, the top event failure possibility of top event "medication not delivered to the patient" is 0.001 and the reliability of "Medication delivered to the patient" is 0.999.

13.2. Tanaka et al. Method

Using Tanaka et al. method and Table 4 (column 4), the fuzzy failure probability of top event is $\begin{pmatrix} 0.0015511, 0.00297288494329, 0.004705098 : 0.8 \\ 0.0015511, 0.00297288494325, 0.004705098 : 1.0 \end{pmatrix}$ and fuzzy reliability is

$$\begin{pmatrix} 0.995294902, 0.99702711505671, 0.9984489 : 0.8 \\ 0.995294902, 0.99702711505671, 0.9984489 : 1.0 \end{pmatrix}.$$

Table 4. Transformation crisp value into triangular fuzzy numbers

Basic Event	Failure Probability	Crisp possibility	TFNs representation
A_1	$\tilde{q}_{A_1}$	0.001	$\begin{pmatrix} 0.0006, 0.0010, 0.0015 : 0.8 \\ 0.0006, 0.0010, 0.0015 : 1.0 \end{pmatrix}$
B_1	$\tilde{q}_{B_1}$	0.001	$\begin{pmatrix} 0.0006, 0.0010, 0.0015 : 0.8 \\ 0.0006, 0.0010, 0.0015 : 1.0 \end{pmatrix}$
C_1	$\tilde{q}_{C_1}$	0.001	$\begin{pmatrix} 0.00055, 0.0010, 0.0014 : 0.8 \\ 0.00055, 0.0010, 0.0014 : 1.0 \end{pmatrix}$
D_1	$\tilde{q}_{D_1}$	0.001	$\begin{pmatrix} 0.0006, 0.00095, 0.00145 : 0.8 \\ 0.0006, 0.00095, 0.00145 : 1.0 \end{pmatrix}$
E_1	$\tilde{q}_{E_1}$	0.001	$\begin{pmatrix} 0.0005, 0.0010, 0.0016 : 0.8 \\ 0.0005, 0.0010, 0.0016 : 1.0 \end{pmatrix}$
F_1	$\tilde{q}_{F_1}$	0.001	$\begin{pmatrix} 0.0005, 0.0010, 0.0016 : 0.8 \\ 0.0005, 0.0010, 0.0016 : 1.0 \end{pmatrix}$
G_1	$\tilde{q}_{G_1}$	0.001	$\begin{pmatrix} 0.00055, 0.00097, 0.0015 : 0.8 \\ 0.00055, 0.00097, 0.0015 : 1.0 \end{pmatrix}$
H_1	$\tilde{q}_{H_1}$	0.001	$\begin{pmatrix} 0.0005, 0.0010, 0.0016 : 0.8 \\ 0.0005, 0.0010, 0.0016 : 1.0 \end{pmatrix}$

13.3. t-norm proposed Method

Using the proposed t-norm operation and from **Table 3**, the fuzzy failure probability is

$$\begin{pmatrix} 0.00247417296853, 0.00297288494329, 0.00357225265339 : 0.8 \\ 0.00247417296853, 0.00297288494329, 0.00357225265339 : 1.0 \end{pmatrix},$$

and fuzzy reliability is

$$\begin{pmatrix} 0.99642774734661, 0.99702711505671, 0.99752582703147 : 0.8 \\ 0.99642774734661, 0.99702711505671, 0.99752582703147 : 1.0 \end{pmatrix}.$$

14. Defuzzification

14.1. Defuzzification by Tanaka et al. method

Defuzzifying by Tanaka et al. by traditional method using **eq.18** the failure probability of top event is 0.0814379427968 and reliability is 0.9185620572032.

14.2. Defuzzification of functional of interval-valued fuzzy probability of top event

Defuzzifying by proposed method the failure probability of top event using equation (23) and equation (24) is 0.0799309006739733 and reliability of top event is 0.92006909932026027.

The difference of both results is 0.00150704212282669 which is towards the left to failure probability obtained by traditional method.

15. Result

For obtaining the critical basic events of top event "Medication not delivered to the patient". We calculated the difference $V\left(\tilde{q}_{T_i}, \tilde{q}_{T_{1i}}\right)$ for each basic event using equation (11) and results are given in Table 7. Based on the value of index V in Table 7, it is analyzed that the most critical basic events are F_1 and H_1 whereas least critical basic events is C_1. The orders of all critical basic events are given below in decreasing manner;

$$(F_1, H_1) > G_1 > E_1 > D_1 > (A_1, B_1) > C_1. \qquad (27)$$

The comparison between various methods is shown in **Table 5** and **Table 6.**

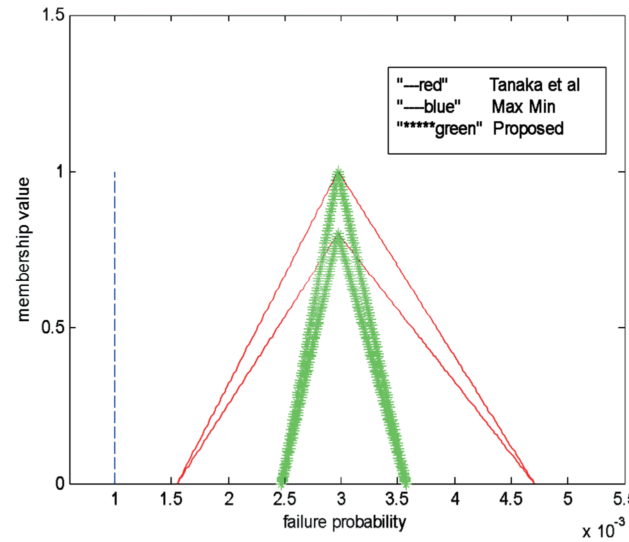

Fig. 7. Failure Probability of "Medication not delivered to Patient

Table 5. Comparison between Max-Min and Tanaka et al. method

Membership value	Max-Min Method	Tanaka et.al method			
		Left Points		Right Points	
0.1	0.001	0.00169327849433	0.00172882311791	0.00448857136791	0.00453187669433
0.2	0.001	0.00183545698866	0.00190654623582	0.00427204473582	0.00435865538866
0.3	0.001	0.00197763548299	0.00208426935373	0.00405551810373	0.00418543408299
0.4	0.001	0.00211981397732	0.00226199247165	0.00383899147164	0.00401221277732
0.5	0.001	0.00226199247165	0.00243971558956	0.00362246483956	0.00383899147164
0.6	0.001	0.00240417096597	0.00261743870747	0.00340593820747	0.00366577016597
0.7	0.001	0.00254634946030	0.00279516182538	0.00318941157538	0.00349254886030
0.8	0.001	0.00268852795463	0.00297288494329	0.00297288494329	0.00331932755463
0.9	0.001	0.00283070644896			0.00314610624896
1	0.001	0.00297288494329			0.00297288494329

Table 6. Comparison between max-min and t-norm proposed method

Membership value	Max-Min Method	Proposed t-norm method			
		Left Points		Right Ponts	
0.1	0.001	0.00252404416601	0.00253651196538	0.00349733168963	0.00351231588238
0.2	0.001	0.00257391536348	0.00259885096222	0.00342241072586	0.00345237911137
0.3	0.001	0.00262378656096	0.00266118995906	0.00334748976210	0.00339244234036
0.4	0.001	0.00267365775843	0.00272352895591	0.00327256879834	0.00333250556935
0.5	0.001	0.00272352895591	0.00278586795275	0.00319764783458	0.00327256879834
0.6	0.001	0.00277340015339	0.00284820694960	0.00312272687081	0.00321263202733
0.7	0.001	0.00282327135086	0.00291054594644	0.00304780590705	0.00315269525632
0.8	0.001	0.00287314254834	0.00297288494329	0.00297288494329	0.00309275848531
0.9	0.001	0.00292301374581			0.00303282171430
1	0.001	0.00297288494329			0.00297288494329

Table 7. Ranking of basic event of Example 1 using failure difference

Eliminated event	$\tilde{q}_{T_{1i}}$	$V\left(\tilde{q}_{T_i},\tilde{q}_{T_{1i}}\right)$	Rank
$A_1(i=1)$	$\begin{pmatrix} 0.0024722231738, 0.00297094556083, 0.00357031413827 : 0.8 \\ 0.0024722231738, 0.00297094556083, 0.00357031413827 : 1.0 \end{pmatrix}$	0.000005827692319999422	5
$B_1(i=2)$	$\begin{pmatrix} 0.00247222317380.00297094556083 0.00357031413827 : 0.8 \\ 0.00247222317380.00297094556083 0.00357031413827 : 1.0 \end{pmatrix}$	0.000005827692319999422	5
$C_1(i=3)$	$\begin{pmatrix} 0.00247222332310.00297094556083, 0.00357031413826 : 0.8 \\ 0.00247222332310.00297094556083, 0.00357031413826 : 1.0 \end{pmatrix}$	0.000005827635119999477	6
$D_1(i=4)$	$\begin{pmatrix} 0.00247133568504, 0.002970004907872, 0.00356941849523 : 0.8 \\ 0.00247133568504, 0.002970004907872, 0.00356941849523 : 1.0 \end{pmatrix}$	0.000008551477067999993	4
$E_1(i=5)$	$\begin{pmatrix} 0.00247118607859 0.00296989967328, 0.00356926886526 : 0.8 \\ 0.00247118607859 0.00296989967328, 0.00356926886526 : 1.0 \end{pmatrix}$	0.000008955948079999217	3
$F_1(i=6)$	$\begin{pmatrix} 0.00147561271983 0.00197485980309, 0.00257452629985 : 0.8 \\ 0.00147561271983 0.00197485980309, 0.00257452629985 : 1.0 \end{pmatrix}$	0.00299431174244	1
$G_1(i=7)$	$\begin{pmatrix} 0.00150563254453 0.00200482962803, 0.00260452717178 : 0.8 \\ 0.00150563254453 0.00200482962803, 0.00260452717178 : 1.0 \end{pmatrix}$	0.00290432122087	2
$H_1(i=8)$	$\begin{pmatrix} 0.00147561271983 0.00197485980309, 0.00257452629985 : 0.8 \\ 0.00147561271983 0.00197485980309, 0.00257452629985 : 1.0 \end{pmatrix}$	0.00299431174244	1

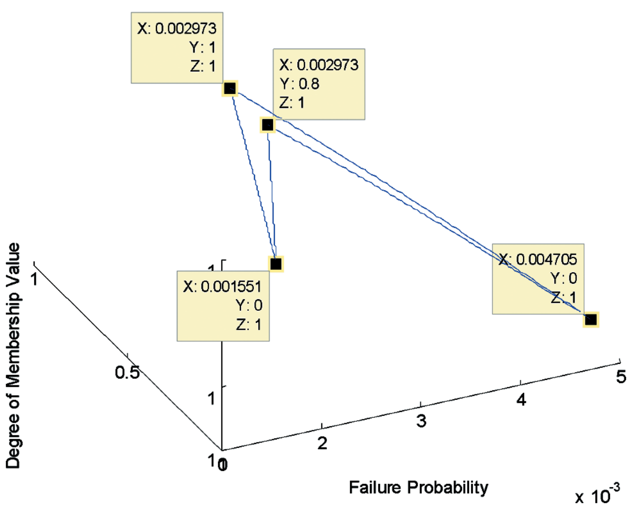

Fig. 8. Functional fuzzy failure Probability of Top Event

16. Conclusion

This whole study developed FTA, t-norm and functional fuzzy numbers for interval valued triangular fuzzy numbers. This study consist two types of healthcare related problems and their defuzzification methods to analyse the reliability from various existing techniques and therefore we conclude that t norm method gives small accumulation and how functional fuzzy number changes the reliability. Similarly from V index method we found the least critical events about any system and health experts can use these methods to reduce the failure probability of any clinical process.

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The authors' contribution

Kapil Naithani changed the fuzzy problem of a clinical system into a functional fuzzy set and applied the centre of gravity defuzzification methods in functional value and compare with other defuzzification techniques in fuzzy set to find fluctuation of reliability value among different methods.

Rajesh Dangwal gave an example of a clinical methods and a fault tree with the failure probability of basic events to find exact possibility of failure of events to increase the reliability of system.

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Comments on the contents of the dependability terminology standard

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Abstract. Aim. *The long-lasting discussion of the dependability-related terminology is evidence of the relevance of the subject matter and, at the same time, identifies difficulties associated with finding middle-ground solutions. This article aims to eliminate the shortcomings associated with the application of the conventional, yet insufficiently substantiated terms in the GOST 27.002-2015 interstate standard. Correct understanding and use of terms are of great significance.* **Methods.** *The paper lays down the requirements for the used terminology in terms of internal logical consistency and identifies specific terms, the use of which violates such requirements. Several terms from the standard underwent a logical and terminological analysis based on statutory requirements and the semantic meanings of such terms.* **Findings and conclusions.** *The paper states that the perfection of terms, definitions and basic concepts comes down to the fact that a standard shall not contain synonyms, homonyms and terms previously adopted in other standards with new or modified definitions. The terminological analysis helped to identify the terms whose use is unjustified. It was noted that the term "dependability" is clearly defined as a property, whose content and meaning are set forth with adequate substantiation. However, other definitions of dependability in the standard are not substantiated. Several cases of the use of terms that do not comply with the proposed requirements were considered, e.g., "dependability estimation", "dependability indicators estimation", "state of item", etc.*

Keywords: *dependability, terminology, requirements for terms.*

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Introduction

In the Russian Federation, an interstate standard [1] was into action that is used practically in all technical fields in the country. It should be noted that the users of the standard also include college students majoring in various branches of technology.

The author responded to the call of the Editorial Board to take part in the discussion of the dependability-related terminology.

In this paper, based on regulatory documents and logical terminological analysis, requirements are defined that, in the author's opinion, the used terms must comply with. Then, several use cases of terms are noted that do not comply with such requirements. At the same time, the author does not engage into a discussion regarding what concepts and their definitions are to be.

Source overview

As of late, a number of papers have been published that are dedicated to the dependability-related terminology. Many authors focused on the definition of the term "dependability". However, the standard [1] contains many other terms and definitions that, in the author's opinion, require rethinking and improvement. The most thorough publication in this subject matter is [8]. It sets forth the main principles that a general dependability-related terminology standard is to conform to: continuity in relation to preceding similar standards, alignment with other general technical standards, close association with international standards, internal consistency and logical coherence. In [8], the concept of dependability is examined subject to the conditions of operation, maintenance, storage and transportation. It is concluded that the definition of the term "dependability" is to reflect its nature as a comprehensive property.

In [5], the discussion continues on a limited number of concepts and terms, namely "entity", "item", "failure", "property", "calculation", "estimate", etc. For instance, it is concluded that the term "dependability estimation" should not be used. It is noted that according to standard [2] estimation (estimator) is understood as the statistics used for the purpose of estimating a certain parameter. It is concluded that the terms "estimate" and "dependability estimation" should not be introduced into the national dependability standard.

In [7], the terms "item" is analyzed that is used in the fundamental standard [1]. The term's history is examined, a list of the types of items is provided, the term "entity" is discussed that is used as a synonym of "item". It is clarified that the concept of "item" may cover hardware and software.

The author of [9] focused on the definition of the term "dependability", in which the author sees two parts, i.e. the functional and the parametric. The paper demonstrates the possibility of a common approach to the functional and parametric dependability, which, in the author's opinion, would allow refining the definition of dependability as a property. The requirement is substantiated for a clear interpretation of the term "dependability".

In [4], the current system of dependability-related terms is criticized and substantiated, in the author's opinion, proposals as to the modification of fundamental terms are suggested. For instance, "dependability" is interpreted not as a property, but as a science; reliability, maintainability, storability, durability are interpreted not as properties, but as dependability indicators (i.e., indicators of a science?), etc. The contradiction is eliminated by introducing the term "item": "item dependability", "item reliability", etc.

Methods

First, let us dwell upon the general principles and distinctive features of their application in the area of dependability. The author agrees that "if the general principles are agreed upon first, then it will be easier to come to solutions for specific terms and definitions" [8].

The Standardization Recommendations [3] state that the terminology is to be unambiguous and self-consistent. The Recommendations set forth the requirements a used term is to comply with. A term must express only one concept and one concept must be expressed by only one term. Two or more definitions of one concept are not acceptable. Violations of such concordance cause polysemy (homonymy) and synonymy.

In the introduction to the standard [1] it is stated that, for each concept, a single standardized term is defined, while Section 1 also states that synonymous terms cannot be applied. It is obvious that the terms, definitions and basic concepts set forth in this standard are to comply with those requirements. Thus, the perfection of terms, definitions and basic concepts, in the author's opinion, comes down to the following:

1) all terms, definitions and basic concept set forth in the standard are to be unambiguous and self-consistent;

2) all terms, definitions and basic concepts set forth in the standard are to be consistent with other national standards and not contradict preceding standards.

That means that a national standard **shall not contain**:

1) different terms, definitions and basic concepts with identical scope and meaning (must not contain synonyms);

2) one and the same term, definition and basic concept with different scope and meaning (must not contain homonyms);

3) terms previously adopted in other national standards with new, modified scope.

When the above deviations and discrepancies are the case, the standard must contain the required explanations and justifications.

Given the above, some remarks regarding standard [1] can be made that could later provide the foundation for subsequent proposals for amendments aimed at improving the standard.

First of all, the meaning of the basic concepts in the name of the standard are to be clarified. Those include the concept of "term", "definition" and "dependability". The definitions of the first two concepts are given in [3]:

Term, a word or phrase belonging to a certain field of knowledge chosen or created for the purpose of expressing a concept and requiring a definition.

Definition, a logical technique that allows distinguishing, finding and representing a relevant concept.

For a better understanding of the above concepts, let us provide their definitions based on information from general purpose dictionaries and encyclopedias.

Term, a word or phrase that clearly designates a certain concept used in a special field of science, technology, art.

Definition, a wording that clarifies the meaning, content, essence, primary characteristic features of the terms using known and meaningful words.

The term “dependability” is defined in item 3.1.5 of standard [1]:

Dependability is the property of an object to maintain in time the ability to perform the required functions in the specified modes and conditions of operation, maintenance, storage and transportation.

In this definition of the term “dependability”, the essence of the term is explained and its content is defined as a property. This definition is unambiguous. No other interpretations, methods, means, variants, varieties of the definition of the term “dependability” must exist.

Thus, the terms, definitions and basic concepts used in standard [1] must comply with the above requirements, including “term”, “definition”, “dependability”, featured in the title of the standard must also comply with such requirements.

Results

Let us take the liberty to note the contradictory and incorrect use of certain terms, definitions and concepts in the standard [1].

