Надежность № 3 2016
Dependability no.3 2016

Original article
DOI: 10.21683/1729-2646-2016-16-3-26-34
UDK 681.3.06+519(076.1)

Description of approach to estimating survivability of complex structures under repeated impacts of high accuracy (part 2)

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Abstract. Purpose. *The paper describes main concepts and definitions, survivability indices, methods used to estimate survivability in different external and internal conditions of application of technical systems, including the studies in the field of structural survivability obtained 30 years ago within the frames of the Soviet school of sciences. An attempt is made to overcome different understanding of technical survivability, which has been formed by now in a number of industrial directions – shipping, aviation, communication networks, energy systems, in industries of defense. Besides, the problem is discussed in relation to the establishing of the continuity between technical survivability and global system resilience. Technical survivability is understood in two basic meanings: a) as a property of a system to resist to negative impacts; b) as a property of a system to recover its operability after a failure or accident caused by external reasons. This article also describes the relation between structural survivability, when the logic of system operability is binary and described by a logical function of operability, and functional survivability, when the system operation is described by a criterion of functional efficiency. Thus, a system failure is a fall in the level of its efficiency lower than the value predetermined in advance.* **Methods.** *Technical system is considered as a controlled cybernetic system installed with specialized survivability aids (SA). Logical and probabilistic methods and results of combinatorial theory of random placements are used in the analysis. It is supposed that: a) negative external impacts (NI) are occasional and single-shot (one impact affects one element); b) each element of the system has binary logic (operability – failure) and zero resistance, i.e. it is for sure affected by one impact. Henceforth this assumption is generalized for the r-time NI and L-resistant elements.*

Besides, the work describes the variants of non-point models when a system's part or entire system are exposed to a group specialized affection. It runs about the variants of combination of reliability and survivability, when both external and internal failures are analyzed. **Results.** *Different variants of affection and functions of survivability of technical systems are reproduced. It has been educed that these distributions are based on simple and generalized Morgan numbers, as well as Stirling numbers of the second kind that can be reestablished on the basis of simplest recurrence relations. If the allowances of a mathematical model are generalized for the case when there are n of r-time negative external impacts and L- resistant elements, the generalized Morgan numbers which participate in the estimate of the affection law, are defined based o nthe theory of random placements, in the course of n-tuple differentiation of a generator polynomial. In this case it is not possible to establish recurrence relation among generalized Morgan numbers. It is shown that, under uniform allowances for a survivability model (equally resistant elements of the system, equally probable negative external impacts) in the core of relations for the function of system survivability, regardless of the affection law, there is a vector of structure redundancy F(u), where u is the number of affected elements, F(u) is the number of operable states of the technical system under u failures.* **Conclusion.** *Point survivability models are a perfect tool to perform an express-analysis of structural complex systems and to obtain approximate estimates of survivability functions. Simplest allowances of structural survivability can be generalized for the case when the logic of system operability is not binary, but is specified by the level of the system efficiency. In this case we should speak about functional survivability. Computational complexity PNP of the task of survivability estimation does not make it possible to solve it by the simplest enumeration of states of the technical system and variants of negative external impacts, it is necessary to look for the ways to egress from the blind enumeration, by transformation of the system operability function and its decomposition, as well. Development and implementation of survivability property into a technical system should be conducted with consideration of the property which is assured in biological and social systems.*

PART 2. Multivariate calculations

This paper is a closing article to the first one [1] and it reproduces multivariate calculations by the procedure described in the references. Computational complexity of the task of survivability

estimation and the ways to overcome this problem are discussed. We also deal with a passing from structural survivability to the tasks of functional survivability, establishing a conceptual joint between technical survivability and mobilization resilience in economy.

