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Adaptive dependability of information management systems

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Abstract. *The paper examines the reliability of an information management system as its ability to provide the required services that can be justifiably trusted. It is assumed that the system functions without an operator. The aim is to ensure the dependability of a multimodule control system, when the problem-solving results are affected by failures, faults and errors of problem-solution by the system's computation modules (CMs). Conventional fault tolerance methods do not provide the desired effect, as even under infinite structural redundancy yet real capabilities of on-line detection of CM failures or faults the system's dependability is significantly lower than expected. The paper proposes and evaluates the methods of adaptive dependability. They are to ensure the observability of control systems under limited capabilities of component CM operability supervision, as well as achieving the required levels of dependability of information management systems in cases of insignificant float time and structural redundancy. These goals are achieved through active (and automatic) reassignment of the available computational resources for on-line information processing. The methods of adaptive dependability enable – with no interruption of computational processes and while solving real-world problems – timely automatic detection and elimination of failures, faults of CMs and errors in the solution of specified problems through on-line localization of faulty modules and subsequent automatic reconfiguration of the system with the elimination of such modules from operation.*

Keywords: *computation modules, dependability, adaptive protection, failures, faults, errors in performance of designated tasks, automatic system reconfiguration, control, allowed time of interruption of operation, time redundancy, protection cycles and beats.*

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1. Introduction

1.1. Dependability of information management systems

The matters related to ensuring the reliability of information technology are the main focus of all experts directly or indirectly involved in its development, manufacture and operation. Over the years of digital technology development the failure rate of the basic components decreased by six orders of magnitude. An information system includes thousands of digital elements each of which is a hardware and software device performing a multitude of functions.

Now, the key problem of ensuring the reliability of an information system is the faultless performance of the assigned functional tasks that, in technical terms, are implemented by information processes. The relevance of this problem is due to the fact that error rate in the operation of an information system and the associated functional failure rate significantly exceed the failure rate of digital technology, while the functional failures themselves may be critical to the environment and controlled objects [1, 2, etc.]

Due to that some researchers assume that reliability of information technology performance should be studied as the ability of an information system to deliver service that can be trusted. The *service* delivered by a system is its properties or behavior as it is perceived by its *user*. In the interpretation of this paper's authors a service that can be trusted is perceived as *overall reliability* [3].

In the mentioned paper [3] the following concepts are used:

correct service is delivered when the service implements the system function(s);

system *failure* is an event that occurs when the delivered service deviates from correct service, i.e. failure is a transition from correct service to *incorrect service*, when the system function is not implemented.

The development of this approach is reflected in the research paper of the Working Group 10.4 of the International Federation for Information Processing [4]. However, instead of the term "overall reliability" the group's experts introduce the term *"dependability"* that in this paper is considered as the "trustworthiness of a computing system which allows reliance to be *justifiably* placed on the service it delivers." Service is a form of activities that do not create a new material product, but change the quality of an existing previously created product. The delivery of service itself creates the desired result [5]. Explicitly, dependability is a property of the *service* and depends on the system's utilization.

1.2. Limitations of the conventional methods of ensuring dependability of control systems

The delivery of service to user with the given level of guaranteed quality is performed with the help of a technical system and is an action, process required for the implementation of the service delivery function. Here we imply the combination of hardware, software and human operator of the information system. Hereinafter, we assume that the control system automatically performs the specified functions without the involvement of the human operator. Consequently, ensuring a high level of system dependability requires prior achievement of even higher level of hardware (product) and software components reliability. The products are an object or a set of objects manufactured at an enterprise. The classic (structural) reliability theory examined the processes of *products* (system, element) failures and recoveries. In [1, 6], it is shown that even under arbitrarily large redundancy it does not appear to be possible to achieve a high level of product reliability. The object of the research was the reliability model of a redundant object with partial redundancy composed of one primary and an infinite number of same-type backup devices. The following is assumed:

• The components' lifetime duration is a random value and is described with a service life distribution that meets the following conditions:

- the times of outage of each of the backup components are statistically independent from each other;

- all the backup components have an identical exponential distribution of service life.

• The system of these random values is an ordinary recovery process.

• The supervision and commutation facilities to the backup devices are perfectly dependable.

• The switch time is negligibly small.