1. “Methods of dependability definition”

The standard mentions three methods of defining the dependability in the following items:

3.7.9 computational method of dependability definition;

3.7.10 computational and experimental method of dependability definition;

3.7.11 experimental method of dependability definition.

Thus, in this standard, the term “dependability” is defined as a property (item 3.1.4) and three more various methods of defining this term, in which no definitions (wording) is given. Therefore, the above methods of defining the term “dependability” are meaningless.

The term “method of dependability definition” is not included in the alphabetical index.

2. Use of the concept of “definition”

The concept of “definition” is used in the following items:

3.7.6 definition of numerical values;

3.7.8 definition of compliance with …

No definition of “dependability estimation and “dependability supervision” is given. Apparently, the concept of “definition” is used in a different sense that is not explained in the standard.

3. “Dependability estimation”

The standard uses the concept of “dependability estimation”:

3.7.6 Dependability estimation as the definition of the numerical values of the item’s dependability;

3.7.10 Method of dependability estimation …

As “Dependability” is a property, the above terms imply the “property estimation”. The definition of the term “property estimation” is not given; the concept is not defined in either regulatory documents, or other sources. The introduction of the term “dependability estimation” by the authors of the standard was not justified.

It should be noted that, according to the standard [2], “estimate” is a statistic used for the purpose of estimating a parameter that is a feature of a family of distributions. Thus, the terms “estimate” is defined in standard [2], according to which parameters, rather than properties (!) are defined.

4. “State”

This term is used in Section “3.2 States”. This section is the only one, whose title consists of a term, whose definition is not given. In order to provide a comprehensive idea of this shortcoming, let us note the sections, whose names are made of defined terms:

3.4 Failures, defects, damage

3.5 Maintenance, restoration and repairs

3.6 Dependability indicators

3.8 Redundancy

3.9 Dependability testing

However, section “3.2. States” is an exception from the rule; the term in the title is not defined.

The term “state” is not included in the alphabetical index.

5. “State of item”

In section “3.2 States”, various states are mentioned that are defined through the term “state of item”. There are more than 10 such states. Therefore, the term “state of item” can be considered fundamental. However, this term is not defined. A simple question arises: is it possible that (in a national standard!) terms are defined through a term that is not defined?

The term “state of item” is not included in the alphabetical index.

Discussion and conclusions

Thus, the paper sets forth substantiated suggestions for improving the dependability terminology standard. It is shown that standard [1] contains ambiguity and logical inconsistency as regards the standardization of certain terms.

In standard [1], the term “dependability” is clearly defined. Other definitions of dependability used in the standard are not substantiated. The term “dependability estimation” is introduced incorrectly. This term contradicts well-known and universally adopted terms “estimate”. The concept of “definition” is used in the standard with different meanings.

The author hopes that the publication and discussion of the above observations will enable a stricter approach to the wordings of the dependability terminology standard.

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The author's contribution

The author conducted a terminological analysis of the fundamental dependability terminology standard and noted incorrect application of certain terms. If the author's point of view is adopted, such terms can be improved or provided with better substantiated definitions.

The analysis identified the terms, whose definition need improvement.

Conflict of interests

The author declares the absence of a conflict of interests.

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On the functional safety of a complex technical control system with digital twins

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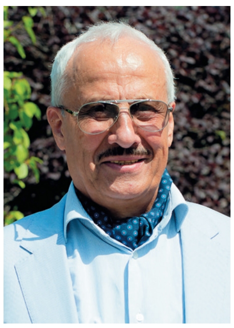

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Abstract. *The* **Aim** *of this paper is to evaluate the advantages of digital twin technology as compared with the conventional approaches to the design of a vital two-channel system.* **Methods.** *The system is described with a Markovian model. This model allows defining the quantitative safety characteristics if the system is affected by right-side failures.* **Results.** *The system's primary quantitative safety indicators were identified as the mean time to wrong-side failure and mean time to right-side failure along with the quantitative relations of the prime and additional costs for a batch of products.* **Conclusion.** *Transforming the initial item into a system with digital twins allows significantly reducing the rate of wrong-side failures. This effect may be obtained not only with the use of digital twins, but also as the result of the system transitioning into the state of right-side failure in each event of discrepancy betwin the initial item and/or the digital twins. It has been established that the mean time to right-side failure under such conditions is not less than the mean time to failure of the initial item. That means that highly efficient measures for safety improvement allow maintaining the system dependability at a level not lower than that of the initial item. The introduction of digital twins into a system is a new, not yet tested way of ensuring system safety. The decision on the benefits of additional costs is taken by the customer and system developer together. At the same time, it must be taken into consideration that in case of large batches of manufactured technical systems, the effect of additional costs is reduced and the effect of significantly improved safety is maintained.*

Keywords: *digital twin, functional safety, control system*

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1. Introduction

The paper examines a control system that is supposed to operate with a high level of functional safety. Possible solutions for control system design are given in the IEC 61508 standard [1]. In the context of train control and/or protection systems, many recommendations regarding the functional safety of hardware and software are sets forth in the EN 50128 [2] and EN 50129 [3] standards, as well as in [4 – 10, etc.]. The key solutions consist in the application of multichannel hardware and multiversion software, which naturally causes significantly higher costs of the systems and often limits their serial use. We must note certain difficulties in terms of upgrading and modification of such system due to the requirement to redesign its redundant components subject to new needs. In railway transportation, those are due to the system's adaptation to another type of rolling stock, variation of track tonnage, change of line class, etc.

The current problem consists in designing affordable mass-producible train control and protection systems that comply with the stricter requirements for functional safety. In this paper, the feasibility is examined of designing a train control and/or protection system comprising an SIL1 or SIL2 initial item and outer circuit of digital twins designed for attaining the desired level of functional safety.

A digital twin is understood as an entity containing:

– the mathematical model of the initial item;

– the software implementation of the model that performs all the operating functions of the initial item;

– the results of model verification and proof of its adequacy to the initial system, as well as a list of hazardous and potentially hazardous states defining the allowed duration of wrong-side failures of the initial item;

– operational documentation.

As a whole, a digital twin can be represented as a complex diagnostics tool.

2. Architecture of a technical system with a digital twin

The architecture of a digital twin is shown in Fig. 1. It is somewhat similar with the architecture of a complex industrial controlled system suggested in [11], but does not repeat it.

A digital twin is generated as a computer model consisting of three interconnected levels:

• *objective* level containing the computer model of the control system hardware components involved in the implementation of the system's operation algorithm, with associated models of executive and measurement devices;

• *logical* level that contains the simulation model of the operation algorithm of the train control and/or protection system;

• *visual* level where data is visualized, user control commands are generated.

Ensuring the adequacy of the virtual model to the real railway facility is the key element of the design of a train protection system. [12] As an item, let us examine a railway signalling system. The station-based automatic block and power (computer-based) interlocking systems contain sensors that provide information on the track circuit operating parameters (voltages at the receiver inputs). Describing the operation of such sensors is in itself a complicated task, as the aim is to select an optimum out of track occupancy observation modes, broken rail detection, cab signalling strength. However, such processes are well-studied and reduced to standard requirements that ensure traffic safety. Accordingly, for the purpose of virtual modeling, their mathematical description may be used as part of predictive diagnostics of the events that constitute the continuous process of their operation. For the next level of the virtual model that represents the discrete-event operation of the simulated item, it suffices to only have the value of the process parameters exceeding the norms of operability and safety.

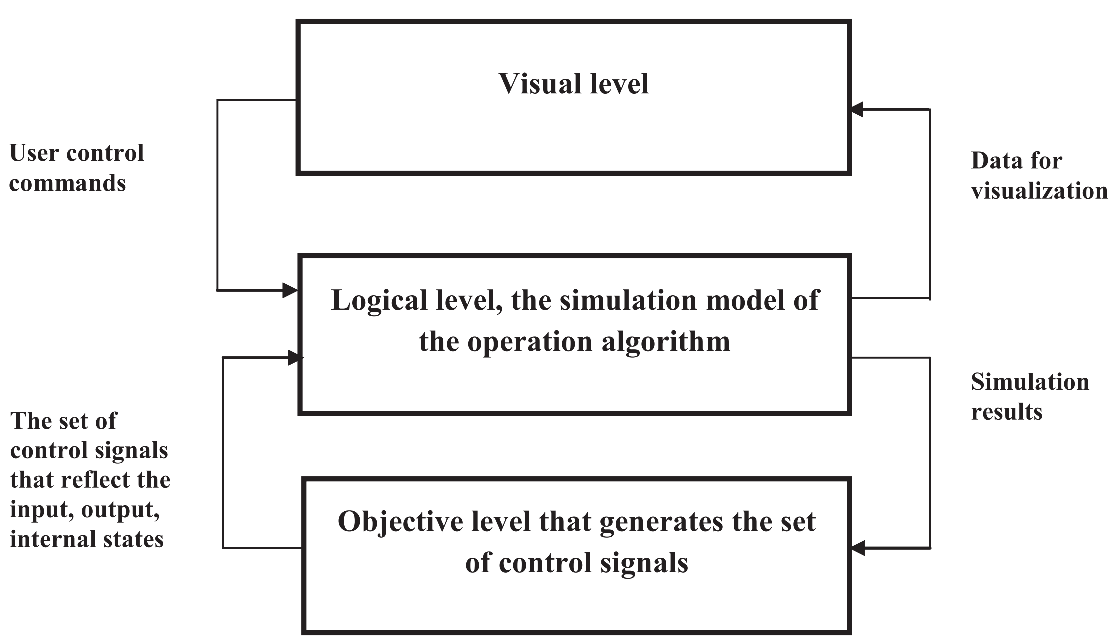

Fig. 1. Architecture of a digital twin

The discrete-event operation in the virtual model is well-represented with a discrete automaton, for which safety criteria have also been developed that are based on the monotonicity of the control functions. Similarly, the virtual model of the operation of individual rolling stock systems can be constructed. Thus, the operation of the brake line of a train in the braking mode comes down to valve opening, which causes the loss of pressure in the line and brake operation. The process itself is described by complex differential equations of airflow propagation throughout the length of the train. Estimating the consequences in terms of safety only requires to have the criteria of pressure drop in the tail car within the specified time. Given that the braking mode itself may be classified as service, full service and emergency, in the virtual model, the respective variants must be generated. It should be noted that the mechanical action of brake blocks against the wheels due to the discharging of the brake line can be described by limiting temporal characteristics that affect the length of braking.

For the next level of the virtual model, i.e., the level of train protection system description, it suffices to have the time marks of the beginning of brake valve opening and end of the train deceleration or its stopping.

Thus, the virtual model of a digital twin combines simplified continuous mathematical models of continuous processes in transformation of information and the associated discrete-event models.

The external circuit of the examined train control and/or protection system is formed by two same-type digital twins according to a dual-channel configuration with independent inputs and outputs and fail-safe comparator. The methods of designing the dual-channel configuration for the purpose of ensuring functional safety are described in the above standards.

The external circuit is connected with the initial single-channel item with an interference-immune and intrusion-protected communication channel (Fig. 2):

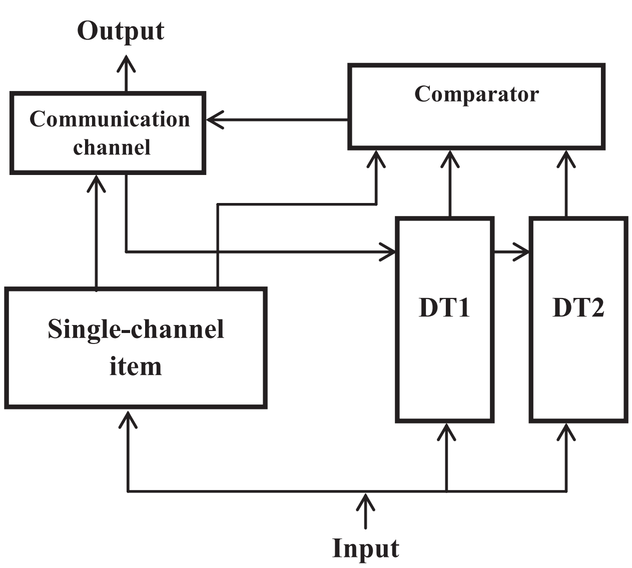

Fig. 2. Summarized structure diagram of a technical system with a digital twin

3. Efficiency estimation of a vital technical system with a digital twin

The system, whose diagram is shown in Fig. 2, falls into the category of vital technical systems (e.g., a train control and/or protection system) that is to comply with stricter requirements for functional safety. The introduction of digital twins into a vital technical system raises concerns and requires a more substantial safety case of such system. IEC 61508 [1] recommends a basic indicator of functional safety of an item, i.e., the rate of wrong-side failures λ. Then, as the indicator of the efficiency of a system with a digital twin we can consider the relation of the rate of wrong-side failures of the initial system λ_S, a single-channel item (Fig. 2), to the probability of wrong-side failure of a system with a digital twin λ_T. The higher is that relation, the more efficient is the application of digital twins in vital systems.

For fixed time intervals, the indicator of efficiency of digital twins is as follows: $E = \lambda_S/\lambda_T$.

In order to identify the rate of wrong-side failures of a system as a whole λ_T, the following prerequisites were adopted:

– a train control and/or protection system operates at a high demand rate;

– the dependability of a single-channel item is defined by the failure rate λ_1;

– the initial item is supervised with the probability of correct failure detection α. The digital twin is also supervised with the probability α. The probability of failure non-detection is $\overline{\alpha}$. The supervision tools are perfectly dependable. The probability of false alarm is negligibly small;

– the adequacy of the digital twin to the initial item is evaluated subject to the results of its verification. It is assumed that both digital twins adequately imitate the operation of the initial item. The corresponding safety integrity level is to be ensured using the IEC 61508 [1] part 3 or EN 50128 [2] standards.

– the dependability of a digital twin is defined by the systematic failures of its software. Failures manifest themselves under certain sets of input data. It is assumed that such sets are varied and random. That implies the feasibility of evaluating the dependability of a digital twin based on the failure rate λ_2. It is also assumed that the dependability of a digital twin is much higher than that of the initial item, i.e., $\lambda_2 << \lambda_1$.

– in case of detection of item failure, a command is issued to replace it by involving two digital twins. At the same time, it is understood that the probability of correct and timely delivery of the command is v;

– the comparator and ruggedized communication node are perfectly dependable (if that assumption is not ensured, the failure rates λ_1 and λ_2 may include respective shares associated with the comparator);

– exponential distributions of failures and recoveries of the item are adopted. That is due to the fact that most train control and/or protection systems include electrical/electronic equipment;

– random failure events of the item and digital twins are mutually independent;

– item failure and digital twin systematic failure restoration rates are equal to μ, as they are performed by a single maintenance crew;

– wrong-side failure restoration rates γ are defined by the duration of hidden (undetected by supervision tools) failures;

– it is assumed that system restoration times are distributed exponentially (that is a common assumption in such cases. However, even if the restoration time distribution function is not exponential, that barely affects the system's steady-state characteristics, see, e.g., Gnedenko and Kovalenko [13]).

Let us examine the model of system safety organization.

Criteria of right-side failure of a system with digital twins:

1. Non-matching performance of the initial item and digital twins caused by an undetected failure of the initial item or one of the digital twins. System restoration.

2. Failure of one of the digital twins. System restoration.

Criterion of wrong-side failure of a system with a digital twin:

Item failure and error in the delivery of the control command to involve the digital twins or failure of the initial item and digital twins.

The state graph of the safety of a technical system with digital twins (see. Fig. 2) according to model 1 is shown in Fig. 3.

Description of states:

1 – perfect state of system;

2 – detected failure of item;

3 – non-matching performance of the item and its digital twins due to an undetected item failure. The cause of non-matching performance is unknown. The system is put into the state of *right-side failure.* The system is restored;

4 – incorrect or untimely delivery of control command to involve the digital twins upon correct detection of item failure, *hazardous failure*. The failure is eliminated upon detection of a hidden failure;

5 – detection of a failure of one of the two digital twins. The system is put into the state of *right-side failure.* The system is restored.

The graph edges in Fig. 3 are marked with the following parameters: **1-2**: $\alpha\lambda_1$ is the detected failure flow of the initial item; **1-3**: $\bar{\alpha}(\lambda_1+2\lambda_2)$ is the non-detected failure flow of the item or digital twins; **1-5**: $\alpha 2\lambda_2$ is the detected failure flow of the digital twins; **4-2:** γ is the rate of hidden wrong-side failure; **2-4:** $\bar{v}2\lambda_2$ is the rarefied, with the probability of non-involvement $\bar{v}$, failure flow of digital twins; **2-5:** $v2\lambda_2$ is the rarefied, with the probability of involvement v, failure flow of digital twins; **3-1, 5-4:** μ is the system recovery rate; **5-4.**

The functional safety model of the examined system in Fig. 3 implies the following logic of operation. Initial state 1, all elements in perfect state. In case of detection of failure or fault in the item's operation, transition into state 2 occurs and command to replace it with digital twins is issued for

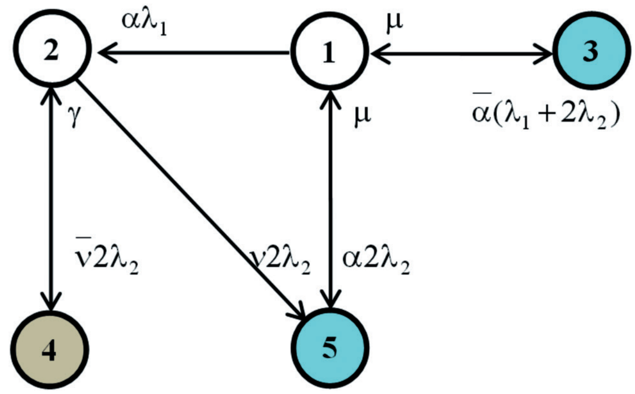

Fig. 3. Safety states graph of a system with digital twins

the period of time not affecting the occurrence of hazardous control actions. In case of actual or potential wrong-side failure, the item's output signals are blocked, as it is shown in patent [12]. If the initial item has failed and the performance of the digital twins does not match, the system is put into the state of right-side failure 3. If a failure of any one of the digital twins is detected and the item is in perfect state, the system goes from state 1 into state 5 of right-side failure. If the item and any one of the digital twins have failed, the system goes from state 2 into state 4 of wrong-side failure (if an error occurred in the process of involvement of the digital twins) or into state 5 in case of faultless digital twin involvement.