Keywords: *survivability, vitality, resilience, risk, negative impact, survivability margin, law of vulnerability, function of survivability.*

Citation format: *Cherkesov G.N., Nedosekin A.O. Description of approach to estimating survivability of complex structures under repeated impacts of high accuracy (part 2) // Depend- ability. 2016. No.3. P. 26-34. DOI: 10.21683/1729-2646-2016-16-3-26-34*

1. Introduction

In part [1] we gave a general definition to technical survivability, classified the main approaches to the analysis of survivability, proposed the simplest models and methods of the analysis, based on the theory of axiological probabilities, random placements and logical functions of operability. In the second part we shall discuss four main issues:

• computational complexity of tasks of survivability;

• multivariate calculations of survivability of the systems with complex structure;

• functional survivability and its relation to structural survivability;

• connection between technical survivability and mobilization economic resilience.

2. Computational complexity of survivability tasks and ways how to overcome it

A task of survivability is set and solved on a Cartesian product of two logical and probabilistic spaces: space of negative impacts (NI) and space of states of technical systems. In the simplest case, both these spaces are discrete. In accordance with the terminology of classic paper [2], the task of distribution of NI over the system elements is a *P*-complete or a *P*-difficult, i.e. the number of calculations and the time of calculations are in proportion to N^n, where n is the number of impacts, and N is the number of system elements. It has long been known that for modern computers *P*-completeness represents no difficulty, let even n be estimated by hundreds and thousands which is impossible in reality. A different matter is the assignment of a complete group of possibly operable states, when from 1 to N-1 elements are sequentially taken out from the system of N elements. Due to the fact that in the task of structural survivability an element may be in one of the states – operability or a failure (binary logic), the total number of states of the system to be enumerated is 2^N, computational complexity corresponds to the same number. Thus, the survivability task becomes *NP*-difficult and has its fixed range.

When logical and probabilistic methods of analysis were pushing their way into science (in 1980s), when the most common computers in the USSR were USEC of different modifications, certain experiments established a limit number of the system elements, exceeding of which did not make it possible to solve the task of survivability analysis for observable time. This number was $N = 27$. All attempts to increase this number failed, until several approaches were found to assure the pass from direct enumeration of states to **intent** enumeration. As the result, the work of the school of Prof. A.S. Mozhaev and his followers [3 – 5] led to the situation when it turned to be possible to decompose the graph of complex system into a main graph and its sub-graphs (joint openings), as well as to develop logical schemes of intent enumeration in the space of states. As the result the limit number of elements in the main graph today is 400, and in a sub-graph – 100 (data according to software complex “ARBITR”).

Therefore, overcoming a “bane of limit number” in relation to the tasks of structural survivability happened. But we have won only the first position war, because when passing from structural survivability to functional survivability, the space of states of the technical system ceases to be numerable, and a “bane of limit number” comes back, but in a frightening form. This feature is described in more detail in section 5 of this work. In a similar way solution of the task of structural survivability is becomes complicated, if the frequency of impacts is r, and the element resistance is L (or a discrete resistance in a model is substituted with a probabilistic function of resistance).

Let us now describe the simplest examples of survivability analysis (these solutions were originally demonstrated in [6], including all figures and tables of section 3). All examples are well estimated by hand and can serve as tests for new algorithms of analysis, as degenerated cases.

3. Calculation of structural survivability by the system state for the simplest structures

3.1. System with bridge structure of five elements

A system with bridge structure (Fig. 1) is exposed to repeated point negative impacts. It is necessary to estimate survivability by the system state supposing that the affection

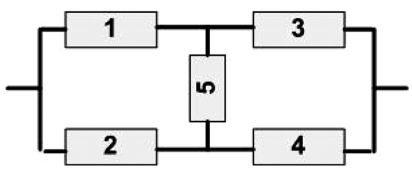

Fig. 1. System with bridge structure

of elements under a single NI is equally probable, and the resistance of elements in relation to the intensity of NI of high accuracy is negligibly low.