Under the given premises, the limit probability of no failure of a redundant group is defined as $P_L(t) \le \sum_{n=0}^{\infty} P(n,t) \cdot y^n$, where $P(n,t)$ is the distribution of the resultant number of the time intervals between the replacements of failed devices of a specific facility, that before the failure performed the functions of the main element; is $\gamma = P\{v \le \tau_A\} = \int_0^{\tau_A} f_v(t)dt = F_v(\tau_A)$ the probability of correct and timely detection of failure and backup switching, v is the random device failure duration, τ_A is the allowed duration of system outage (for control systems this time is comparable with the duration of control cycle); $f_v(t)$ is the density function of failure duration in the system.

Under the above assumptions [7] established that the mean time to failure of a redundant object with partial redundancy composed of one primary and an infinite number of same-type backup devices does not exceed the level defined by formula (1) on the assumption of simple device failure or fault flow

$$T_{FS} \le 1/\lambda(1-\gamma) \quad (1)$$

where λ is the failure rate of one device.

In [7], it is established that the expected increase of the mean time to failure of the initial device due to multiple redundancy with recovery can not be more than 2…10 times even under a very high probability of correct and timely detection of failure and backup switching $0.8 < \gamma \le 0.9$.

Taking into consideration that the system's software is also executed with errors and more often with faults [8, 9, 10, etc.], the achievement of a high level of system dependability by means of conventional methods should not be expected even under condition of heavy investment into system redundancy.

2. Definition of the problem of adaptive dependability

It is required to ensure the specified high level of information management system dependability ***without introducing large*** structural, time, functional and other redundancy by means of:

- dependability management based on the results of evaluation of the ***correctness*** of system tasks performance, not the rate of failures and recovery;
- use of ***natural*** time redundancy that persists in many systems within the control cycle;
- ***adaptation*** of the system to erroneous results of system tasks performance with dynamic rearrangement of the system and parallel performance of tasks with beat-to-beat comparison of results;
- ***priority*** handling of the most important tasks in order to ensure their higher dependability.

The ideas and principles of adaptive dependability have much in common with the concept of active protection (AP) that we set forth in [11]. They can be briefly described as follows:

- the duration of all cycles of the information processing divides into certain constant or random time intervals that shall be further called beats, within each of which the specified set of software modules are executed and hold points are formed;
- the whole set of the constituent computation modules (CMs) of an information system is divided into two compound sets: the computing environment, i.e. a set of m same-type CMs; the protective environment, i.e. a set of $k \le m$ same-type CMs redundant in terms of the specified tasks;
- dynamic rearrangement of control system modules is carried out at every second beat for the organization of parallel information processing;
- beat-by-beat virtual redundancy by means of parallel solution of all specified m tasks at the primary CMs provided there is at least one operational redundant CM;
- minimal system configuration must include not less than $m = 2$ main and one redundant CM for detection of erroneous result in the solved task, classification and localization of malfunctions;
- synthesis of adaptive dependability (AD) is based on the selection of the value of beat duration τ, under which within the allowed duration of outage the error in the task solution must – with the specified level of assurance – be detected and eliminated through the localization of the error source CM and its swapping for an operable redundant CM.

3. Organization of systems with adaptive dependability

Different disciplines can be suggested for the practical implementation of ideas and methods of AD organization. In this paper, two disciplines are examined, i.e. ***D1*** and ***D2***.

D1. A system with one-beat restart containing m main and one controlling CM, non-priority control, no reassignment of modules. In the case of failure of one of a pair of CMs repeated calculation with the previous operands is performed. Matching results in the next beat eliminates the possibility of failure of modules, the failure has been eliminated, the hold point of assignment of the first CM in the i-th protection cycle is updated. If CM fault is detected by own control facilities, the hold point is naturally updated based on the data of the first main CM. A failure of one of the pair of CMs is detected by means of a restart for one AP beat. If, in the process of solution of the same part of a task, over two beats the results of the operation of a pair of same-type CMs do not match twice, the hold point is not updated until joint operation of the controlling CM with the next main (the third in this example) CM. In case of matching results for this last pair the decision is made regarding the failure of the previous main CM (the second one in this example), the hold point for the second CM is updated based on the data of the controlling module that now performs the role of the second main CM. If in three adjacent protection beats the results do not match, the decision is made regarding the failure of the controlling CM and the system may for some time operate without protection, if there is no operable backup module.