Under the adopted exponential distribution laws and, subsequently, constant failure and recovery rates in the examined system there is no consequence. That means that the system behaviour in the future depends on the current state and does not depend on the previous ones. Under the above prerequisites, the system's behaviour is described using a Markovian process.

In order to solve the problem, the input data is predetermined:

– the distribution functions of the system being in the states of the graph in Fig. 3.

$$F_1(t) = 1 - \exp[-(\lambda_1 + 2\lambda_2)t];$$

$$F_2(t) = 1 - \exp(-2\lambda_2 t);$$

$$F_4(t) = 1 - \exp(-\gamma \cdot t);$$

$$F_3(t) = F_5(t) = 1 - \exp(-\mu \cdot t);$$

– the mathematical expectation of the system being in the states of the graph in Fig. 3 according to formula:

$$T_i = \int_0^\infty [1 - F_i(t)]dt;\ T_i = \frac{1}{\lambda_1 + 2\lambda_2};\ T_2 = \frac{1}{2\lambda_2};$$

$$T_4 = \frac{1}{\gamma};\ T_3 = T_5 = \frac{1}{\mu}; \tag{1}$$

- probabilities of transition according to formula: $p_{ij} = \int_0^\infty \lambda_{ij}[1 - F_i(t)]dt$, where λ_{ij} is the rate of system transition from state i into state j

$$p_{12}=\frac{\alpha\lambda_1}{\lambda_1+2\lambda_2};\ p_{13}=\frac{\overline{\alpha}(\lambda_1+2\lambda_2)}{\lambda_1+2\lambda_2};\ p_{15}=\frac{\alpha\cdot 2\lambda_2}{\lambda_1+2\lambda_2};$$

$$p_{24}=\overline{\nu};\ p_{25}=\nu;\ p_{31}=p_{42}=p_{51}=1; \qquad (2)$$

Key safety indicator, i.e., mean time to wrong-side failure T_{WS} can be defined using the topological method [14] according to formula

$$T_{WS}=\frac{T_1\Delta G^1_{S_{WS}}+\sum_{(k)}\sum_{i,j} l_k^{ij}\Delta G_k^j T_j}{\Delta G_{S_{WS}}}, \qquad (3)$$

where $\Delta G^1_{S_{WS}}$ is the weight of the expansion of the graph without the initial node 1 and set of hazardous states $S_{WS}=\{4\}$ and associated graph edges; $\Delta G_{S_{WS}}$ is the weight of the expansion of the graph without the set of hazardous states and associated graph edges; l_k^{ij} is the weight of the k-th path from node i to node j; ΔG_k^j is the weight of graph resolution without the nodes situated on the k-th path and without node j in the set of non-hazardous states $S_H=\{1,2,3,5\}$.

The resolution weights can be defined using Mason's gain formula [15]

$$\Delta G=1-\sum_i C_i+\sum_{ij} C_iC_j-\sum_{ijk} C_iC_jC_k+\ldots,$$

where the weights of boundaries are found within the set of non-hazardous states (Fig. 3):

$$C_1=p_{13}\cdot p_{31}=\frac{\overline{\alpha}(\lambda_1+2\lambda_2)}{\lambda_1+2\lambda_2};\ C_2=p_{15}\cdot p_{51}=\frac{2\lambda_2}{\lambda_1+2\lambda_2};$$

$$C_3=p_{12}\cdot p_{25}=\frac{\alpha\nu\lambda_1}{\lambda_1+2\lambda_2}.$$

All boundaries intersect, since they have a common node 1. The resolution weights of the graph in Fig. 3.

$$\Delta G^1_{S_{WS}}=1;$$

$$\Delta G_{S_{WS}}=1-C_1-C_2-C_3=1-\frac{\overline{\alpha}(\lambda_1+2\lambda_2)+2\lambda_2+\alpha\nu\lambda_1}{\lambda_1+2\lambda_2} \qquad (4)$$

According to the graph in Fig. 3 and substituting expressions (1), (2) and (4) into formula (3), we find within the set of non-hazardous states (1.2.5)

$$T_{WS}=\frac{T_1+p_{12}T_2+p_{13}T_3+(p_{15}+p_{12}p_{25})\cdot T_5}{1-C_1}=$$

$$=\frac{\mu(\alpha\lambda_1+2\lambda_2)+\overline{\alpha}2\lambda_2(\lambda_1+2\lambda_2)}{2\lambda_2\mu\cdot[\alpha(\lambda_1+2\lambda_2)-\alpha(\lambda_1\nu+2\lambda_2)]}. \qquad (5)$$

Given that the failure rate of the digital twin λ_2 is 2 to 3 orders of magnitude lower than that of the λ_1 initial item and $\mu>>2\lambda_2\lambda_1$, expression (5) with an error not higher than one order of vanishing, can be transformed as follows:

$$T_{WS}\approx\frac{1}{2\lambda_2\overline{\nu}}.$$

As the system's flow of wrong-side failures is multiply rarefied in relation to the right-side failure flow of the initial item that is a simplest one, then, according to [16, 17, 18] a multiply rarified, irregularly simplest failure flow is also a simplest one with constant parameter

$$\lambda_T=1/T_{WS}=2\lambda_2\overline{\nu}.$$

Note. In order to ensure an important assumption, i.e., "the failure rate of a digital twin is 2 or 3 orders of magnitude lower than that of the initial item", it is important that the software was designed using methods that comply with higher safety integrity levels, for instance, 2 of 3 safety integrity levels higher. Alternatively, the failure rate is to be proven statistically [19].

Ensuring the compliance with the EN 50159 [20] requirements for the communication channel safety, implies that the probability of timely and faultless communication of the command to involve the digital twins tends to one. Therefore, a probability $\overline{\nu}$ of incorrect delivery of digital twin control command close to 0 can be achieved. Subsequently, by using digital twins, the safety of the initial item in terms of wrong-side failure rate may be improved by several orders of magnitude. Indeed, let us examine the relation of the wrong-side failure rates of the initial item ($\lambda_O=\lambda_1$) to the wrong-side failure rate of the system: $E=\frac{\lambda_S}{\lambda_T}=\frac{\lambda_1}{2\lambda_2\overline{\nu}}$. As $\lambda_1>>\lambda_2$ and $\overline{\nu}\to 0$, our assertion is correct.

The above effect may be achieved not only with the use of digital twins, but also as the result of the system transitioning into the state of right-side failure in each event of initial architecture modification. Therefore, the time to system transition into any safe state should be compared to the time to failure of the initial item.

Let us identify the system's mean time to right-side failure. For that purpose, in the state graph in Fig. 3, we must calculate states 3.4.5 (states of wrong-side and right-side failures) together with the adjacent edges. Then, the graph on Fig. 3 modifies into the form shown in Fig. 4.

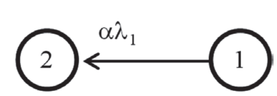

Fig. 4. Graph of the examined system without hazardous and safe states

We find the mean time to right-side failure according to formula (3), where all the expansion weights are equal to 1 due to the absence of boundaries in the graph in Fig. 4:

$$T_{RS}=T_1+p_{12}T_2=\frac{1+\alpha\lambda_1}{\lambda_1+2\lambda_2}.$$

Then, the relation of the mean time to right-side failure to the mean time to failure of the initial item subject to correlation $\lambda_1>>\lambda_2$ is defined as follows:

$$\frac{T_{RS}}{T_1} \approx \frac{1+\alpha\lambda_1}{\lambda_1}. \quad (6)$$

Thus, the mean time to right-side failure is not less than the mean time to failure of the initial item. That means that, within the examined model, provided highly efficient measures for safety improvement are in place, the system dependability is maintained at a level not lower than that of the initial item.

The introduction of digital twins into a system is a new, not yet tested way of ensuring system safety. Naturally, it requires a substantial safety case. That is associated with significant expenditures. On the one hand, there is a significant effect in terms of improved functional safety of the system. On the other hand, significant one-off costs may be required for the development of the digital twin algorithm C_{DTA} and preparation of the system safety case C_{SC}. Given the above, let us evaluate the economic feasibility of this approach.

Let the cost of the initial item be C_1. The cost of a system with digital twins is $C_1 + \Delta C_1$. The size of the batch of manufactured products is m units. The cost of a batch m systems with digital twins is $C_{BAT} = (C_1 + \Delta C_1)m + C_{DTA} + C_{SC}$. The cost of development of such system along with the cost of the safety case are acceptable if the following is true:

$$C_{BAT} - C_1 m \leq C_{SC}, \quad (7)$$

where C_{SC} is the acceptable investment in the assurance of the desired level of safety. The effect of additional costs on a batch of products can be estimated using the following expressions:

$$\frac{C_{BAT}}{C_1 m} = \frac{(C_1 + \Delta C_1)m + C_{DTA} + C_{SC}}{C_1 m}. \quad (8)$$

If $m \to \infty$, expression (8) modifies into

$$\lim_{m\infty\to} \frac{C_{BAT}}{C_1 m} = \frac{C_1 + \Delta C_1}{C_1}. \quad (9)$$

As the cost ΔC_1 of series production of digital twins in the system is significantly lower than the cost C_1 of production of the initial item, the expression (9) tends to 1. That means that in case of large batches of manufactured technical systems, the effect of additional costs is reduced.

The decision on the benefits of additional costs is taken by the customer and system developer together based on the requirement to ensure the safety of such system. However, the cost of ensuring a high level of system safety is about 10 to 50 times higher than the cost of the initial single-channel item, whereas the reduction of the rate of wrong-side system failures as compared with the same indicator for the initial item may amount to several orders of magnitude. This circumstance may play a key role in the decision regarding the application of digital twins for the purpose of technical system safety.

4. Conclusion

Transforming the initial item into a system with digital twins allows significantly reducing the rate of wrong-side failures. This effect may be obtained not only with the use of digital twins, but also as the result of the system transitioning into the state of right-side failure in each event of discrepancy between the initial item and/or the digital twins. It has been established that the mean time to right-side failure under such conditions is not less than the mean time to failure of the initial item. That means that highly efficient measures for safety improvement allow maintaining the system dependability at a level not lower than that of the initial item.

The introduction of digital twins into a system is a new, not yet tested way of ensuring system safety. Naturally, it requires a substantial safety case. That is associated with significant additional expenditures. The decision on the benefits of additional costs is taken by the customer and system developer together. At the same time, it must be taken into consideration that in case of large batches of manufactured technical systems, the effect of additional costs is reduced and the effect of significantly improved safety is maintained.

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The author's contribution

Igor B. Shubinsky developed the mathematical model, analyzed the findings.

Hendrik Schäbe developed the system state graph, defined the limits of the proposed model.

Efim N. Rozenberg defined the research problem.

Conflict of interests

The authors declare the absence of a conflict of interests.

 Original article
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A study of the socionic characteristics of males and females for improving the reliability of aptitude screening of aviation specialists

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Abstract. Aim. *This article continues the series of studies aimed at improving the aptitude screening of commercial aviation personnel. The socionic characteristics of a human operator define his/her work with information flows, and their significance is the higher, the greater is the time shortage they have to deal with as part of their professional activities, therefore, in this paper, those characteristics were examined as professionally important qualities of both a pilot, and an air traffic controller. The task consisted in evaluating the socionic characteristics of male and female control room specialists, who have successfully completed aptitude screening in commercial aviation, identifying the presence or absence of differences between the obtained results. Additionally, for the sake of comparison, the research covered the socionic characteristics of males and females, whose professional activities have nothing to do with technology. In total, the study includes data of over 3116 tested persons.* **Methods.** *The 5-th modification of the MM-1 socionic test developed by the Saint Petersburg State University of Civil Aviation was used as the psychodiagnostic method for estimating constituent socionic characteristics. The obtained samples were primarily compared using Pearson's chi-squared test. The results were also processed using correlation analysis.* **Results.** *The paper presents socionic portraits, i.e. the distribution of the dominating components of the human socionic model among various samples, socionic models of various professional groups (human socionic model for a typical member of a sample), as well as graphical data per individual psychological dichotomies: "extraversion – introversion", "logic – ethics", "sensorics – intuition", "rationality – irrationality".* **Conclusions.** *The identified differences between the studied samples are primarily professional in their nature, i.e. comparing samples of individuals from the same professional group and approximately the same age, but different gender, in no case reliable differences were identified. Thus, no fundamental gender-specific differences were identified by the socionic psychodiagnostic method used as part of this work. However, the analysis of a number of Russian and foreign sources dedicated to gender differences suggests that improving the reliability of aptitude screening of aviation specialists requires further research involving the evaluation of the differences in the expression of the necessary professionally significant qualities of control room specialists, not by criterion of biological sex, but rather in accordance with the identified gender-related personality type.*

Keywords: *aptitude screening, gender differences, socionics, socionic characteristics.*

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Introduction

The positive properties of intelligence, such as logic, quick-wittedness etc. were always classified as "general abilities adequate to the flying work" [1]. However, it would be more correct to classify them as any type of operational activity. And, without calling the above into question, it should also be noted that, for an operational activity, not only the level of intelligence matters, but also the ability to use it in a timely manner. If a software designer or an engineer can afford to stop and think over the optimal solution to a problem, an operator cannot do so. He/she has to not only continuously process large amounts of information, but do it at a high pace. Therefore, his/her thinking process is to comply with a number of quite specific requirements.

In the last century, Polish psychologist Antoni Kępiński [2] introduced the concept of "information metabolism" (IM) as the process of continuous exchange of information, in its broadest meaning, between an individual and the environment. The Lithuanian researcher Aušra Augustinavičiūtė, a follower of the Swiss psychiatrist Karl Gustav Jung, integrated his theory of psychological types [3] with Kępiński's theory of information metabolism, thus creating such discipline as socionics [4] that studies such processes of information exchange.

Therefore, it is quite obvious that the socionic characteristics of an operator that define his/her capabilities in terms of information exchange with the environment, including other crewmembers or air traffic controllers [5-8], are to be considered as his/her professionally important qualities (PIQ). Therefore, their correct consideration has a direct effect on the reliability of aptitude screening (AS) of aviation specialists.

Problem definition

In [9], the authors already defined the problem of the requirement to take gender differences into account as part of AS of aviation specialists. This matter is completely ignored in the current AS Guidelines [10] that, being a worsened version of the Soviet-era Guidelines [11] and due to then-working regulations, was designed exclusively for selecting males. That is to say nothing of other shortcomings of the Guidelines [10] that the authors analyzed in detail in [12-14] and a number of other works.

In [15], the authors dwelled upon the reasons why AS for females is to differ from the AS for males. It is another matter that it is quite difficult to pinpoint those PIQ, where it is required to take into consideration exactly the male and female features. It is quite obvious that, at least at the level of common sense, male psychology differs from female. The question is whether it affects the performance of aviation specialists and, if it does, then in what way? In [9], the authors aimed to examine some professionally important qualities in males and females and identify the presence or absence of differences in the obtained results. The analysis of the results of the conducted research [9] showed that, according to the employed psychodiagnostic methods – the Arnold H. Buss and Ann Durkee test[1], Prognoz-2 questionnaire[2] for estimating the stress tolerance and Hans Jürgen Eysenck's[3] test identifying the level of intellectual development – no fundamental gender-based differences were identified. An exception is the tendency towards physical aggression that was identified using the Arnold H. Buss and Ann Durkee test, where positive differences were found using Pearson's chi-squared test ($\chi^2_{0.01} = 11.345 > \chi^2_{emp} = 11.1289 > \chi^2_{0.05} = 7.815$ for $\nu = 3$). In females, this indicator is clearly lower, though there are girls who display high aggressiveness.

In this paper, the authors had the goal similar to that in [9], i.e. to examine whether there are gender-based differences in the socionic characteristics.

Inputs and methods

Naturally, as the main purpose of the research was to improve the reliability of AS of traffic control specialists, the majority of study participants were aviation professionals, primarily pilots and air traffic controllers.

However, in order to correct the shortcomings described in [14], humanities students were additionally tested in the Saint Petersburg State University of Civil Aviation (SPBGU GA) and Institute of Philology, Foreign Languages and Media Communication of the Irkutsk State University (IPFLMC ISU). For that purpose, with the assistance of V.S. Kamenskaya, a freelance psychologist, to whom the authors express their sincere gratitude, IPFLMC ISU undergraduate students majoring in Foreign Studies and Practice and Theory of Translation underwent comprehensive testing.

In this paper, the authors used data on 3116 tested individuals, including:

- 2582 males.
- 534 females.

Including:

- professional pilots from more than three dozen airlines of Russia, Azerbaijan, Belarus, Kazakhstan, Ukraine, Uzbekistan and Estonia (803 people);
- air traffic controllers from practically all regions of Russia (563 people);
- pilot students (males) of SPBGU GA (659 people);
- pilot students (females) of SPBGU GA (24 people);
- air traffic controller students (males) of SPBGU GA (103 people);
- air traffic controller students (females) of SPBGU GA (53 people);
- humanities students (males) of SPBGU GA (34 people);
- humanities students (females) of SPBGU GA (195 people);
- humanities students (males) of IPFLMC ISU (29 people);

[1] Karelin A.A. [Large encyclopedia of psychological tests]. Moscow: Eksmo; 2007. (in Russ.)

[2] Berg T.N. [Anxiety disorder and methods of its identification: a study guide]. Vladivostok: Maritime State University; 2005. (in Russ.)

[3] Eysenck H.J. Check your own I.Q. EKSMO-Press; 2003.