Logical function of operability in an orthogonal disjunctive normal form (ODNF) is as follows [7, chapter 4]:

$$F = x_1x_3 \vee x_1'x_2x_4 \vee x_1x_2x_3'x_4 \vee x_2'x_3'x_1x_4x_5 \vee x_1'x_4'x_2x_3x_5. \quad (1)$$

Let us take formulas (31) and (32) from [1], setting $m = 5$, $s_1 = 2$, $N = 5$, $s_2 = 3$, $s_3 = 4$, $s_4 = s_5 = 5$, and we will obtain

$$R(n) = (1 - s_1/N)^n + \sum_{k=2}^{3}\sum_{i=1}^{n} C_n^j N^{-i}(1 - s_k/N)^{n-i} +$$

$$+2N^{-n}\sum_{i=1}^{n-1} C_n^i = 2(0,6)^n + 2(0,4)^n - 5(0,2)^n. \quad (2)$$

Values $R(n)$ with $n \le 5$ are given in Table 1.

Table 1. Function $R(n)$

n	1	2	3	4	5	6	7
$R(n)$	1	0,84	0,52	0,3024	0,1744	0,1012	0,0592

Let us now take formulas (33) – (37) from [1] to define $R(n)$. For this purpose we shall use formula (37) to draw up a table of coefficients L_{nk} (Table 2) and note that it does not depend on the system characteristics (structure and number of elements). That is why it can be used as a common table to calculate survivability of any systems. Table 3 shows the values of coefficients B_{ki} for nine operable structures obtained from the basic structure by means of removal of one, two or three elements (Fig. 2).

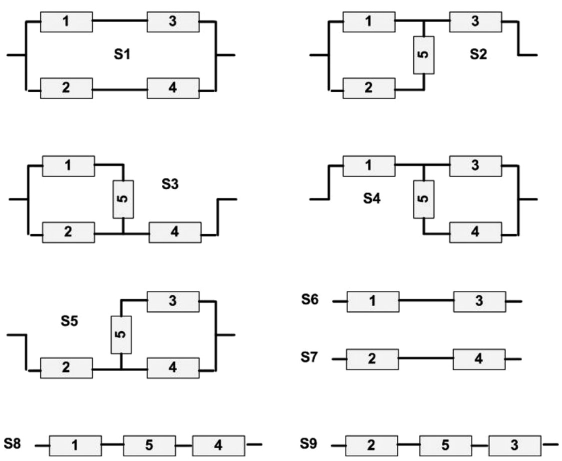

Fig. 2. Operable structures obtained from the basic bridge structure

Multiplying the lines of matrix $||L_{nk}||$ by the columns of matrix $|B_{ki}||$, we shall get the matrix of coefficients r_{ni}, expressing the number of ways which may be used to pass form basic structure S_0 to structure S_i under n-tuple NI (Table 4). Putting the elements of one line together we

Table 2. Numbers L_{nk}

n	L_{nk}						
	k= 1	k= 2	k= 3	k= 4	k= 5	k= 6	k=7
1	1	0	0	0	0	0	0
2	1	2	0	0	0	0	0
3	1	6	6	0	0	0	0
4	1	14	36	24	0	0	0
5	1	30	150	240	120	0	0
6	1	62	540	1560	1800	720	0
7	1	126	1806	8400	16800	15120	5040

Table 3. Numbers B_{ki}

k	B_{ki}								
	i=1	i=2	i=3	i=4	i=5	i=6	i=7	i=8	i=9
1	1	1	1	1	1	0	0	0	0
2	0	0	0	0	0	3	3	1	1
3	0	0	0	0	0	1	1	0	0

will find the number of different disjoint events which lead to an operable structure under n-tuple NI. It is easy to show that values $R(n) = r_n/N^n$ coincide with the values listed in Table 4.

Using formula (5) from [1] and formula (2), we shall find the average number of NI leading to loss of operability:

$$\bar{\varpi} = \sum_{n=0}^{\infty} R(n) = 1 +$$

$$+\sum_{n=1}^{\infty}\left\{2(0,6)^n + 2(0,4)^n - (0,2)^{n-1}\right\} = 4,083 \quad (3)$$

Table 4. Numbers r_{ni}

n	r_{ni}					r_n	N^n
	i=1..5	i=6	i=7	i=8	i=9		
1	1	0	0	0	0	5	5
2	1	6	6	2	2	21	25
3	1	24	24	6	6	65	125
4	1	78	78	14	14	189	625
5	1	240	240	30	30	545	3125
6	1	726	726	62	62	1581	15625
7	1	2184	2184	126	126	4625	78125

Average survivability margin $\bar{d}$ = 3,083. Significantly, for this structure d = 2, and m = 3. Therefore, average survivability margin is more than the maximum number of elements that can be removed without loss of operability, more than m-survivability. This effect is explained by the fact that certain elements appear in the field of NI for several times.