Thus, relative to discipline ***D1*** the parameters A, b and x_E are characterized by the following: number of beats in the protection cycle $A = m$; number of main CM failure or fault decision-making beats $b = 2$; number of beats for recovery of computation process from the last hold point $x_E \le m + 2$.

Table 1

Number of beat	Numbers of primary CMs	Number of controlling CM	Pairs of controlled CMs	Reassigned CMs	CM polling rate		
					2	5	1, 3, 4, 6, 7, 8
1	1 8 3 4 5 6 7	2	**2**–7	8–2	**4**	**2**	**1**
2	1 8 3 4 5 6 7	2	**2**–3	8–2			
3	1 2 3 4 5 6 7	8	8–**5**	-			
4	8 2 3 4 5 6 7	1	1–**2**	8–1			
5	1 2 3 8 5 6 7	4	4–**2**	8–4			
6	1 2 3 4 8 6 7	5	**5**–6	8–5			

D2. A system with restart and CM reassignment containing m main and one controlling module. The organization of detection and elimination of malfunctions is the same as in discipline ***D1.*** *CM reassignment* is required in order to shorten the protection cycle, when the number of main CMs is significantly higher than that of the backup modules. The point of reassignment consists in the fact that in specific beats CMs are redistributed between the computing and protective environments. For the time of a beat some modules of the protective environment are assigned the functions of main modules and vice versa. This eliminates the inherent weakness of methods of controlling CM fixation, when the modules of the computational environment are controlled much less frequently that those of the protective environment. Indeed, in all cases of fixation the modules of the protective environment within the AP cycle take part in all pairs of controlled CMs, whereas the modules of the computational environment take part in just one pair, or somewhat more frequently, if in each protection beat two and more CM pairs are formed.

Thus, relative to discipline ***D2*** parameters A b and x_E are as follows: $A = \text{int}\left(\frac{m+1}{2}\right)$, $b = 2$, $x_E = \text{int}(\frac{m+5}{2})$.

Organization of ***priority control*** of the control system's ability to correctly solve the specified tasks allows significantly increasing the level of its dependability in terms of priority tasks. Priority control is organized by means of CM reassignment. However, the intention is different. Whereas the reassignment of modules aimed to equalize the frequency of controls of main and backup CMs, priority control aims to increase the frequency of control of the modules most significant in terms of the specified tasks.

Let us illustrate the feasibility of systems with two modules identified as priority (Table 1). It is assumed that the first identified module (zero priority) is controlled in the AP cycle with the assigned maximum frequency, the second one (first priority) is controlled with increased frequency, yet it is lower than with the zero priority module. The remaining CMs in the system are controlled with an equal frequency that is yet lower than that of the priority modules. Let $m = 7$, $k = 1$ ($m + k = 8$), zero priority is given to module 2, while first priority is given to module 5. Let us stipulate that in the AD cycle module 2 was controlled in four beats, module 5 was controlled in two beats, while the remaining modules 1, 3, 4, 6, 7 and 8 were controlled in one beat. The solution of this problem is shown in Table 1.

The following results were obtained. AD cycle $A = 6$ beats, CM are reassigned four times, module 2 is controlled in two beats out of three adjacent ones, while module 5 is controlled at every third beat. The duration of AD cycle increased 1.5 times compared to uniform CM reassignment, since in that case the duration of cycle would be $A = (m + k)/2k = 4$. This is natural, since the reduction of time intervals between the controls of some CMs is possible at the expense of longer intervals between the controls of non-priority CMs. Solving such AP problems should involve reasonable trade-offs. This applies fully to the selection of the method of CM fixation or reassignment. In the first case AD management is simpler, in the second case control cycle is shorter. Reassignment of CM is more preferable in case of very low values of allowed duration of outage, although AB management is somewhat more complicated. Under less strict time restrictions AG should be attempted to be implemented by means of fixation of controlled CMs.

4. The efficiency of the methods of adaptive dependability of control systems

The efficiency of adaptive dependability is evaluated based on the indicator of probability of successful adaptation of an information management system to failures, faults, software errors. The adaptation will be successful if as the result of the actions performed as part of the protection algorithms the duration of the specified malfunctions is less or equal to the allowed value, which enables the elimination of erroneous results in the control process. The allowed value means the control cycle, i.e. the time within which the detection and elimination of system malfunction will not cause subsequent erroneous control. Since the elimination time for each protection discipline is a constant number of AD beats, it will suffice to compare the duration of malfunction detection with the allowed detection time.