Table 1. Gender-specific socionic portraits of samples for various professional groups (as of 01.01.2020)

TIM	"Fitness" coefficient	Flying personnel students			Air traffic controller students			Ground crew students		Humanities students		Transportation organization and cabin crew students		TOTAL
		Professionals	SPBGU GA students		Professionals	SPBGU GA students		males	females	males	females	males	females	
			males	females		males	females							
SLE	0	319	184	8	182	31	15	85	23	11	55	26	21	960
LSE	0	201	143	8	133	36	12	76	16	8	30	29	10	702
SLI	0.75	121	38	3	74	7	3	30	14	5	11	11	11	328
LSI	0.75	81	47	3	57	13	1	29	9	6	15	11	4	276
SEE	0.75	30	15	1	25	7	1	17	10	5	30	8	9	158
LIE	0.75	5	3	0	8	3	1	15	6	6	15	3	0	65
SEI	1.5	12	5	0	17	1	1	2	5	2	9	8	4	66
LII	1.5	9	3	0	6	1	0	5	1	2	9	1	0	37
ESE	1.5	3	4	0	5	0	0	5	2	2	17	1	3	42
ILE	1.5	5	1	0	5	0	0	3	2	1	9	0	1	27
ESI	2,25	2	1	0	3	0	1	1	0	1	10	2	2	23
ILI	2,25	5	3	0	3	0	0	6	0	3	4	2	0	26
IEE	2,25	2	3	0	3	1	0	2	3	3	18	0	2	37
EIE	2,25	3	3	0	7	1	0	6	5	5	23	1	4	58
IEI	3	2	1	0	10	0	1	3	0	3	9	0	1	30
EII	3	3	1	0	3	2	0	1	0	0	9	2	1	22
TOTAL		803	455	23	541	103	36	286	96	63	273	105	73	2857
Here, TIM are:														
LSE – logic, sensoric, extroverted; ESE – ethical, sensoric, extroverted; SLE – sensoric, logical, extroverted; SEE – sensoric, ethical, extroverted; LSI – logical, sensoric, introverted; ESI – ethical, sensoric, introverted; SLI – sensoric, logical, introverted; SEI – sensoric, ethical, introverted; LIE – logical, intuitive, extroverted; EIE – ethical, intuitive, extroverted; ILE – intuitive, logical, extroverted; IEE – intuitive, ethical, extroverted; LII – logical, intuitive, introverted; EII – ethical, intuitive, introverted; ILI – intuitive, logical, introverted; IEI – intuitive, ethical, introverted;														

- humanities students (females) of IPFLMC ISU (93 people);
- nonflying personnel (males) (286 people);
- nonflying personnel (females) (96 people);
- transportation organizers and cabin crew members (males) from various Russian aviation enterprises (105 people);
- transportation organizers and cabin crew members (females) from various Russian aviation enterprises (73 people);

Additionally, the analysis covered previously obtained data that were published by the authors in [14, 16] and a number of others. The data were collected by the authors between 1999 and 2019. Due to such long period of data collection, in some cases, while the final results were preserved, the initial data were lost and new samples could not be made in full. That also explains the fact that in certain tables taken from other papers the numbers of individuals of certain professional categories slightly differ from those stated above (sometimes a characteristic is present in the general data, while another one is not present due to being lost, and vice versa). However, in the authors' opinion, such factors cannot have a crucial effect on the final result, as the difference in the used data that differ from table to table does not exceed 1.5%.

The findings were analyzed with the R programming language that is widely used as statistical software for data analysis and became a de-facto standard statistical program[1] (licensed under GNU GPL[2]). This work used correlation analysis methods and Pearson's chi-squared test ($\chi2$)[3].

The research was conducted in accordance with primary bioethical rules[4] on a voluntary basis.

[1] Data Science and Analytics / University Information Technology. Available at: http://it.unt.edu/research

[2] Free Software Foundation. Available at: https://fsf.org/

[3] Bock D.E., Velleman P.F., De Veaux R.D. Stats: modeling the world. 4th Edition. Boston (USA): Pearson Addison Wesley; 2015

[4] Bioethics / Internet Encyclopedia of Philosophy. Available at: https://www.iep.utm.edu/bioethic/

Table 2. Comparison of TIM distribution per Pearson's chi-square test

1-st sample	N_1	2-nd sample	N_2	Number of degrees of freedom (ν)	χ^2_{emp}	χ^2_{crit}	Conclusion
1	455	2	23	2	0.294	5.991 for $p < 0.05$ 9.210 for $p < 0.01$	No reliable differences identified ($p > 0.05$)
1	455	3	103	3	8.874	11.070 for $p < 0.05$ 15.086 for $p < 0.01$	No reliable differences identified ($p > 0.05$)
1	455	7	63	4	83.982	9.488 for $p < 0.05$ 13.277 for $p < 0.01$	Differences are highly reliable ($p \leq 0.01$)
2	23	4	36	2	0.332	5.991 for $p < 0.05$ 9.210 for $p < 0.01$	No reliable differences identified ($p > 0.05$)
2	23	8	273	3	20.956	7.815 for $p < 0.05$ 11.345 for $p < 0.01$	Differences are highly reliable ($p \leq 0.01$)
3	103	4	36	3	2.213	7.815 for $p < 0.05$ 11.345 for $p < 0.01$	No reliable differences identified ($p > 0.05$)
3	103	7	63	5	32.664	11.070 for $p < 0.05$ 15.086 for $p < 0.01$	Differences are highly reliable ($p \leq 0.01$)
4	36	6	96	3	12.500	7.815 for $p < 0.05$ 11.345 for $p < 0.01$	Differences are highly reliable ($p \leq 0.01$)
4	36	8	273	4	31.551	9.488 for $p < 0.05$ 13.277 for $p < 0.01$	Differences are highly reliable ($p \leq 0.01$)
4	36	10	73	4	11.574	9.488 for $p < 0.05$ 13.277 for $p < 0.01$	Differences are reliable ($p \leq 0.05$)
5	286	6	96	7	10.014	14.067 for $p < 0.05$ 18.475 for $p < 0.01$	No reliable differences identified ($p > 0.05$)
6	96	8	273	10	31.987	18.307 for $p < 0.05$ 23.209 for $p < 0.01$	Differences are highly reliable ($p \leq 0.01$)
7	63	8	273	8	5.683	15.507 for $p < 0.05$ 20.090 for $p < 0.01$	No reliable differences identified ($p > 0.05$)
7	63	9	105	6	15.636	12.592 for $p < 0.05$ 16.812 for $p < 0.01$	Differences are reliable ($p \leq 0.05$)
9	105	10	73	6	8.530	12.592 for $p < 0.05$ 16.812 for $p < 0.01$	No reliable differences identified ($p > 0.05$)

SAMPLES			
1	Student pilots Males	2	Student pilots Females
3	Student air traffic controllers Males	4	Student air traffic controllers Females
5	Ground crew students Males	6	Ground crew students Females
7	Male humanities students	8	Female humanities students
9	Operations division Males	10	Operations division Females

Results and discussion

Let us examine the socionic portraits [16, 17], i.e., the distribution of the types of information metabolism (TIM) or, more precisely, the dominating components of an individual's socionic model (ISM) [17] out of various samples (Table 1). All data were obtained using the 5-th version of the MM-1 test [14, 16, 18]. Let us compare the obtained samples based on Pearson's chi-squared test and put the obtained results into Table 2.

Analyzing the findings shown in Tables 1 and 2 clearly shows that the differences between the studied samples are primarily professional in their nature. Comparing samples of individuals from the same professional group and approximately the same age, but different gender, in none of the five cases reliable differences were identified ($p > 0.05$). That wholly confirmed the prediction of Aušra Augustinavičiūtė [4] regarding the absence of differences in the gender-based distribution of TIM, but somewhat contradicts Jung's theory [3], according to which such psychological function as "ethics" in females (Jung's "Fühlen") is dominant. At the same time, highly reliable ($p \leq 0.01$) for both males, and females are the differences between the humanities specialists and nonflying personnel. The "service" professional group, as expected, in terms of its socionic characteristics, turned out to be something between the "humanities" and the "technology", but here the differences between the professional groups are reliable as well ($p \leq 0.05$). There are no reliable differences ($p > 0.05$) between same-gender student pilots and air traffic controller students, which was to be expected as well.

Table 3. Gender-specific socionic models of samples for various professional groups (%) according to the SPBGU GA data (as of 01.01.2020)

TIM	"Fitness" coefficient	Flying personnel students			Air traffic controller students			Ground crew students		Humanities students		Transportation organization and cabin crew students	
		Professionals	Students SPBGU GA		Professionals	Students SPBGU GA		males	females	males	females	males	females
			males	females		males	females						
SLE	0	14.9	14.1	12.8	12.8	11.3	13.9	11.6	12.3	9.6	9.5	10.4	11.7
LSE	0	11.1	11.8	14.0	10.4	11.6	9.9	10.7	8.9	7.9	7.6	10.3	8.5
SLI	0.75	10.0	8.2	9.2	9.2	7.0	86	7.8	7.9	6.8	5.8	8.3	86
LSI	0.75	7.5	7.5	8.9	7.4	7.6	6.1	7.4	5.6	6.5	5.6	7.2	5.3
SEE	0.75	86	86	7.5	8.4	7.6	9.6	7.8	9.8	7.8	8.7	7.5	9.7
LIE	0.75	5.7	6.8	6.9	6.2	7.7	6.6	7.2	6.6	6.5	6.6	6.8	5.8
SEI	1.5	6.0	5.2	5.2	6.2	5.1	6.3	5.3	6.4	5.7	5.3	6.4	7.0
LII	1.5	4.3	4.4	4.3	4.6	5.3	4.2	5.1	4.1	5.6	4.8	5.3	3.7
ESE	1.5	5.1	5.8	5.9	5.4	6.5	5.5	6.1	5.8	5.8	7.2	5.7	6.0
ILE	1.5	6.3	6.7	6.1	6.2	6.1	6.2	6.4	6.9	6.6	7.0	5.7	6.5
ESI	2.25	3.7	3.7	3.7	4.1	4.5	3.8	4.3	3.8	4.6	4.8	4.9	3.9
ILI	2.25	4.5	4.0	4.2	4.7	4.1	4.5	4.5	4.6	5.7	4.5	4.9	4.8
IEE	2.25	3.9	4.5	3.7	4.4	4.4	4.5	4.7	5.8	6.0	7.0	4.5	6.1
EIE	2.25	3.1	3.6	3.1	3.7	4.7	3.8	4.6	4.7	5.4	6.7	4.3	5.2
IEI	3	3.0	2.7	2.5	3.5	3.1	3.7	3.3	3.9	5.2	4.4	4.0	4.2
EII	3	2.3	2.4	2.0	2.8	3.4	2.8	3.2	2.9	4.3	4.5	3.8	3.0
TOTAL (people)		803	455	23	541	103	36	286	96	63	273	105	73

Here, TIM are:

LSE – logic, sensoric, extroverted; ESE – ethical, sensoric, extroverted; SLE – sensoric, logical, extroverted; SEE – sensoric, ethical, extroverted; LSI – logical, sensoric, introverted; ESI – ethical, sensoric, introverted; SLI – sensoric, logical, introverted; SEI – sensoric, ethical, introverted; LIE – logical, intuitive, extroverted; EIE – ethical, intuitive, extroverted; ILE – intuitive, logical, extroverted; IEE – intuitive, ethical, extroverted; LII – logical, intuitive, introverted; EII – ethical, intuitive, introverted; ILI – intuitive, logical, introverted; IEI – intuitive, ethical, introverted;

Table 4. Identified correlation between gender-specific socionic models of samples for various professional groups according to the SPBGU GA data (as of 01.01.2020)

Sample (1-st / 2-nd)	1	2	3	4	5	6	7	8	9	10
1		+0.9674	+0.9682	+0.9702	+0.9932	+0.9387	+0.9606	+0.7869	+0.9701	+0.8931
2	$p < 0.001$		+0.9718	+0.9014	+0.9790	+0.8453	+0.8840	+0.6579	+0.9831	+0.8019
3	$p < 0.001$	$p < 0.001$		+0.8977	+0.9865	+0.8557	+0.8945	+0.7526	+0.9574	+0.7906
4	$p < 0.001$	$p < 0.001$	$p < 0.001$		+0.9477	+0.9801	+0.9658	+0.7932	+0.9414	+0.9566
5	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$		+0.9128	+0.9420	+0.7721	+0.9758	+0.8618
6	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$		+0.9690	+0.8714	+0.8846	+0.9845
7	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$		+0.8419	+0.8955	+0.9276
8	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$		+0.6587	+0.8432
9	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$		+0.8511
10	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	

Notes: On the right and at the top are the values of the Pearson correlation coefficient between such performance indicators, while on the left and at the bottom there are the characteristics of correlation significance.
The number of samples corresponds to the numbers of samples in Table 2.

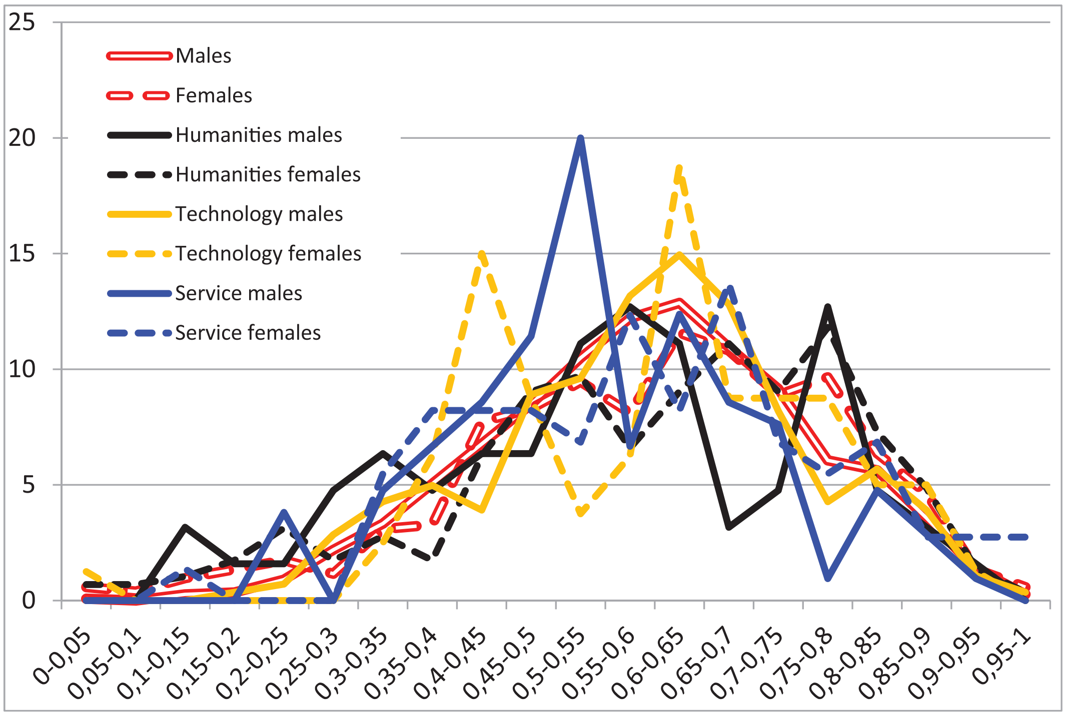

Fig. 1. Distribution of the obtained values per the "extraversion – introversion" psychological dichotomy among various samples studied by the authors

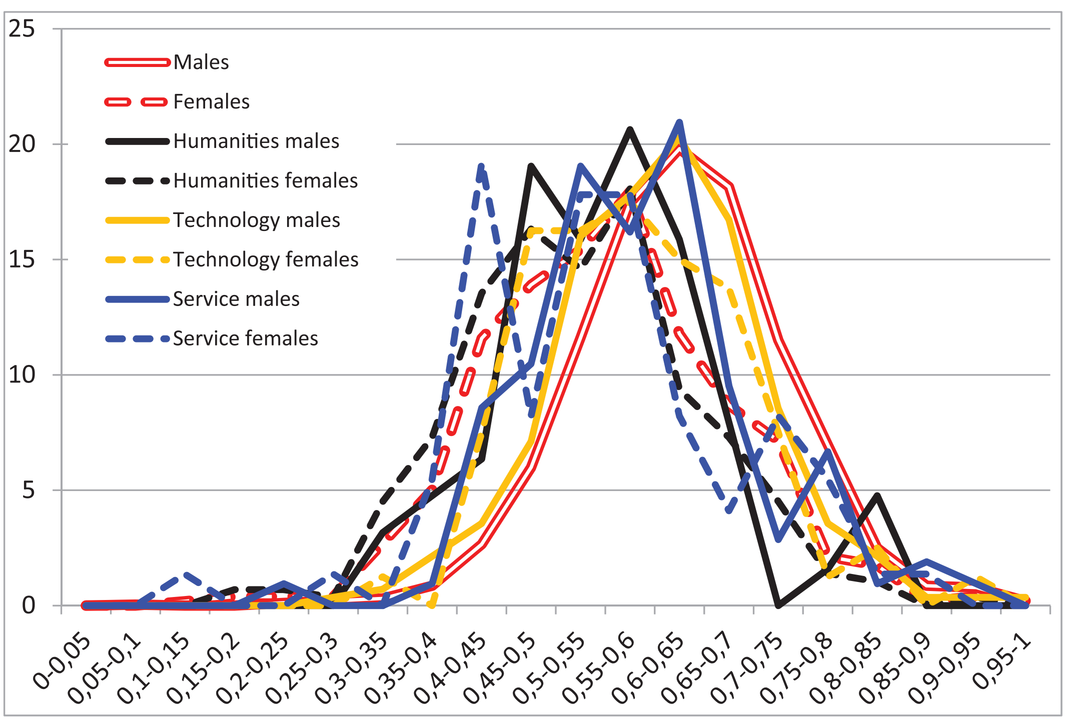

Fig. 2. Distribution of the obtained values per the "logic – ethics" psychological dichotomy among various samples studied by the authors

After the socionic portraits of various professional groups, let us examine their socionic models that are the ISM of a typical member of this sample. Table 3 shows the gender-specific socionic models of samples for various professional groups (%) according to the SPBGU GA data (as of 01.01.2020)

As can be seen from the comparison of the socionic models of various samples shown in Table 3, there is a certain dominance of the logical and sensoric components in the model even for "humanities people". Probably, that is explained by local specificities (in [17], data is quoted on the specificity of TIM distribution in US citizens and the differences from the similar distribution in the UK). However, most probably that is due to the fact that most of the data was collected from air transport professionals.