The system of calculation of this paragraph which is based on Stirling numbers of the second kind, was completely described in [6] and [10].

3.2. Electric power system with bridge structure of eight elements

Electric power system consists of generating power units 1 and 2, main distribution boards 3 and 4, jumper straps 8, cables 5 and 6, distribution board7 (Fig. 3). It is necessary to estimate survivability by the system state after repeated NI, supposing that at each NI one element of the system becomes non-operable, and the affection of the elements at a single NI is equally probable.

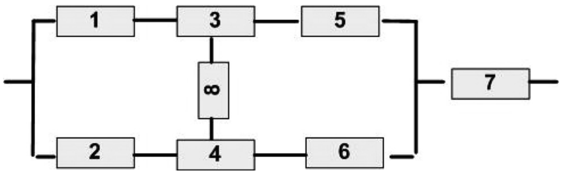

Fig. 3. Structure of electric power system

Logical function of the system operability is as follows:

$$F = x_7(x_1x_3(x_5 \vee x_4x_6x_8) \vee x_2x_4(x_6 \vee x_3x_5x_8) \qquad (4)$$

Orthogonal disjunctive normal form:

$$F = x_1x_3x_5x_7 \vee x_1'x_2x_4x_6x_7 \vee x_1x_2x_3'x_4x_6x_7 \vee$$
$$\vee x_1x_2x_3x_4x_5'x_6x_7 \vee x_1x_2'x_3x_4x_5'x_6x_7x_8 \vee$$
$$\vee x_1'x_2x_3x_4x_5x_6'x_7x_8. \qquad (5)$$

Thus, the logical function of the system operability contains 6 implicants in total, including one implicant without negation, three with one negation and two with two negations. Probabilities

$$P\,(Q_1 = 1 / A_n) = 2^{-n};$$

$$P\,(Q_l = 1 / A_n) = \sum_{j=1}^{n} C_n^j N^{-j}(1 - s_1 / N)^{n-j},$$

$$l = 2, 3, 4;\ s_2 = 5,\ s_3 = 6,\ s_4 = 7$$

$$P(Q_l = 1 \mid A_n) = \sum_{j=1}^{n-1} C_n^j N^{-n},\ N = 8,\ s_5 = s_6 = 8. \qquad (6)$$

According to (1) we have:

$$\sum_{l=1}^{6} P(Q_l = 1 \mid A_n) = 2^{-n} + 8^{-n}(4^n + 2^{n+1} - 5) =$$
$$= 2^{-n+1} + 2^{-2n+1} - 5 \times 2^{-3n}. \qquad (7)$$

Table 5. Function of survivability *R*(*n*)

n	1	2	3	4	5	6
***R*(*n*)**	7/8	35/64	139/ 5122	539/ 4096	2107/ 32768	8315/ 262144
***R**(*n*)**	7/8	1/2	8/56	1/35	0	0

The results of calculations by formula (7) are listed in **Table 5.**

The last line indicates the data of calculations by strategy 2, when the affected elements are excluded from the next affection.

Average number of NI

$$\overline{\omega} = 1 + \sum_{n=1}^{\infty} \left\{ 2(0,5)^n + 2(0,25)^n - 5(0,125)^n \right\} = 2,9524$$

Average survivability margin $\overline{d} = 1,9524$. It is substantially less than m-survivability (here $m = 4$). Survival rate of the system is found using formulas (33) – (37) from **[1]**. We take into account that except a basic structure, the system may have nine more different operable decomposed structures (i=1…9). Let us define coefficients B_{ki} first (Table 6).