Let us perform the verification of the efficiency of adaptive dependability for the following types of protection organization conditions.

The tasks of information processing are divided into equal parts (beats) τ, with the duration of a beat being much shorter than the duration of the task. The tasks are solved with random time intervals υ_2, however the duration of task solutions υ_1 are much longer than the duration of pauses, i.e. $\upsilon_1 >> \upsilon_2$. That allows dividing the task into protection beats (e.g. for generality, random duration beats). Additionally, it is taken into consideration that the allowed outage of the system is a constant value τ_A. It is assumed that there are no simultaneous failures or faults of the operable and controlled CM that is verified within the current beat. The duration of the beat is defined by the duration of execution within the beat of a group of functionally complete software modules. Since all CMs that execute software modules are same-type, the order of distribution of the software modules per CM operation beats is common for all CMs. This allows adopting the distributions $F_\upsilon(t)$ of beat duration as identical for all CMs.

It is required to establish the probability of the system's successful adaptation to failures:

$$\beta = P\{\nu \le \tau_A - t_E\} = \int_0^{\tau_A - t_E} f_\nu(t)dt \qquad (2)$$

where $f_\nu(t)$ is the density function of the time ν of a dormant fault's existence in the system.

In order to find the functions of density $f_\nu(t)$ and probability of successful adaptation to failures β in general, the following parameters are used:

• distribution functions and characteristics of protection time intervals, i.e. beat duration, allowed time of system outage and time of elimination of detected failure (τ_A and t_E respectively);

• parameters of the adopted AP discipline: $A, b, t, x_E = t_E/\tau$.

The time of connection of the controlling CM to the next main CM consists of the random duration of beat υ and wait time ψ from the moment of completion of the parallel operation with the previous CM to the moment of the beginning of the next operation beat of the next CM. $\psi \le \upsilon$ and during the wait time the memory of the controlling CM is loaded with commands and operands of the next main module.

For each time density function ν let us preliminarily set the total time density function ψ + υ. In the Laplace domain it is as follows

$$f_\varsigma(s) = \phi_\psi(s) * f_\upsilon(s),$$

where $\phi_\psi(s)$ is the portrayal of the distribution density of wait time ψ, while $f_\upsilon(s)$ is the portrayal of the distribution density of the duration of the AP beat.

Let us assume that between the occurrence of a dormant failure of CM and the moment the controlling CM connects to it x beats elapsed. Then, the conditional probability of $x < X$, where X = 0, 1, …, A, …, can be found using the appropriate Laplace transformation

$$f_x(s) = [f_\xi(s)]^x.$$

Due to the equally likely possibility of failure of any CM that are not protected during the current beat, it can be assumed that the integer random variable x is uniformly distributed over the number range 1, 2, …, A–1. Out of this, the distribution density of the number of beats of malfunction existence within the system is identified using the following formula:

$$f(x) = \sum_{i=1}^{A-1} \frac{\delta(x-i)}{A-1}, \qquad (3)$$

where $\delta(x)$ is the delta function of parameter x.

The total duration of failure existence until its detection is the sum of time x(υ+ψ) and time b(υ+ψ) from the moment of detection of the fact of malfunction to the localization of the failed CM in accordance with the chosen AP discipline.

The density function of random value x(υ+ψ)=θ in the Laplace image is depicted as follows according to the total probability formula.

$$f_\theta(s) = \sum_{i=1}^{A-1} \frac{1}{A-1} \left(f_\xi(s)\right)^i.$$

The density function of random value (x+b)· (υ+ψ) in the Laplace image is calculated as

$$f_\nu(s) = f_\theta(s) * (f_\upsilon(s))^b = \frac{1}{A-1} \sum_{i=1}^{A-1} \left(f_\xi(s)\right)^{i+b} \qquad (4)$$

The next step in the identification of the probability of successful adaptation to failures of a system with AP design under consideration consists in developing function $f_\xi(s)$ in the above formula, that in the Laplace image is the density function of the sum of beat duration and time delay of controlling CM connection to the main module within the beat ($\xi = \upsilon + \psi \le 2\upsilon$).