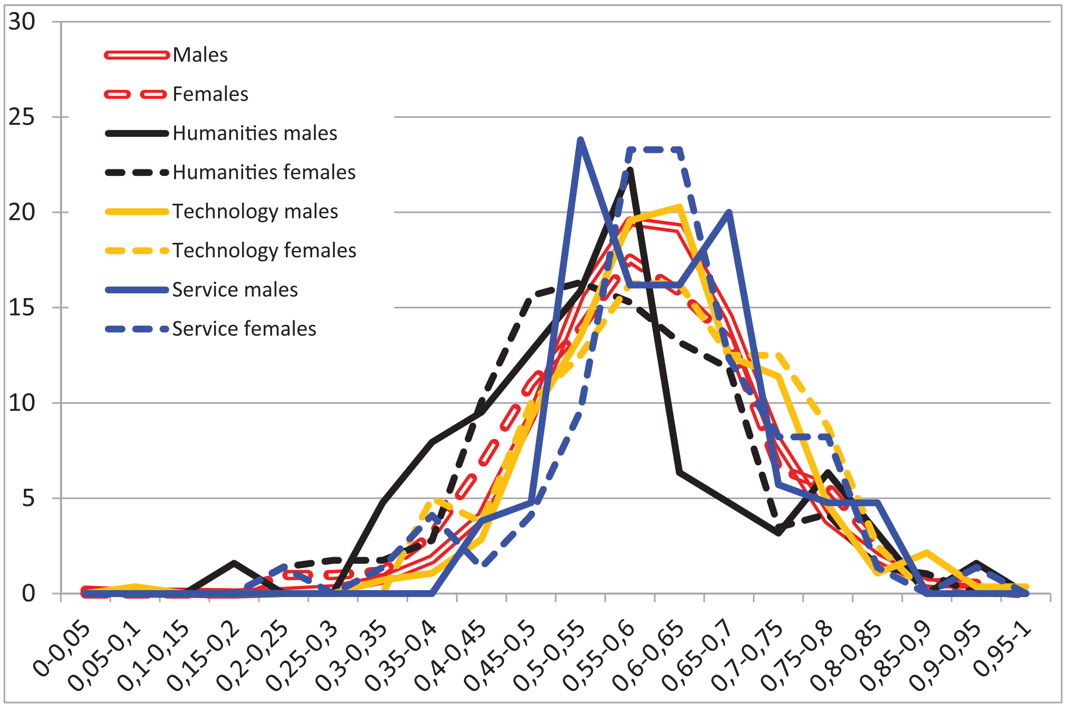

Fig. 3. Distribution of the obtained values per the "sensorics – intuition" psychological dichotomy among various samples studied by the authors

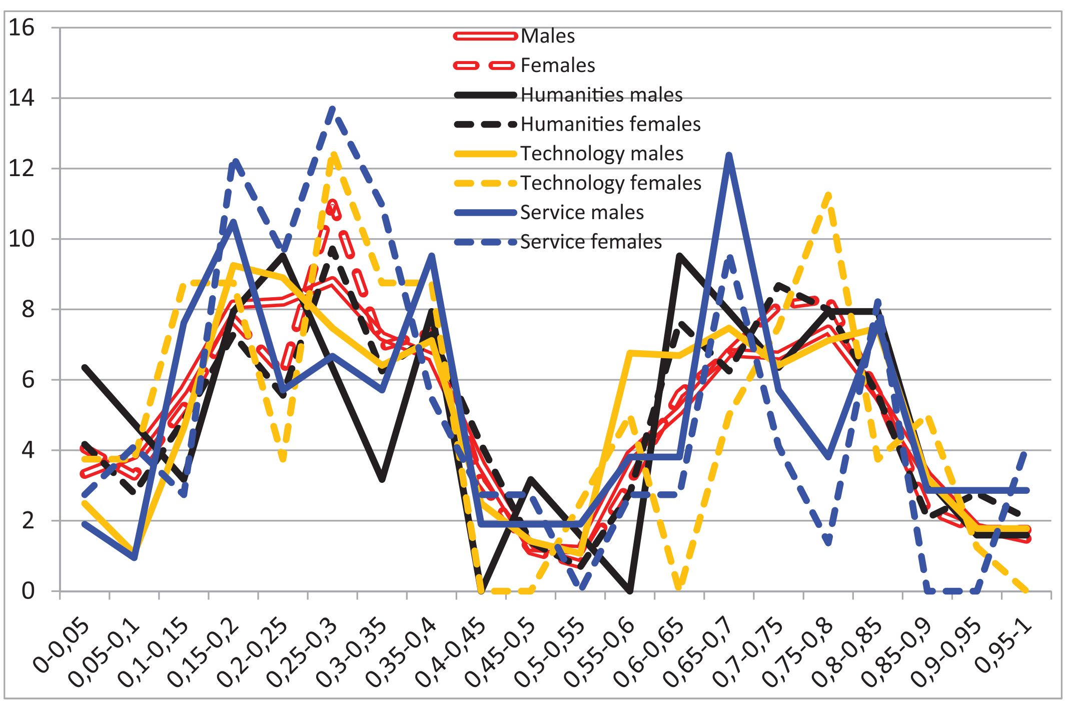

Fig. 4. Distribution of the obtained values per the "rationality – irrationality" psychological dichotomy among various samples studied by the authors

(The "humanities people" in Tables 1 to 3 are the 214 persons out of 336, students of the Humanities Faculty of SPBGU GA and only 122 are student of IPFLMC ISU).

Unlike in Table 1, in Table 3, what catches the eye is the similarity between the socionic models, rather than their differences, as that was in the case of socionic portraits. This difference is even more evident in Table 4 that shows the identified correlations between the socionic models of individual professional groups. Practically all of them, except two, are strong. All the average strength correlations are those between the ISM of "humanities" females and a number of other ISM. Additionally, all of them, except those two, are highly significant ($p < 0.001$). That could appear quite strange, but the authors are inclined to attribute those factors to the Russian mindset described in detail in [19].

Table 5. Correlation between the PDs obtained for various samples researched by the authors (the numbers of the samples correspond to the numbers of the samples in Tables 2 and 4)

First sample	Second sample	r_{corr}	Conclusion on the strength of correlation	Conclusion on the significance of correlation	
"Extraversion – introversion" psychological dichotomy					
Males	Females	+0.9428	strong	$p < 0.001$	very highly significant
7	8	+0.7043	strong	$p < 0.001$	very highly significant
5	6	+0.7215	strong	$p < 0.001$	very highly significant
9	10	+0.6632	medium	$p < 0.01$	highly significant
7	5	+0.7059	strong	$p < 0.001$	very highly significant
7	9	+0.5941	medium	$p < 0.01$	highly significant
5	9	+0.7634	strong	$p < 0.001$	very highly significant
8	6	+0.7100	strong	$p < 0.001$	very highly significant
8	10	+0.7207	strong	$p < 0.001$	very highly significant
6	10	+0.7001	strong	$p < 0.001$	very highly significant
"Logic – ethics" psychological dichotomy					
Males	Females	+0.7681	strong	$p < 0.001$	very highly significant
7	8	+0.9170	strong	$p < 0.001$	very highly significant
5	6	+0.9177	strong	$p < 0.001$	very highly significant
9	10	+0.7824	strong	$p < 0.001$	very highly significant
7	5	+0.8125	strong	$p < 0.001$	very highly significant
7	9	+0.8843	strong	$p < 0.001$	very highly significant
5	9	+0.9178	strong	$p < 0.001$	very highly significant
8	6	+0.8850	strong	$p < 0.001$	very highly significant
8	10	+0.8824	strong	$p < 0.001$	very highly significant
6	10	+0.7597	strong	$p < 0.001$	very highly significant
"Sensorics – Intuition" psychological dichotomy					
Males	Females	+0.8642	strong	$p < 0.001$	very highly significant
7	8	+0.8530	strong	$p < 0.001$	very highly significant
5	6	+0.9610	strong	$p < 0.001$	very highly significant
9	10	+0.8019	strong	$p < 0.001$	very highly significant
7	5	+0.7100	strong	$p < 0.001$	very highly significant
7	9	+0.6715	medium	$p < 0.01$	highly significant
5	9	+0.8726	strong	$p < 0.001$	very highly significant
8	6	+0.8494	strong	$p < 0.001$	very highly significant
8	10	+0.7390	strong	$p < 0.001$	very highly significant
6	10	+0.9118	strong	$p < 0.001$	very highly significant
"Rationality – Irrationality" psychological dichotomy					
Males	Females	+0.9489	strong	$p < 0.001$	very highly significant
7	8	+0.7028	strong	$p < 0.001$	very highly significant
5	6	+0.6237	medium	$p < 0.01$	highly significant
9	10	+0.6726	medium	$p < 0.01$	highly significant
7	5	+0.6589	medium	$p < 0.01$	highly significant
7	9	+0.5383	medium	$p < 0.05$	significant
5	9	+0.7767	strong	$p < 0.001$	very highly significant
8	6	+0.6727	medium	$p < 0.01$	highly significant
8	10	+0.5960	medium	$p < 0.01$	highly significant
6	10	+0.4744	moderate	$p < 0.05$	significant

In conclusion, let us examine the data for individual psychological dichotomies (PD) in the form of a diagram. As can be seen from the graphs shown in Figures 1 to 4 (here, just as in Table 5, in the used samples, 2556 are males, 518 are females, 281 are "technology" males and 80 are "technology" females. In terms of size, the remaining samples match the data cited in "Inputs and methods") per all PDs, except "rationality – irrationality" (see Fig. 4), for all presented samples, a unimodal distribution is observed. (Not presented are samples of professional pilots and air traffic controllers, as well as student pilots and student air traffic controllers, but they are also unimodal, and those categories of specialists are part of the total numbers of males or females. For brevity, humanities students from SPBGU GA and IPFLMC ISU are shown as "humanities", the nonflying personnel are shown as "technology", while the transportation organizers and cabin crew members are shown as "service"). In the graphs, the left-hand parts (values from 0 to 0.5) fall into "introversion", "ethics", "intuition" and "irrationality", while the right-hand parts (values from 0.5 to 1) fall into "extraversion", "logic", "sensorics" and "rationality" (Jung's Introversion, Fühlen, Intuition, Irrationalität and Extraversion, Denken, Empfinden, Rationalität, respectively).

The bimodal distribution in Fig. 4 is explained by the approach to its definition that is different from traditional socionics [4], as in Jung's interpretation this PD is not independent, because it is a dichotomy of not a psychic functions and mental sets, but pairs of psychic functions [3].

Out of Fig. 1 to 4 already clearly follows that the distributions of the degree of certain PD in an ISM for various samples are quite similar. That is further confirmed by the correlations shown in Table 5. In the "logic – ethics" PD, the correlations between all samples are strong ($r_{corr} > 0.7$) and very highly significant ($p < 0.001$). It must be noted that the "service" group goes the furthest outside the general trend. In the "extraversion – introversion" PD, the only just highly significant ($p < 0.01$) correlations of average strength ($0.5 < r_{corr} < 0.7$) are between the "service" samples of males and females, as well as males from the samples "humanities" and "service", while the rest are strong and very highly significant.

The situation is exactly the same in the last pair of samples both in the "sensorics – intuition" and "rationality – irrationality" PDs, where the correlation barely reached average and significant ($p < 0.05$). Finally, in the "rationality – irrationality" PD, the correlations between almost all samples are relatively the weakest, less significant, while between samples of "technology" and "service" females there is only a significant ($p < 0.05$) and moderate ($0.3 < r_{corr} < 0.5$) correlation. Table 3 shows that the manifestation of such psychological qualities as "logic" and "sensorics" is the highest in "pilots". That largely corresponds to the theoretical assumptions, as the relative dominance of such qualities as "logic" and "sensorics" according to [17] is exactly preferable for traffic control specialists. But even in the "humanities people" such psychological qualities are a little stronger than "ethics" and "intuition" respectively, the peak in the ISM being at the level of 0.45-0.6 of such qualities' manifestation (see Fig. 2 and Fig. 3.).

Conclusions

The analysis of research findings showed that the socionic psychodiagnostic methods used by the authors have not identified fundamental gender differences. Even in terms of the socionic portraits, positive differences are of professional, rather than gender-specific nature. That wholly confirmed the prediction of Aušra Augustinavičiūtė [4] regarding the absence of differences in the gender-based distribution of TIM, but somewhat contradicts Jung's theory [3], according to which such psychological function as "ethics" in females, as the "logic – ethics" PD (Jung's "Denken – Fühlen") is where the correlation between all the above considered samples is the strongest and highly significant.

The analysis of the results obtained by us in the works referred to herewith and our paper [9] (as well as an analysis of global scientific research in the subject of gender differences [20-24]) suggest that improving the reliability of AS requires researching the differences in the expression of the necessary PIQ of aviation specialists, especially control room employees, not by criterion of gender, but rather in accordance with the identified gender-related personality type.

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The authors' contribution

Arinicheva O.V. Review and analysis of the state of the art of the problem under consideration, collection of psychodiagnostic data for statistical processing. The theoretical component of the work. Processing of the obtained results.

Malishevsky A.V. Overview and analysis of the state of the art of the problem under consideration, collection of psychodiagnostic data for statistical processing. The theoretical component of the work. Processing of the obtained results.

Conflict of interests

The authors declare the absence of a conflict of interests.

Original article
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Information support of the system for managing technical assets in railway transportation

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Abstract. Aim. *JSC RZD is one of the largest and most advanced companies in Russia who actively deploys and uses best practices in asset and risk management. In 2010, the railway industry initiated the project for the management of resources, risks and dependability at life-cycle stages of railway facilities (URRAN) that is currently under way. The aims of this paper are to overview the asset management tasks covered by URRAN; examine the marketed IT tools designed to address such problems; present the progress of the URRAN project in terms of process automation implemented by JSC RZD in light of the international best practice and the specificity of the Company.* **Methods.** *The preparation of this paper involved empirical and theoretical research. The authors analysed the URRAN project's package of guidelines and regulations, public information on the globally available software products enabling asset management, as well as the program documentation of the EKP URRAN automated system. They analysed the functionalities and and engineering solutions used in the development of this automated system. The results of the EKP URRAN deployment and practical application by units and branches of JSC RZD were evaluated.* ***Results.*** *Asset management involves using Enterprise Asset Management Systems (EAMS) specially designed to suit the needs of specific companies or mass-produced "out-of-the-box" systems, e.g. SAP ERP, IBM MAXIMO, ABB Ability™ and Simeo™ that are examined in the paper. The EKP URRAN implements a single information space that is a decision support tool for the asset management system as it possesses the required regulatory and procedural resources, hardware and software assets intended for comprehensive management of assets and processes for the purpose of efficient railway service. In the future, the EKP URRAN is to become part of the Digital Platform for Risk and Traffic Safety Management deployed in JSC RZD and will comprise modules that implement dynamic predictive analytics models for the purpose of predicting undesirable events involving infrastructure and rolling stock that may disrupt traffic safety.* **Conclusions.** *Further development of the EKP URRAN will soon provide all levels of company management with an efficient tool that allows, in the context of limited resources, making substantiated managerial decisions and rational investment allocation. The EKP URRAN is an asset of JSC RZD designed to be used by the managers and specialists of various JSC RZD units. It can be implemented as a standalone IT product for the purpose of developing and deploying an asset management system in various railway companies.*

Keywords: *asset management, automated system, dependability, risk, railway transportation.*

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Introduction

JSC RZD is one of the largest and most advanced companies in Russia who actively deploys and uses best practices in asset and risk management [1, 2]. However, it must be understood that a railway system is not only multi-industry, but also multilevel. Each system or service have independent managerial goals and tasks, internal and external connections, which is the reason for the great amount of information and data management flows that circulate both between the system's layers vertically, and horizontally, covering the corresponding geographically distributed entities of the adjacent services and directorates.

Based on the international experience and taking into consideration the specificity of JSC RZD, the project for management of assets, risks and dependability at lifecycle stages (URRAN) was started and is now under way.

In terms of methodology development, the URRAN project started in 2011 and is undergoing continuous improvements by assimilating the obtained experience and taking into account the rapid technological developments.

As part of the project, a process of comprehensive management of operational dependability and safety of railway facilities has been introduced that is composed of three interconnected components:

- risk-based management methodology of railway facility maintenance, structural unit activities, dependability and safety of the transportation process;

- the system's regulatory and procedural framework;

- computerization of data capture and processing, technical asset management, automation of all guidelines and regulations developed as part of the URRAN project.

Fig. 1 shows the key landmarks of the URRAN project development from the concept to a working information system.

The standards and regulations developed as part of the URRAN project include more than 150 regulatory documents covering various aspects of asset management and activities of the branches of JSC RZD. Those include GOST, GOST R, industry standards (STO) and methods. The documents cover:

- infrastructure facilities (track and structures, signalling, electrification and power supply, communications);

- rolling stock (locomotives, EMUs and DMUs, cars and wagons);

- additional functions related to fire, environmental safety and labour protection, train traffic safety.

The methodology and know-how of the URRAN project were repeatedly covered in the Dependability Journal, e.g. [3, 4, 5, 6, 7].

As noted in [1], the introduction of the asset management system is impossible without the deployment of IT tools. Normally, automated systems like EAMS are used for purposes of asset management. Such systems can be either purpose designed for a specific company, or mass-produced "out-of-the-box" solutions. A great number of such systems have been developed worldwide. We will note the main ones that are used in the railway industry.

1. SAP ERP, the best-known enterprise resource planning software developed by SAP SE (Germany). The introduction of SAP ERP includes the development and implementation of the following processes:

– maintenance of reference information (RI);
– overhauls and maintenance;
– annual maintenance planning;
– operational planning;
– work performance and accounting for actual costs;
– maintenance management.

The functional scope of the software includes:

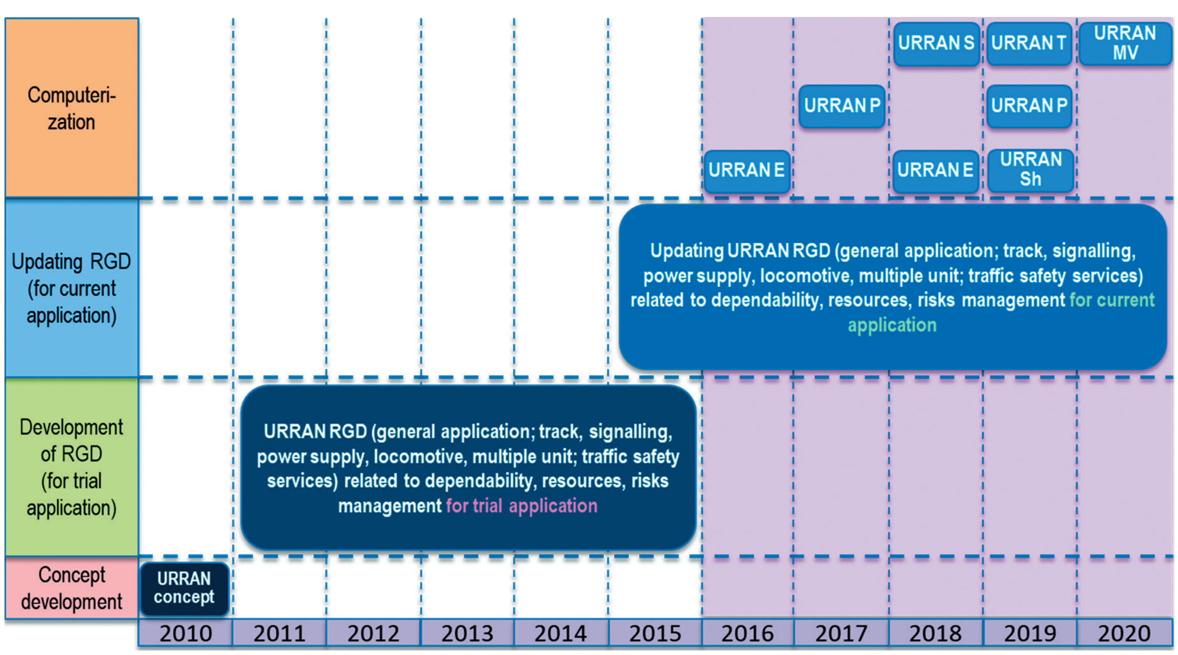


Fig. 1. URRAN project history

– automated equipment data management (functional locations, equipment units, classification, specification of technical facilities, etc.);

– equipment record-keeping;

– maintenance of databases of standards and directories on equipment maintenance and repair (EM&R);

– calculation of required materials, assemblies, spare parts and preparation of purchase requests in the required quantities and ranges;

– record-keeping and performance control of repair activities, including performance control of executed repairs, confirmation of the actual number of hours spent on repairs, release of materials, etc.;

– procurement management (procurement scheduling in order to ensure timely delivery of materials and parts for equipment repair and maintenance);

– planning of manpower and other types of material resources required for EM&R;

– efficient allocation and adjustment of repair costs per selected indicators (business unit, time period).