Table 6. Numbers B_{ki}

k	B_{ki}				
	***i*=1…5**	***i*=6**	***i*=7**	***i*=8**	***i*=9**
1	1	1	1	0	0
2	0	6	6	1	1
3	0	4	4	0	0
4	0	1	1	0	0

Structures $S_1 \ldots S_5$ occurs at the loss of only one element ($k = 1$), i.e.: 1, 2, 5, 6, 8. Structure S_6 (1357) may occur at the loss of one (4), two (24, 26, 46, 82, 84, 86), three (246, 248, 268, 468) or four (2, 4, 6, 8) elements. Similarly, structure S_7 (2467) occurs at the loss of 1, 2, 3 or 4 elements. Their number is the same as for structure S_6. Structure S_8 (operable elements 138467) occurs at the loss of two elements (25), and S_9 (248357) occurs at the loss of two elements: 1 and 6.

Using the data of tables 2 and 6, we shall define r_{ni}. Results are listed in Table 7.

Table 7. Numbers r_{ni}

n	r_{ni}					r_n	N^n	R_n
	***i*=1…5**	***i*=6**	***i*=7**	***i*=8**	***i*=9**			
1	1	1	1	0	0	7	8	0,875
2	1	13	13	2	2	35	64	0,546875
3	1	61	61	6	6	139	512	0,271484
4	1	253	253	14	14	539	4096	0,131592
5	1	1021	1021	30	30	2107	32768	0,064301

We see that the results in tables 5 and 7 coincide. The analysis of data of Table 7 makes it possible to determine an interesting consistency. Relation r_{ni}/r_n expresses a conditional probability that structure S_i, is saved after n-tuple NI provided the system remained operable. As it is shown from the calculation results (Table 8), only for one type of structure (S_6 and S_7) a conditional probability grows at the increase of the number of NI, and this structure is non-redundant having the least number of elements. Even with $n = 5$ for the share of structures S_6 and S_7 there are 97% of all cases when the system ensures operability.

Table 8. Conditional probabilities

n	r_{ni} / r_n		
	$i = 1\ldots5$	$i = 6,7$	$i = 8,9$
1	0,1429	0,1429	0
2	0,0286	0,3714	0,0571
3	0,0072	0,4388	0,0432
4	0,0019	0,4694	0,0260
5	0,0005	0,4846	0,0142

Under strategy 2, when the affected elements are excluded from the field of the next NI, and equally probable affection of the remained operable elements, the function of survivability is calculated by the formula:

$$R^*(n) = \sum_{i=1}^{l} C_{N-s_i}^{n-k_i} / C_N^n, \qquad (8)$$

where l is the number of implicants in ODNF, s_i is the number of letters in the implicant, k_i is the number of negations. The results of calculations are listed in Table 8. We see that the function of survivability is falling much faster that in the scheme of independent NI (under a "passive strategy"). The average number of NI before affection $\overline{\omega} = 2{,}547$. It is less that under strategy 1.

In general we can speak about the existence of a vector of numbers of operable states of the system $F_N(u)$, $u = 0\ldots N$, where u is the number of the elements removed from the system at one moment. Formula

$$f(u) = F_N(u) / C_N^u \qquad (9)$$

is a conditional probability that under many-fold affection of u elements in the system of N elements, this system shall keep operability. Then (8) is rewritten in the form

$$R^*(n) = f(n) \qquad (10)$$

Vector $F_N(u)$ specifies **structural redundancy** in the system and its profile. And occurrence of this redundancy in the interests of survivability is kept under aby distribution of NI probabilities. This very redundancy equally works on reliability as well. For instance, probability of reliable operation of non-recoverable system with complex structure of homogeneous elements

$$P(t) = F_N(0)^*p(t)^N + F_N(1)^*\, p(t)^{N-1}(1 - p(t)) + \\ +\ldots + F_N(N-1)^*\, p(t)(1 - p(t))^{N-1}, \qquad (11)$$

where $p(t)$ is the probability of reliable operation of one system element. Reliability of such system is the higher, the higher $F_N(u)$ is. It is described in detail in [14].

We can pass from the estimating the survivability by state to estimating the survivability by the result of task execution. This work was carried out in [6], where the same structures were the basis: bridge of five elements and electric power structure of eight elements. Estimate of survivability in this assignment makes it possible to hybridize separate properties of survivability and reliability, getting new complex properties of NI-reliability, NI-safety, etc. [11, 12].