Using experimental data [2] let us take the distributions of random beat durations υ as an Erlang distribution of the a-th order with the density function $f_\upsilon(t) = \frac{\rho(\rho \cdot t)^a}{a!} e^{-\rho \cdot t}$ that in the Laplace image are as follows:

$$f_\upsilon(s) = \left(\frac{\rho}{\rho + s}\right)^{a+1},$$

where ρ is the Erlang distribution parameter (number of events per unit of time).

According to [12], the density function of wait time ψ (in our case, the time of controlling CM connection to the main CM) in the Laplace image is as follows:

$$\phi_\psi(s) = \frac{\rho}{(a+1)s}\left[1 - \left(\frac{\rho}{\rho + s}\right)^{a+1}\right].$$

Consequently, in formula (4) density function $f_\xi(s)$ equals to

$$f_\xi(s) = f_\upsilon(s) \cdot \phi_\psi(s) = \left(\frac{\rho}{\rho + s}\right)^{a+1} \cdot \frac{\rho}{(a+1)s}\left[1 - \left(\frac{\rho}{\rho + s}\right)^{a+1}\right].$$

By substituting this formula into formula (3.4) we deduce that

$$f_\nu(s) = \frac{1}{A-1} \sum_{i=1}^{A-1} \left\{\left(\frac{\rho}{\rho + s}\right)^{a+1} \frac{\rho}{(a+1)s}\left[1 - \left(\frac{\rho}{\rho + s}\right)^{a+1}\right]\right\}^{i+b}.$$

By moving from the image to the original under a constant value of the allowed outage time and using formula (3) we identify the probability of successful adaptation to failures of a system with AD

$$\beta = 1 - \frac{e^{-(a+1)\cdot x_A^*}}{A-1} \sum_{i=1}^{A-1} \left(\frac{1}{a+1}\right)^{i+b} \sum_{|\bar{n}|=i+b} \frac{(i+b)!}{\bar{n}!} \cdot \sum_{k=0}^{\eta} \frac{((a+1)x_A^*)^k}{k!} \qquad (5)$$

where $\bar{n}! = n_0! \cdot n_1! \cdot \ldots \cdot n_a!$; $|\bar{n}| = n_0 + n_1 + \ldots + n_a$; $x_A^* = \tau_A^*/\tau$; $t_A^* = \tau_A - t_E$;

$$\eta = (a+2)(i+b) + \sum_{j=1}^{a} j n_j + 1.$$

In the special case a = 0 (exponential distribution of beat duration) the following formula for the probability of the system's successful adaptation to failures is true $\beta = 1 - \frac{e^{-x_A^*}}{A-1} \sum_{i=1}^{A-1} \sum_{k=0}^{2(i+b)+1} \frac{(x_A^*)^k}{k!}$, as in this case $\bar{n}! = 1$, while $|\bar{n}| = 0$.

Using expression (5) let us analyze the dependence of the probability of successful adaptation of a system with AP from the allowed number of outage beats, number m of main modules and subject to the above examined disciplines ***D1*** and ***D2***.

Figure 1 shows the dependences $\beta = f(x_A)$ under $a \ge 2$ in respect to disciplines ***D2*** (solid lines) and ***D1*** (dotted lines).

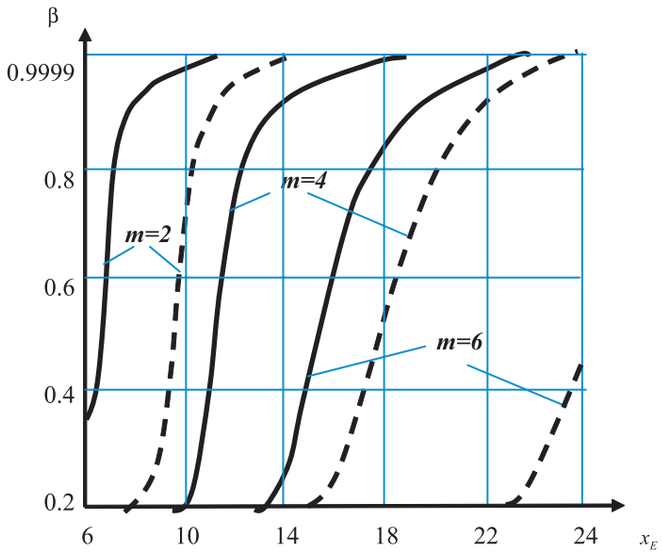

Figure 1. Dependences of the probability of successful adaptation of a system with random protection beats to failures depending on the allowed number x_E of protection beats and number m of main CMs

Beginning from the second order of the Erlang distribution of beat durations and higher the results of such dependences are practically identical. This shows that disciplines similar to ***D2*** have the highest speed of adaptation to CM failure. These disciplines react to the errors in the task solution results about a few beats quicker than the discipline of class ***D1***. The advantages of the above disciplines increase with the number of main computation modules.