This software product is used by such railway companies as IrishRail (Ireland) and Infrabel (Belgium).

2. Maximo Asset Management, a software solution by IBM (US) designed for the purpose of managing all types of assets regardless of their location. Within the IBM Maximo, six interconnected functional blocks can be distinguished that enable a complete life cycle of enterprise asset management and maintenance:

– asset management;

– procurement management;

– contract management;

– material management;

– work management;

– service management.

This system is used by Network Rail (UK) and Trafikförvaltningen (Stockholm Public Transport Administration, Sweden).

3. ABB Ability™ (ELLIPSE), AVV's (Switzerland, Sweden) industrial automation software solution that allows optimizing process control, improving energy efficiency and productivity (through reduced operating costs, longer equipment life, better dependability and responsiveness).[1]

This software is also used by Network Rail (UK).

4. The Simeo™ software suite by the Oxand consulting company holds in its database reference information on more than 600 types of assets, analysis of 70000 km of railway infrastructure and more than 40 million m^2 of real estate. The system implements a decision-support module that uses accumulated statistical data on various types of technical assets for the period of 15 years. The primary key indicators for decision-making are the RAMS indicators.

Yet most railway companies prefer custom-designed asset management software. ADIF (Spain), VAYLA (Finland), ÖBB (Austria), as well as JSC RZD made that choice.

As the vast regulatory framework of the URRAN project implies the collection of a large amounts of statistical data, as well as a lot of calculations involving large volumes of data on various facilities (assets) and structural units of services, JSC RZD is actively automating such standards and regulations using the URRAN Single Corporate Platform (EKP URRAN). As of today, about 35% of all documents have been automated (mainly in the area of dependability analysis, risk assessment and structural unit activities, as well planning of maintenance and lifecycle cost assessment).

1. EKP URRAN architecture

The purpose of the system's development is to implement adaptive management of railway facilities maintenance at the lifecycle stages or a business process based on the compliance with the criteria of dependability, safety and economic efficiency of the operation using the risk-oriented approach.

The primary processes implemented in the EKP URRAN include:

– collection and processing of information on failures, pre-failures and critical parameters of railway facilities;

– assessment of wear, residual operating life and limit state of railway infrastructure facilities;

– standardization of dependability and safety indicators of railway facilities;

– analysis and prediction of actual dependability and safety indicators of railway facilities;

– assessment of risks related to technology dependability, traffic safety disruptions, occupational and fire risks;

– evaluation of railway infrastructure life cycle cost;

– evaluation of JSC RZD business units performance subject to the results of activities aimed at ensuring dependability and safety of operated facilities;

– management decision support, including repair planning, maintenance resource management.

The EKP URRAN contains six functionally complete technical systems (hereinafter referred to as systems) and two enabling systems, namely:

Technical systems:

– Single Corporate Platform for Management of Resources, Risks and Dependability at Lifecycle Stages of Railway Track and Structures (EKP URRAN P);

– Single Corporate Platform for Management of Resources, Risks and Dependability at Lifecycle Stages of Railway Signalling Facilities (EKP URRAN Sh);

– Single Corporate Platform for Management of Resources, Risks and Dependability at Lifecycle Stages of Railway Electrification and Power Supply Facilities (EKP URRAN E);

[1] Available at: https://new.abb.com/cpm/production-optimization/eam-enterprise-asset-managment-systems (accessed 17.01.2021)

– Single Corporate Platform for Management of Resources, Risks and Dependability at Lifecycle Stages of Railway Communications Facilities (EKP URRAN S);

– Single Corporate Platform for Management of Resources, Risks and Dependability at Lifecycle Stages of Railway Motive Power Facilities (EKP URRAN T);

– Single Corporate Platform for Management of Resources, Risks and Dependability at Lifecycle Stages of Railway Motor Unit Facilities (EKP URRAN MV).

Enabling systems:

– Single database of calculated indicators of dependability and functional safety, risk assessment for comprehensive assessment of the condition of infrastructure and rolling stock that is a database management system (DBMS) enabling:

a) storage of primary characteristics of railway power supply facilities, track superstructure, telecommunications, signalling, data on locomotives and motor units;

b) storage of data on accidents, failures and incidents that occurred with the facilities of railway power supply, track superstructure, telecommunications, signalling, locomotives and motor units;

c) storage of data on performed repairs obtained from related systems;

d) storage of user-added lifecycle cost data;

e) storage of calculated dependability data (actual and standard);

f) storage of reference information.

– The external automated system interaction modules are intended for the collection and processing of primary information from related systems that calculate the actual and standard dependability indicators, assessment and monitoring of risk levels, residual life assessment, evaluation of professional risks, assessment and monitoring of fire risk, rating service units activities, overhaul planning.

The functional configuration of the EKP URRAN is shown in Fig. 2.

The EKP URRAN contains two load balancing servers (primary and standby), primary and standby servers hosting virtual application servers, as well as virtual database servers. Additionally, the EKP URRAN includes a primary and a standby synchronization servers (see Fig. 2).

The load balancing servers automatically switch requests from one application server to the other if one of them fails.

Each application server is equipped with virtualization tools.

For each application (URRAN E, URRAN P, URRAN S, URRAN T, URRAN Sh, URRAN MV), an Apache Tomcat or Node.js virtual application server is configured.

The database is deployed on separate servers.

Synchronization modules (URRAN E, URRAN P, URRAN S, URRAN T, URRAN Sh, URRAN MV) are configured on individual Apache Tomcat virtual servers.

The application server software is implemented using client/server technologies. User access is through a Web browser.

The user workstation (WS) and administrator WS are a single web application with different access settings designed for managing the System's interaction with administrators and users.

The synchronization modules enable the EKP URRAN's interaction with many of the JSC RZD's primary network-level systems:

1) Automated System for Centralized Reference Information (AS CRI) in terms of retrieval of data from industry-wide directories and classifiers.

2) Integrated Automated System for Technical Failures Tracking, Investigation and Dependability Analysis (KASANT) in terms of retrieval of data on technical failures.

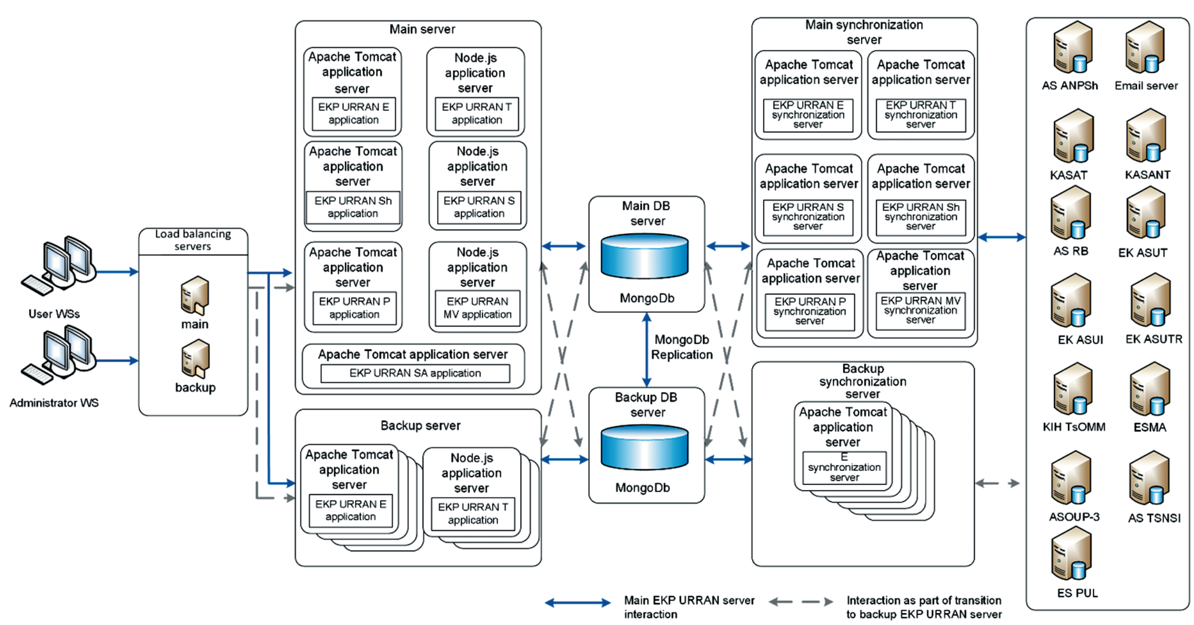


Fig. 2. Functional configuration of the EKP URRAN

3) Integrated Automated System for Recording, Investigation and Analysis of Process Violations (KASAT) in terms of retrieval of data on process violations.

4) Automated Traffic Safety Management System (AS RB) in terms of retrieval of information on traffic safety disturbances.

5) Automated System for Statistical Analysis of Dependability Indicators and Prescriptive Management of Signalling Processes (AS ANPSh) in terms of retrieval of data on railway signalling facilities and their key characteristics.

6) Single Corporate Automated System for Infrastructure Management (EK ASUI) in terms of retrieval of data on electrification and power supply facilities, track and structures, as well as incidents that affect them.

7) JSC RZD's Single System for Monitoring and Administration of Communication Networks (ESMA) in terms of:

a) retrieval of data on railway telecommunications facilities, incident and maintenance sheets;

b) transmission to the ESMA of data on standard and actual dependability indicators of railway telecommunications facilities, risks (risk matrices), integrated assessment of business unit activities.

8) Corporate Data Warehouse of the System for Centralized Processing of Driver's Itinerary List (KIH TsOMM) in terms of retrieval of data on the amount of work performed by locomotivesы and multiple units.

9) Single Corporate Automated System for Motive Power Management (EK ASUT) in terms of retrieval of data on the number of locomotive repairs, activation of barrier functions.

10) New (Third) Generation Automated System for Operational Transportation Process Management (ASOUP-3) in terms of retrieval of data on the number of locomotive and multiple unit repairs, cases of barrier function activation for a motive power depot.

11) Single Corporate Automated System for Workforce Management (EK ASUTR) in terms of retrieval of information on accidents in operating motive power depots and average number of drivers.

12) Single System for Locomotive Number Tracking (ES PUL) in terms of retrieval of data on the inventory multiple unit fleet.

Effectively, the EKP URRAN represents a four-layer architecture. The *lower layer* consists of data sources (KASANT, KASAT, EK ASUI, ASRB, ESMA, AS TsNSI, AS ANPSh, EK ASUT, etc.). The *second layer* is the integration layer containing the data integration modules. The *third layer* is the data warehouses. It includes databases, aggregate functions and computational pipeline for data aggregation. The *fourth layer* is the core layer. This is the analytics layer that implements the URRAN methodology.

2. Technical solutions used as part of the EKP URRAN

The EKP URRAN employs Big Data technology.

The System's data storage layer is based on the MongoDB modern document DBMS.

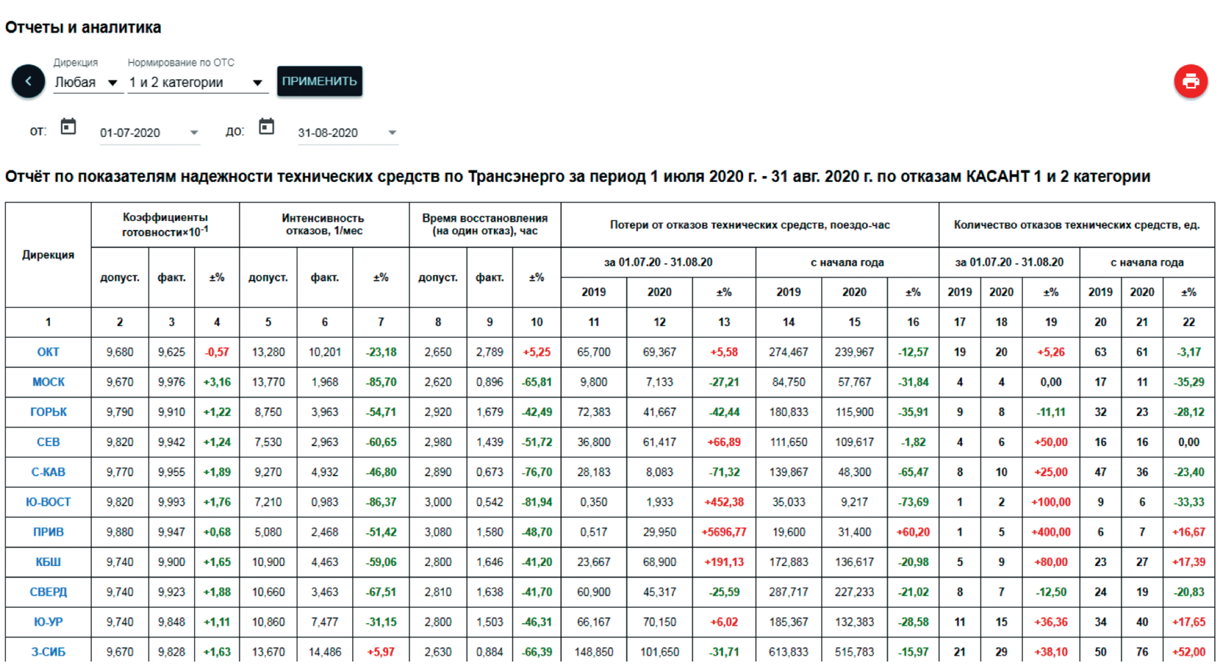
The list and description of the software making part of the EKP URRAN hardware and software architecture is given in Table 1

The System's role model implies the following user categories, as well as the end user rights and privileges:

1) Administrators, including:

– users with the "Administrator" role, who are authorized to add users to the EKP URRAN, as well as all operations at all levels of the organizational hierarchy and have access to all subsystems of the EKP URRAN;

– *technical administrators* who maintain the hardware and software system, install updates.


Отчеты и аналитика

Дирекция: Любая | Нормирование по ОТС: 1 и 2 категории | ПРИМЕНИТЬ

от: 01-07-2020 до: 31-08-2020

Отчёт по показателям надежности технических средств по Трансэнерго за период 1 июля 2020 г. - 31 авг. 2020 г. по отказам КАСАНТ 1 и 2 категории

Дирекция	Коэффициенты готовности×10^{-1}			Интенсивность отказов, 1/мес			Время восстановления (на один отказ), час			Потери от отказов технических средств, поездо-час						Количество отказов технических средств, ед.					
	допуст.	факт.	±%	допуст.	факт.	±%	допуст.	факт.	±%	за 01.07.20 - 31.08.20			с начала года			за 01.07.20 - 31.08.20			с начала года		
										2019	2020	±%	2019	2020	±%	2019	2020	±%	2019	2020	±%
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
ОКТ	9,680	9,625	-0,57	13,280	10,201	-23,18	2,650	2,789	+5,25	65,700	69,367	+5,58	274,467	239,967	-12,57	19	20	+5,26	63	61	-3,17
МОСК	9,670	9,976	+3,16	13,770	1,968	-85,70	2,620	0,896	-65,81	9,800	7,133	-27,21	84,750	57,767	-31,84	4	4	0,00	17	11	-35,29
ГОРЬК	9,790	9,910	+1,22	8,750	3,963	-54,71	2,920	1,679	-42,49	72,383	41,667	-42,44	180,833	115,900	-35,91	9	8	-11,11	32	23	-28,12
СЕВ	9,820	9,942	+1,24	7,530	2,963	-60,65	2,980	1,439	-51,72	36,800	61,417	+66,89	111,650	109,617	-1,82	4	6	+50,00	16	16	0,00
С-КАВ	9,770	9,955	+1,89	9,270	4,932	-46,80	2,890	0,673	-76,70	28,183	8,083	-71,32	139,867	48,300	-65,47	8	10	+25,00	47	36	-23,40
Ю-ВОСТ	9,820	9,993	+1,76	7,210	0,983	-86,37	3,000	0,542	-81,94	0,350	1,933	+452,38	35,033	9,217	-73,69	1	2	+100,00	9	6	-33,33
ПРИВ	9,880	9,947	+0,68	5,080	2,468	-51,42	3,080	1,580	-48,70	0,517	29,950	+5696,77	19,600	31,400	+60,20	1	5	+400,00	6	7	+16,67
КБШ	9,740	9,900	+1,65	10,900	4,463	-59,06	2,800	1,646	-41,20	23,667	68,900	+191,13	172,883	136,617	-20,98	5	9	+80,00	23	27	+17,39
СВЕРД	9,740	9,923	+1,88	10,660	3,463	-67,51	2,810	1,638	-41,70	60,900	45,317	-25,59	287,717	227,233	-21,02	8	7	-12,50	24	19	-20,83
Ю-УР	9,740	9,848	+1,11	10,860	7,477	-31,15	2,800	1,503	-46,31	66,167	70,150	+6,02	185,367	132,383	-28,58	11	15	+36,36	34	40	+17,65
З-СИБ	9,670	9,828	+1,63	13,670	14,486	+5,97	2,630	0,884	-66,39	148,850	101,650	-31,71	613,833	515,783	-15,97	21	29	+38,10	50	76	+52,00

Fig. 3. Report on dependability performance by power supply directorates

Показатели надежности путевого хозяйства за период с 01.12.2020 по 31.12.2020. Сетевой уровень
(Объекты оценки: все объекты; категория ОТС: 1 и 2 категории)

		ОКТ	КЛНГ	МОСК	ГОРЬК	СЕВ	С-КАВ	Ю-ВОСТ	ПРИВ	КБШ	СВЕРД	Ю-УР	З-СИБ	КРАС	В-СИБ	ЗАБ	ДВОСТ	СЕТЬ
Интенсивность отказов, 1/мес	норм.	5,391780	6,945950	5,444340	5,555300	4,345690	4,241300	5,110000	4,807780	4,396060	4,850120	4,252250	4,182170	2,368850	4,072670	4,091650	3,845640	4,561770
	факт.	0,887379	0,000000	0,475090	0,638309	0,453273	0,039252	0,057719	0,245405	0,669371	1,061108	0,654907	0,717565	0,350538	0,492524	1,217215	0,315519	0,568167
	+/-, %	-83,54	-100	-91,27	-88,51	-89,57	-99,07	-98,87	-94,90	-84,77	-78,12	-84,60	-82,84	-85,20	-87,91	-70,25	-91,80	-87,55
Среднее время до восстановления, ч	норм.	2,88	12,32	2,89	3,13	3,2	3,25	3,3	3,38	3,35	3,09	3,37	3,28	3,89	3,5	3,38	2,73	2,28
	факт.	1,07	0,0	1,05	0,97	1,49	2,22	0,6	1,33	0,62	0,93	1,34	0,78	0,69	5,84	1,19	1,02	1,28
	+/-, %	-62,92	-100	-63,70	-69,05	-53,40	-31,74	-81,80	-60,85	-81,38	-69,92	-60,24	-76,30	-82,36	+66,65	-64,66	-62,78	-44,04
Коэффициент готовности	норм.	0,944500	0,934100	0,944200	0,943500	0,951000	0,951600	0,946300	0,948100	0,950700	0,947900	0,951500	0,952000	0,966500	0,952700	0,952600	0,954200	0,949600
	факт.	0,998704	1,000000	0,999318	0,999154	0,999074	0,999881	0,999953	0,999555	0,999428	0,998651	0,998801	0,999237	0,999670	0,996075	0,998014	0,999561	0,999007
	+/-, %	+5,74	+7,05	+5,84	+5,90	+5,06	+5,07	+5,67	+5,43	+5,13	+5,35	+4,97	+4,96	+3,43	+4,55	+4,77	+4,75	+5,20
Интенсивность опасных отказов, 1/мес		0,126622	0,000000	0,031653	0,049061	0,075482	0,039252	0,000000	0,000000	0,044600	0,000000	0,046728	0,113218	0,140187	0,098138	0,233710	0,000000	0,065608
Количество ОТС		28	0	15	13	12	1	1	4	15	27	14	19	5	10	26	9	199
Потери от ОТС, поездо-час		69,87	0,00	30,30	15,82	70,18	0,00	0,22	6,35	12,60	69,32	27,33	19,77	4,52	74,73	230,73	61,03	692,77
Структурные подразделения (СП)	СП в "красной зоне"	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	СП в "оранжевой зоне"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
	СП в "жёлтой зоне"	13	0	10	11	9	1	1	4	8	15	9	13	5	8	10	6	123
	СП в "зелёной зоне"	18	1	21	9	17	24	16	12	14	10	12	13	9	10	9	22	217

СП в "красной зоне" - 3 показателя надежности хуже нормативного
СП в "оранжевой зоне" - 2 показателя надежности из 3 хуже нормативного
СП в "желтой зоне" - 1 показатель надежности из 3 хуже нормативного
СП в "зеленой зоне" - нет показателей надежности хуже нормативного

Fig. 4. Evaluation of dependability indicators in the track and structures services of Infrastructure Directorates

Table 1 EKP URRAN software

Name	Purpose
CentOS	Operating system
VMware	Virtualization tool
MongoDB	DBMS
Apache Tomcat 8.5/ Node.js 12	Application server
Keepalived	Server health monitoring and failover
Haproxy	Load balancing for TCP and HTTP applications by distributing incoming requests to multiple servers

2) Technical users, including:

– users with the *"RI editor"* role can perform all operations at all levels of the organizational hierarchy and have access to all sections of the EKP URRAN except "Administration";

– users with the *"Information user"* role are authorized to, depending on the access level, generate calculation parameters in all subsystems, generate and print reports, view RI.

– users with the *"Technical user"* role are authorized to, depending on the access level, generate calculation parameters in all subsystems, generate and print reports, view RI.

– users with the *"Unit manager"* role are authorized to agree and approve reports, as well as generate calculation parameters in all subsystems, generate and print reports.

3. Using EKP URRAN

We must note the wide application of the EKP URRAN functionality in the business activities of the branches and divisions of JSC RZD. Thus, the EKP URRAN is supporting activities aimed at improving technical facilities depend-

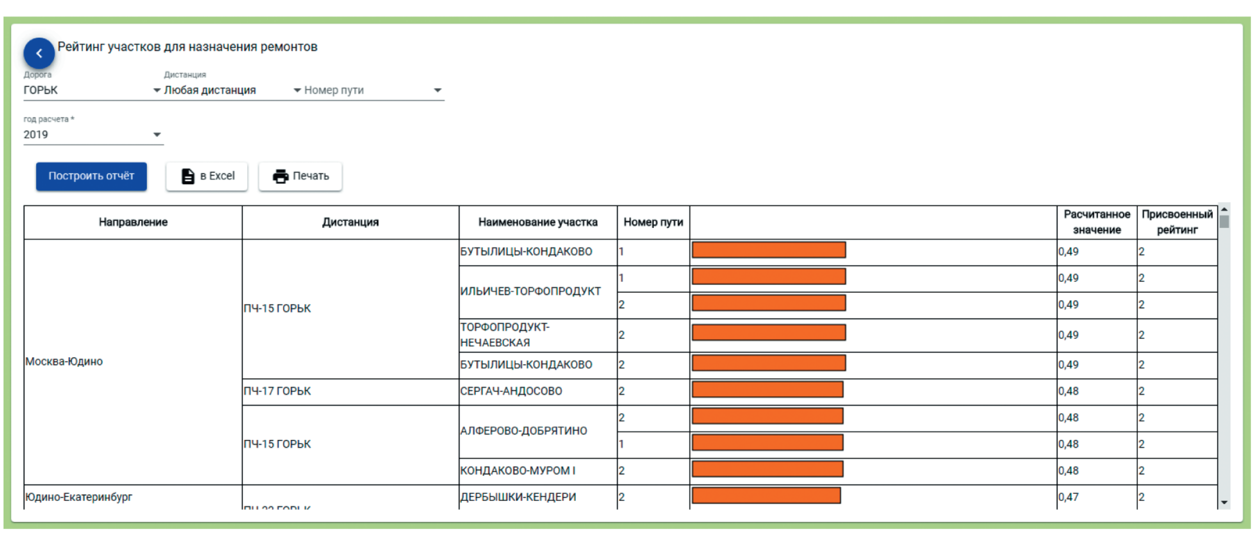


Fig. 5. Line section ranking for overhauls

Ведомость оценки интегрального показателя устойчивости функционирования железнодорожной электросвязи

Наименование подразделения	Показатель неготовности объектов железнодорожной электросвязи	Показатель интенсивности отказов объектов железнодорожной электросвязи	Показатель интенсивности предотказов объектов железнодорожной электросвязи	Показатель среднего времени до восстановления объектов железнодорожной электросвязи	Балльная оценка интегрального показателя устойчивости функционирования железнодорожной электросвязи
	K11	K121	K122	K13	B1
По дирекции	20.004375	59.478027	100	81.429565	52
РЦС-1	0.89099985	28.567501	100	1.5256927	54
РЦС-2	41.140522	69.56835	100	100	53
РЦС-3	12.53277	40.315468	68.69776	51.3834	38
РЦС-4	3.1610045	82.8538	96.13721	3.1373253	49
РЦС-5	13.087995	17.127426	100	98.32765	46
РЦС-6	15.977224	32.91246	100	69.13891	53

Ведомость оценки интегрального показателя влияния функционирования железнодорожной электросвязи на перевозочный процесс

Наименование подразделения	Показатель неготовности услуг железнодорожной электросвязи, отказы которых привели к задержкам поездов	Показатель интенсивности отказов услуг железнодорожной электросвязи, приведших к задержкам поездов	Показатель среднего времени до восстановления услуг железнодорожной электросвязи, отказы которых привели к задержкам поездов	Балльная оценка интегрального показателя влияния функционирования железнодорожной электросвязи на перевозочный процесс
	K21	K22	K23	B2
По дирекции	25.030964	8.716195	100	52
РЦС-1	0	0	0	0
РЦС-2	16.518341	2.9053981	100	53
РЦС-3	1.9730561	2.9053981	10.712373	5
РЦС-4	0	0	0	0
РЦС-5	13.665926	2.9053981	100	46
РЦС-6	0	0	0	0

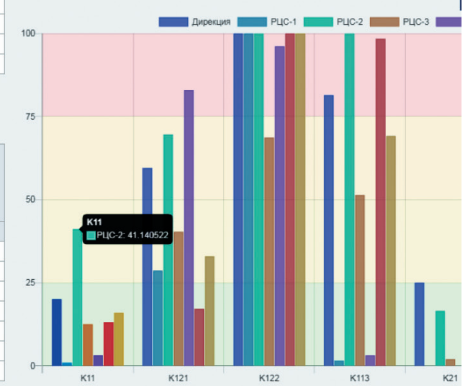


Fig. 6. Evaluation of the impact of business units on the transportation process in the communications service

Рейтинг структурных подразделений путевого хозяйства

Дорога: ГОРЬК | Дистанция: Любая дистанция | год расчета *: 2020 | период расчета *: год

- Выбрать все
- Балльная оценка безопасности движения поездов (БДД)
- Балльная оценка надёжности в целом (БН)
  - Балльная оценка качества технического содержания ($Б_λ$)
  - Балльная оценка оперативности устранения отказов объектов ВСП ($Б_в$)
  - Балльная оценка влияния на перевозочный процесс ($Б_п$)
- Балльная оценка компетентности персонала (БЧ)

Построить отчёт | в Excel | Печать

№ рейтинга	Период оценки с 01.2020 по 12.2020								
Наименование структурного подразделения	Интегральная балльная оценка, $Б^И$		Балльная оценка безопасности движения поездов, $Б^Д$		Балльная оценка надёжности, $Б^Н$		Балльная оценка компетентности персонала, $Б^Ч$		Место
	кол-во баллов	оценка	кол-во баллов	оценка	кол-во баллов	оценка	кол-во баллов	оценка	
ГОРЬКОВСКАЯ									
ИЧ-4 КАНАШ П ГОРЬК	11,05	ОТЛИЧНО	0	ОТЛИЧНО	36,84	ХОРОШО	0	ОТЛИЧНО	1
ПЧ-13 ГОРЬК	11,17	ОТЛИЧНО	0	ОТЛИЧНО	37,22	ХОРОШО	0	ОТЛИЧНО	2
ПЧ-10 ГОРЬК	12,64	ОТЛИЧНО	0	ОТЛИЧНО	42,15	ХОРОШО	0	ОТЛИЧНО	3
ИЧ-2 НИЖНИЙ НОВГОРОД П ГОРЬК	12,71	ОТЛИЧНО	0	ОТЛИЧНО	42,38	ХОРОШО	0	ОТЛИЧНО	4
ИЧ-3 МУРАШИ П ГОРЬК	13,14	ОТЛИЧНО	0	ОТЛИЧНО	43,79	ХОРОШО	0	ОТЛИЧНО	5
ИЧ-5 ИЖЕВСК П ГОРЬК	13,27	ОТЛИЧНО	0	ОТЛИЧНО	44,24	ХОРОШО	0	ОТЛИЧНО	6
ПЧ-1 ГОРЬК	13,71	ОТЛИЧНО	0	ОТЛИЧНО	45,72	ХОРОШО	0	ОТЛИЧНО	7
ПЧ-4 ГОРЬК	13,83	ОТЛИЧНО	0	ОТЛИЧНО	46,11	ХОРОШО	0	ОТЛИЧНО	8
ПЧ-30 ГОРЬК	14,07	ОТЛИЧНО	0	ОТЛИЧНО	46,91	ХОРОШО	0	ОТЛИЧНО	9
ПЧ-6 ГОРЬК	14,15	ОТЛИЧНО	0	ОТЛИЧНО	47,18	ХОРОШО	0	ОТЛИЧНО	10
ПЧ-25 ГОРЬК	14,72	ОТЛИЧНО	0	ОТЛИЧНО	49,06	ХОРОШО	0	ОТЛИЧНО	11
ПЧ-22 ГОРЬК	15,16	ОТЛИЧНО	0	ОТЛИЧНО	50,52	УДОВЛЕТВОРИТЕЛЬНО	0	ОТЛИЧНО	12
ПЧ-9 ГОРЬК	15,5	ОТЛИЧНО	0	ОТЛИЧНО	51,68	УДОВЛЕТВОРИТЕЛЬНО	0	ОТЛИЧНО	13

Fig. 7. Comparative rating of the activities of business units of the track and structures service in terms of operational dependability and safety indicators

ability on the basis of target indicators calculated by means of URRAN-based rating for the purpose of optimizing the resource allocation as part of planning dependability improvement activities.

Standard dependability indicators are calculated yearly according to the URRAN methodology, their standard values, according to an established procedure, are approved in the 4 quarter of the reporting year as targets for the next year.

Based on the results of the reporting year, the URRAN-rated dependability indicators approved as targets for the following year are updated in the first quarter of the following year.

Standard target dependability indicators calculated in the EKP URRAN, are associated with the effectiveness of the performed activities aimed at improving the dependability of technical facilities and guide the planning of preventive measures subject to optimization of resource allocation.

Fig. 3 and 4 show examples of output forms for evaluating the compliance with the established standard dependability indicators of electrification and power supply facilities.

The EKP URRAN also enables detailed analysis of operational dependability of line-level units in general (track maintenance divisions, power supply divisions, etc.) and

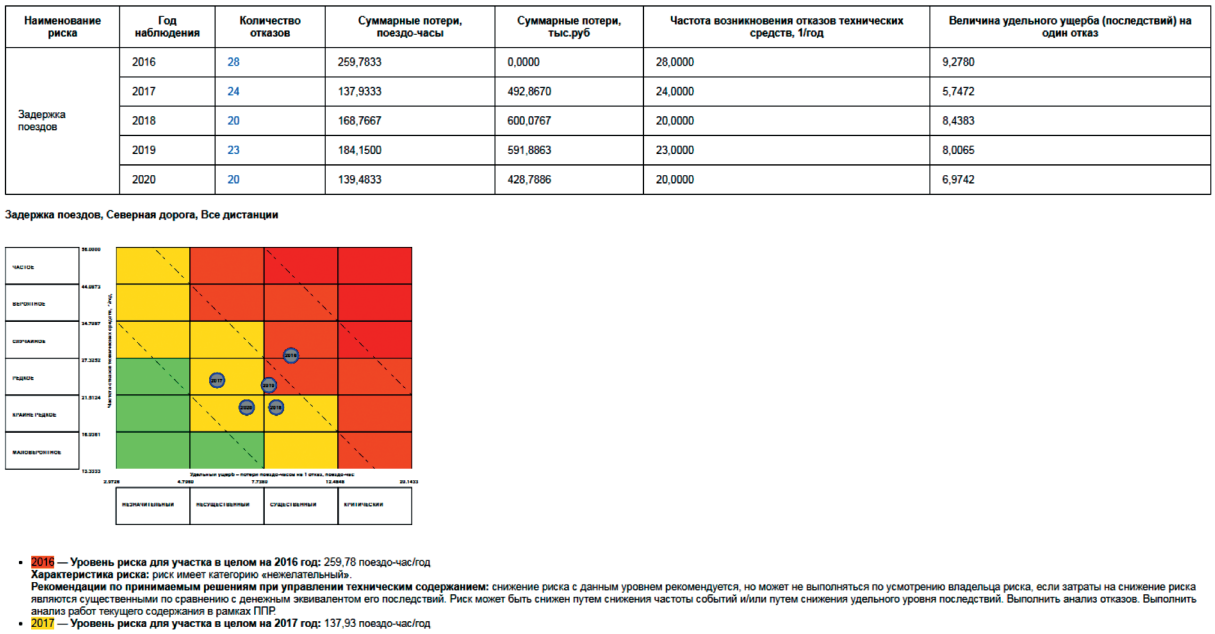


Fig. 8. Risk matrix

individual assets (track sections, contact network, etc.) of business units.

Depending on the level of management targeted by the dependability and safety performance analysis, both individually, and along with the risk assessment, it is used for:

1) identification of the most frequently failed facilities over a period of time (operation life);

2) ranking of facilities (assets) for inclusion into renovation and repair plans (see Fig. 5). Here, along with the dependability indicators, the residual life of a facility and risk assessment are used for confirming the need for repairs. The system will also prioritize the track sections to be repaired first.

3) identification of facilities of a certain type with the least time to/between failure (active, put into operation, upgraded).

4) estimation of the impact of facility failures and their timely elimination on the transportation process, both in tabular form, and graphic form (see Fig. 6).

5) comparative evaluation of the performance of the business units (see Fig. 7).

In the EKP URRAN, risk assessment is based on the principles set out in [4, 8] and results in a matrix for the selected risk type and the selected assessed facility (see Fig. 8). It can be presented both for the selected year, and a number of years.