At the same time, ABs with random beat duration are much more inertial than ABs with constant beat duration. Thus, even under the minimal for AD number of main modules m = 2 the time of detection and elimination of CM failure increases 1.5 – 2 times. Since for many control system architectures and associated computational processes it does not appear to be possible to provide AD with constant beats, additional opportunities of increasing in the speed of adaptation of system with AD to failures of component CMs should be found. For instance, such opportunity exists if built-in control of main CMs is also used that can accelerate the detection and elimination of CM failures in systems with AD.

5. Conclusion

Limited capabilities to ensure redundancy, on-line detection of failures, faults, errors of information process performance, as well as the limited capabilities of the hardware and software system require the development of unconventional technological solutions to ensure dependability of information management systems. One of them is the adaptive dependability technology proposed in this paper. Essentially, it consists in the active use of natural time and structural redundancy and active (and automatic) reassignment of available processing resources not only for real-time information processing, but also for observability of the system under limited supervision facilities. Adaptive dependability is intended for enabling the required levels of dependability of information management systems under insignificant time margin, limited efficiency of component processing modules fault detection facilities, as well as under the condition of the amount of redundant equipment not exceeding the amount of primary equipment. Adaptive protection provides viable opportunities of achieving a much higher level of dependability compared to conventional redundancy methods. The adaptive dependability technology enables – under restricted time while solving real-world problems – timely automatic detection and elimination of failures and faults through on-line localization of faulty modules and subsequent automatic reconfiguration of the system with the elimination of such modules from operation. At the same time, this technology is geared towards multimodule systems and is not adapted for systems of information storage and display, documentation, power supply of information management systems.

References

[1]. Shubinsky IB. Nadiozhnye otkazoustoychivye informatsionnye sistemy. Metody sinteza [Dependable failsafe information systems. Synthesis methods]. Moscow: Dependability Journal; 2016 [in Russian].

[2]. Kirpichnikov AP, Vasiliev SN. Particular characteristics of today's microelectronics and matters of highly dependable and secure control systems design. Dependability 2017;3:10-16.

[3]. Avizienis A, Laprie J-C and Randell B. Dependability of computer systems. Fundamental concepts, terminology and examples. Technical report. LAAS – CNRS; October, 2000.

[4]. Rus I, Komi-Sirvio S, Costa P. Computer program with insurance of high reliability. Technical report. IFIP WG-10.4; March, 2008.

[5]. Borisov AB. Bolshoy ekonomicheskiy slovar [Large economic dictionary]. Moscow: Knizhny mir; 2003 [in Russian].

[6]. Shäbe H, Shubinsky IB. Limit reliability of structural redundancy. Dependability 2016;1:9-13.

[7]. Shubinsky IB. Methods of software functional dependability assurance. Dependability 2014;4:95-101.

[8]. Potapov IV. Issues of software systems dependability. Dependability 2015;1:58-61.

[9]. Shubinsky IB, Schäbe H. A systematic approach to protection against glitches. Dependability 2014;3:103-107.

[10]. Shubinsky IB, Shäbe H. On the definition of functional reliability. In: Steenbergen et al., editors. Proceedings of the ESREL 2013, Safety, Reliability and Risk Analysis: Beyond the Horizon. London (UK): Taylor & Francis Group; 2014. pp. 3021-3027. ISBN 978-1-138-00123-7.

[11]. Shubinsky IB. Adaptive fault tolerance in real-time information systems. Life Cycle Engineering and Management. In: Proceedings of ICDQM-2016. Prijevor (Serbia); 29-30 June 2016. pp.3-14.

[12]. Gnedenko BV, Kovalenko IN. Vvedenie v teoriyu massovogo obsluzhivaniya [Introduction into the waiting theory]. Kiev: Nauka; 1963 [in Russian].

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