In general, the EKP URRAN, along with the risk matrix, provides a risk assessment in the form of recommendations

Table 2. Decision-making scenarios as part of risk assessment

Coefficient comparison	Characteristic	Recommendations
$R > R_{o.al}$	The risk is higher than allowed	Risk reduction is required. The risk can be reduced by reducing the frequency of events and/or by reducing the specific level of consequences
$\frac{R_{o.al}}{K} < R \le R_{o.al}$	The risk is within the ALARP region, classified as “undesirable”	Reduction of such risk is recommended, but is left to the discretion of the risk owner, if the cost of risk reduction is substantial compared to the money equivalent of its consequences. The risk can be reduced by reducing the frequency of events and/or by reducing the specific level of consequences
$\frac{R_{o.al}}{K^2} < R \le \frac{R_{o.al}}{K}$	The risk is within the ALARP region, classified as “acceptable”	Reduction of such risk is not recommended, but can be done at the discretion of the risk owner, if the cost of risk reduction is not substantial compared to the money equivalent of its consequences. The risk can be reduced by reducing the frequency of events and/or by reducing the specific level of consequences
$R \le \frac{R_{o.al}}{K^2}$	The level of risk is negligible	No risk reduction is required. The risk is to be routinely monitored

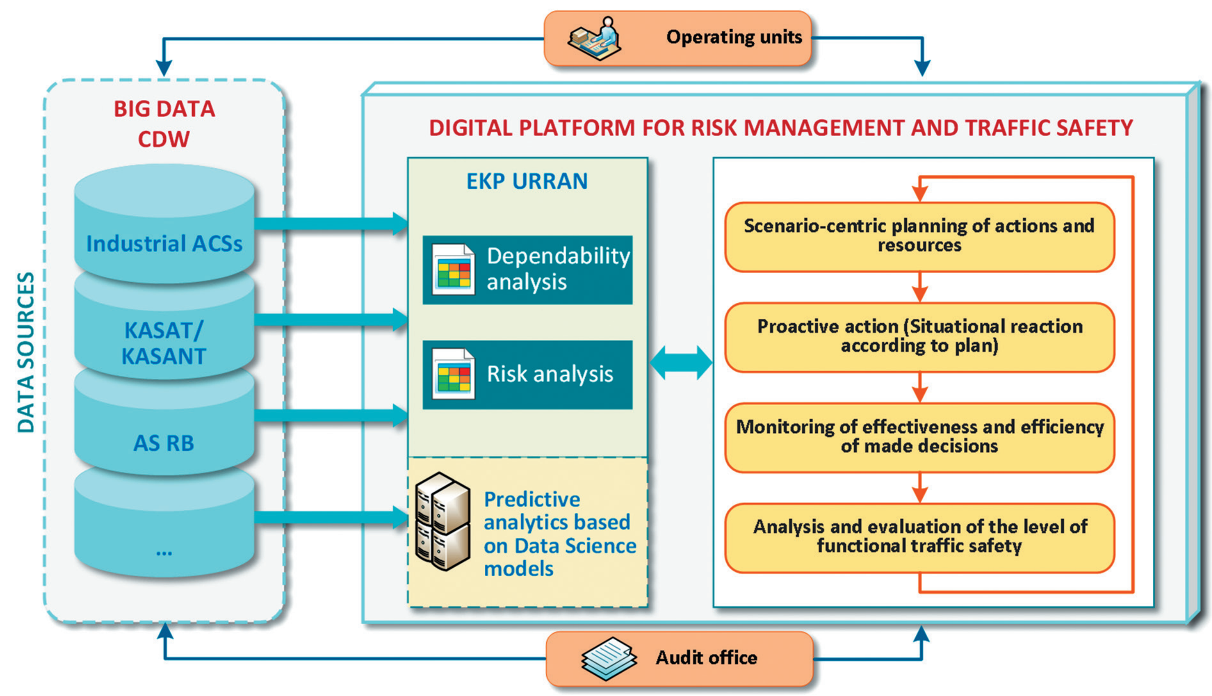


Fig. 9. Digital platform for risk management and traffic safety

for one of the scenarios of Table 2, where $K = 3…15$ is the scaling coefficient of the adopted risk score.

4. Future development of EKP URRAN

As noted in [6, 7], the future development of the URRAN project will focus on the Data Science-based data mining system in terms of construction of predictive dynamic models of infrastructure and rolling stock condition.

Data Science technology combines the management of large amounts of input data for simulation (i.e., Big Data) and training of models using an array of data [9, 10, 11]. Such simulated results will be employed in flexible resource management by operating branches for the purpose of facility maintenance, as well as in the preparation by the JSC RZD Situation Center of procedures aimed at preventing undesirable events. Thus, in the future, the EKP URRAN will contain modules that implement dynamic predictive analytics models for the purpose of predicting undesirable events involving infrastructure and rolling stock that may disrupt traffic safety.

This feature of the EKP URRAN is to become a component of the Digital Platform for Risk and Traffic Safety Management deployed in JSC RZD (see Fig. 9).

Conclusions

The EKP URRAN implements a single information space that supports decision-making as part of the asset management system, as it possesses the required regulatory and procedural resources, hardware and software assets intended for comprehensive management of assets and processes for the purpose of efficient railway service.

Further development of the EKP URRAN will soon provide all levels of company management with an efficient tool that allows, in the context of limited resources, making substantiated managerial decisions and rational investment allocation.

The EKP URRAN is an asset of JSC RZD designed to be used by the managers and specialists of various JSC RZD units. It can be implemented as a standalone IT product for the purpose of developing and deploying an asset management system in various railway companies.

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The authors' contribution

Bublikova M.A. analysed the URRAN project and its potential future developments, along with open information sources on the existing asset management software products.

Khokhlov I.P. analysed the functionality and technical solutions of the URRAN system, its applicability as part of various JSC RZD activities.

Conflict of interests

The authors declare the absence of a conflict of interests.

GNEDENKO FORUM

INTERNATIONAL GROUP ON RELIABILITY

The Gnedenko Forum was founded in 2004 by an unofficial international group of experts in the dependability theory for the purpose of professional support of researches from all over the world who are interested in studying and developing the scientific, technical and other aspects of the dependability theory, risk analysis and safety in the theoretical and practical domains.

The Forum exists on the Internet as a non-for-profit organization. It aims to involve into joint discussion and communication technical experts interested in developing the dependability theory, safety and risk analysis regardless of their home country and membership in whichever organization.

The Forum acts as an impartial and neutral entity that delivers scientific information to the press and public as regards the matters of safety, risk analysis and dependability of complex technical systems. It publishes reviews, technical documents, technical reports and research essays for the purpose of dissemination of knowledge and information.

The Forum is named after Boris V. Gnedenko, an outstanding Soviet mathematician, expert in the probability theory and its applications, member of the Ukrainian Academy of Sciences. The Forum is the platform for distribution of information on educational grants, academic and professional positions related to dependability, safety and risk analysis all over the world.

Currently, the Forum has 500 members from 47 countries.

Since January 2006, the Forum has been publishing its quarterly journal, Reliability: Theory & Applications (www.gnedenko.net/RTA). The Journal is registered in the Library of Congress (ISSN 1932-2321) and publishes articles, reviews, memories, information and literature references regarding the theory and application of dependability, survivability, maintenance, risk analysis and management methods.

Since 2000, the Journal is indexed in Scopus.

Membership in the Gnedenko Forum does not imply any obligations. It is only required to send your photograph and a brief professional biography (resume) to a.bochkov@gmail.com.
Templates can be found at http://www.gnedenko.net/personalities.htm.

www.gnedenko.net

DEPENDABILITY JOURNAL ARTICLE SUBMISSION GUIDELINES

Article formatting requirements

Articles must be submitted to the editorial office in electronic form as a Microsoft Office Word file (*.doc or *.docx extension). The text must be in black, on a A4 sheet with the following margins: 2 cm for the left, top and bottom margins; 1.5 or 2 cm for the right margin. An article cannot be shorter than 5 pages and longer than 12 pages (can be extended upon agreement with the editorial office). The article is to include the structural elements described below.

Structure of the article

The following structural elements must be separated with an *empty line*. Examples of how they must look in the text are shown *in blue*.

1) Title of the article

The title of the article is given in the English language.

Presentation: The title must be in 12-point Times New Roman, with 1.5 line spacing, fully justified, with no indentation on the left. The font face must be bold. The title is not followed by a full stop.

An example:

Improving the dependability of electronic components

2) Author(s)' name.

This structural element for each author includes:

In English: second name and first name as "First name, Second name" (John Johnson).

Presentation: The authors' names must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with no indentation on the left. The font face must be bold. The authors' names are separated with a comma. The line is not followed by a full stop.

An example:

John Johnson[1], Karen Smith[2*]

3) The author(s)' place of employment

The authors' place of employment is given in English. Before the place of employment, the superscripted number of the respective reference to the author's name is written.

Presentation: The reference to the place of employment must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with no indentation on the left. The font face must be normal. Each place of employment is written in a new line. The lines are not followed by a full stop.

An example:

[1] Moscow State University, Russian Federation, Moscow

[2] Saint Petersburg Institute of Heat Power Engineering, Russian Federation, Saint Petersburg

4) The e-mail address of the author responsible for maintaining correspondence with the editorial office

Presentation: The address must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with no indentation on the left. The font face must be normal, all symbols must be lower-case. Before the address reference, symbol * is written. The title is not followed by a full stop.

An example:

*johnson_j@aaa.net

5) Abstract of the article

This structural element includes a structured summary of the article with the minimal size of 350 words and maximum size of 400 words. The abstract is given in the English language. The abstract must include (preferably explicitly) the following sections: Aim; Methods; Results/Findings; Conclusions. The abstract of the article should not include newly introduced terms, abbreviations (unless universally accepted), references to literature.

Presentation: The abstract must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with no indentation on the left. The font face must be normal, except "**Abstract**", "**Aim**", "**Methods**", "**Conclusions**", that (along with the full stop) must be in bold. The text of the abstract must not be paragraphed (written in a single paragraph).

An example:

Abstract. Aim.Proposing an approach … taking into consideration the current methods. **Methods.** The paper uses methods of mathematical analysis,…, probability theory. **Results.** The following findings were obtained using the proposed method … **Conclusion**. The approach proposed in the paper allows…

6) Keywords

5 to 7 words associated with the paper's subject matter must be listed. It is advisable that the keywords complimented the abstract and title of the article. The keywords are written in English.

Presentation: The text must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with no indentation on the left. The font face must be normal, except "**Keywords:**" that (along with the colon) must be in bold. The text must not be paragraphed (written in a single paragraph). The text must be followed by a full stop.

An example:

Keywords: dependability, functional safety, technical systems, risk management, operational efficiency.

7) Text of the article

It is recommended to structure the text of the article in the following sections: Introduction, Overview of the sources, Methods, Results, Discussion, Conclusions. Figures and tables are included in the text of the article (the figures must be "In line with text", not "behind text" or "in front of text"; not "With Text Wrapping").

Presentation:

The titles of the sections must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with no indentation on the left. The font face must be bold. The titles of the sections (except the Introduction and Conclusions) may be numbered in Arabic figures with a full stop after the number of a section. The number with a full stop must be separated from the title with a no-break space (Ctrl+Shift+Spacebar).

The text of the sections must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with a 1.25-cm indent. The font face must be normal. The text of the sections must be paragraphed. There must be no indent in the paragraph that follows a formula and contain notes to such formula, e.g.:

where n is the number of products.

An example:

1. State of the art of improving the dependability of electronic components

An analysis of Russian and foreign literature on the topic of this study has shown that …

Figures (photographs, screenshots) must be of good quality, suitable for printing. The resolution must be at least 300 dpi. If a figure is a diagram, drawing, etc. it should be inserted into the text in editable form (Microsoft Visio). All figures must be captioned. Figures are numbered in Arabic figures in the order of their appearance in the text. If a text has one figure, it is not numbered. References to figures must be written as follows: "Fig. 3. shows that …" or "It is shown that … (see. Fig. 3.)." The abbreviation "Fig." and number of the figure (if any) are always separated with a no-break space (Ctrl+Shift+Spacebar). The caption must include the counting number of the figure and its title. It must be placed a line below the figure and center justified:

Fig. 2. Description of vital process

Captions are not followed by a full stop. *With center justification there must be no indent!* All designations shown in figures must be explained in the main text or the captions. The designations in the text and the figure must be identical (including the differences between the upright and oblique fonts). *In case of difficulties with in-text figure formatting, the authors must – at the editorial office's request – provide such figures in a graphics format (files with the* *.tiff, *.png, *.gif, *.jpg, *.eps extensions).

The tables must be of good quality, suitable for printing. The tables must be editable (not scanned or in image format). All tables must be titled. Tables are numbered in Arabic figures in the order of their appearance in the text. If a text has one table, it is not numbered. References to tables must be written as follows: "Tab. 3. shows that …" or "It is shown that … (see. tab. 3.)." The abbreviation "tab." and number of the table (if any) must be always separated with a no-break space (Ctrl+Shift+Spacebar). The title of a table must include the counting number and its title. It is placed a line above the table with center justification:

Table 2. Description of vital process

The title of a table is not followed by a full stop. *With center justification there must be no indent!* All designations featured in tables must be explained in the main text. The designations in the text and tables must be identical (including the differences between the upright and oblique fonts).

Mathematical notations in the text must be written in capital and lower-case letters of the Latin and Greek alphabets. Latin symbols must always be oblique, except function designators, such as sin, cos, max, min, etc., that must be written in an upright font. Greek symbols must always be written in an upright font. The font size of the main text and mathematical notations (including formulas) must be identical; in Microsoft Word upper and lower indices are scaled automatically.

Formulas may de added directly into the text, for instance:

Let $y = a \cdot x + b$, then…,

or written in a separate line with center justification, e.g.:

$$y = a \cdot x + b.$$

In formulas both in the text, and in separate lines, the punctuation must be according to the normal rules, i.e. if a formula concludes a sentence, it is followed by a full stop; if the sentence continues after a formula, it is followed by a comma (or no punctuation mark). In order to separate formulas from the text, it is recommended to set the spacing for the formula line 6 points before and 6 points after). If a formula is referenced in the text of an article, such formula must be written in a separate line with the number of the formula written by the right edge in round brackets, for instance:

$$y = a{\cdot}x + b. \tag{1}$$

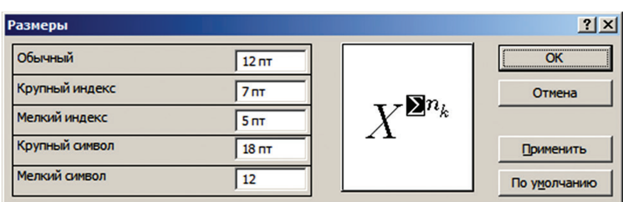
If a formula is written in a separate line and has a number, such line must be right justified, and the formula and its number must be tab-separated; tab position (in cm) is to be chosen in such a way as to place the formula roughly at the center. Formulas that are referenced in the text must be numbered in Arabic figures in the order of their appearance in the text.

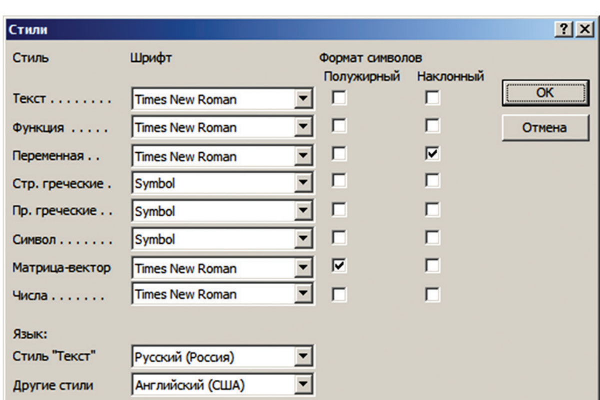
Simple formulas should be written without using formula editors (in MS Word, Latin should be used, as well as the "Insert" menu + "Special Characters", if Greek letters and mathematical operators are required), while observing the required slope for Latin symbols, for example:

$$\Omega = a + b{\cdot}\theta.$$

If a formula is written without using a formula editor, letters and +, –, = signs must be separated with no-break spaces (Ctrl+Shift+Spacebar).

Complex formulas must be written using a formula editor. In order to avoid problems when editing and formatting formulas it is highly recommended to use Microsoft Equation 3.0 or MathType 6.x. In order to ensure correct formula input (symbol size, slope, etc.), below are given the recommended editor settings.





When writing formulas in an editor, if brackets are required, those from the formula editor should be used and not typed on the keyboard (to ensure correct bracket height depending on the formula contents), for example (Equation 3.0):

$$Z = \frac{a\cdot\left(\sum_{i=1}^{n} x_i + \sum_{j=1}^{m} y_i\right)}{n+m}. \tag{2}$$

Footnotes in the text are numbered with Arabic figures, placed page by page. Footnotes may include: references to anonymous sources on the Internet, textbooks, study guides, standards, information from websites, statistic reports, publications in newspapers, magazines, autoabstracts, dissertations (if the articles published as the result of thesis research cannot be quoted), the author's comments.

References to bibliographic sources are written in the text in square brackets, and the sources are listed in the order of citation (end references). The page number is given within the brackets, separated with a comma and a space, after the source number: [6, p. 8].

8) Acknowledgements

This section contains the mentions of all sources of funds for the study, as well as acknowledgements to people who took part in the article preparation, but are not among the authors. Participation in the article preparation implies: recommendations regarding improvements to the study, provision of premises for research, institutional supervision, financial support, individual analytical operations, provision of reagents/patients/animals/other materials for the study.

Presentation:

The information must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with no indentation on the left. The font face must be normal.

9) References

The References must include only peer-reviewed sources (articles from academic journals and monographs) mentioned in the text of the article. It is not advised to references autoabstracts, dissertations, textbooks, study guides, standards, information from websites, statistic reports, publications in newspapers, websites and social media. If such information must be referred to, the source should be quoted in a footnote.

The description of a source should include its DOI, if it can be found (for foreign sources, that is possible in 95% of cases).

References to articles that have been accepted, but not yet published must be marked "in press"; the authors must obtain a written permission in order to reference such documents and confirmation that they have been accepted for publication. Information from unpublished sources must be marked "unpublished data/documents"; the authors also must obtain a written permission to use such materials.

References to journal articles must contain the year of publication, volume and issue, page numbers.

The description of each source must mention all of its authors.

The references, imprint must be verified according to the journals' or publishers' official websites.

Presentation:

References must be written in accordance with the Vancouver system.

The references must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with a 1.25-cm indent on the left. The font face must be normal. Each entry must be numbered in Arabic figures with a full stop after the number. The number with a full stop must be separated from the entry with a no-break space (Ctrl+Shift+Spacebar).

10) About the authors

Full second name, first name (in English); complete mailing address (including the postal code, city and country); complete name of the place of employment, position; academic degree, academic title, honorary degrees; membership in public associations, organizations, unions, etc.; official name of the organization in English; e-mail address; list and numbers of journals with the author's previous publications; the authors' photographs for publication in the journal.

Presentation:

The information must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with no indentation on the left. The font face must be normal.

11) The authors' contribution

Detailed information as to each author's contribution to the article. For example: Author A analyzed literature on the topic of the paper, author B has developed a model of real-life facility operation, performed example calculation, etc. Even if the article has only one author, his/her contribution must be specified.

Presentation:

The information must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with no indentation on the left. The font face must be normal.

12) Conflict of interests

A conflict of interests is a situation when people have conflicting and competing interests that may affect editorial decisions. Conflicts of interests may be potential or conscious, as well as actually existing. The objectivity may be affected by personal, political, financial, scientific or religious factors.

The author must notify the editorial office on an existing or a potential conflict of interests by including the corresponding information into the article.

If there is no conflict of interests, the author must also make it known. An example of wording: "The author declares the absence of a conflict of interests".

Presentation:

The text must be in 12-point Times New Roman, with a 1.5-line spacing, fully justified, with no indentation on the left. The font face must be normal.

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