Structural survivability of multipolar technical systems

Let us consider the variants of constructing a multipolar technical system, when the system can be expressed by a multipolar graph, in which the nodes (without violation of entity) are unexposed to NI, and these are only connections in a graph, which are exposed to impacts. One of possible criteria of non-operability of such system is the occurrence of isolated nodes or separated sub-graphs.

An example is the communication network with the nodes effectively protected from NI and from the line destruction. If any node (or group of nodes) has no connection, the system will lose a critical source of information or a function of control. In practice, it will fall into several subsystems, each of which will start to function independently; and this event is accepted as a fact of loss of survivability.

With no violation of entity let us assume that the branches of the graph of a multipolar system break out one after another, i.e. they are excluded from the field of affection of new NI. Then our task is to form a vector of the system redundancy $F_N(u)$, and then to use formulas (9) – (10) to estimate its probability of survival with n of single NI.

Let us consider two multipolar systems, sequentially in four and five nodes (Fig. 4), in two configurations – non-redundant, when the nodes are closed into a circle, and full-redundant, when the nodes are connected under the principle "each with each one".

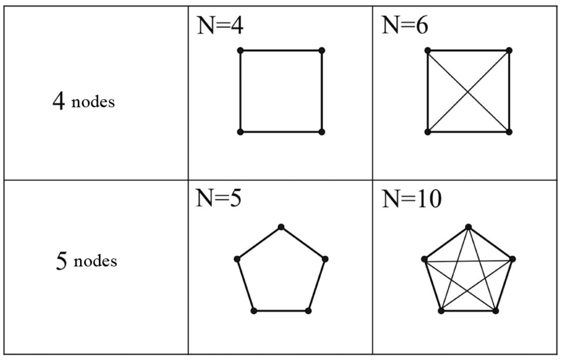

Fig. 4. Different configurations of multipolar systems

Four-polar network, non-redundant system (N=4). It is easy to see that the first NI under the active strategy does not put the system out of operation (the same is valid for the structures with more poles). At the same time, any second NI automatically makes the system non-operable. Therefore:

$$R(n) = 1 \text{ with } n \leq 1 \text{ and } R(n) = 0 \text{ with } n \geq 2.$$

And the function of survivability becomes threshold, and it means there is no survivability at all, and it is determined by its non-redundancy.

Four-polar network, full-redundant system (*N*=6). Here we can see that the system of *N*=6 connections keeps its operability under any double NI (in all cases the system keeps connectivity). And there are even four scenarios of the system survival under 3-time impact (from 20 possible scenarios). Therefore, the results of estimation of the survivability function are listed in Table 9.

Table 9. Function of survivability for a full-redundant system on 4 nodes

n	$F_6(n)$	C_6^n	$R^*(n) = f(n)$
0	1	1	1
1	6	6	1
2	15	15	1
3	4	20	0,2
≥ 4	0		0

Here the element of a smooth degradation occurs, but nevertheless it leaves much to be desired. Smoothness occurs when additional branches occur (for instance, channels based on another principle of coding and transfer of informationи) alongside with main branches in a graph of multipolar system. Roughly, when digital communication fails there is the possibility of using classical radio communication.

Five-polar network, non-redundant system (*N*=5). Similarly to non-redundant four-polar network we see that the first NI under the active strategy does not put the system out of operation, and each second one does. Thus, again we deal with a threshold function of survivability:

$$R(n) = 1 \text{ with } n \leq 1 \text{ and } R(n) = 0 \text{ with } n \geq 2.$$

Five-polar network, full-redundant system (*N*=10). System keeps its operability under a three time NI of any direction. With $n = 4$ the first scenarios of degradation occur (it becomes possible to isolate one of five nodes). With $n = 7$ and more the system will fail for sure. Therefore, the results of estimation of the function of survivability are listed in Table 10.

Here we really have a slow degradation of survivability. And the more N is, the smoother this degradation is realized with the increase of n.

Table 10. Function of survivability for a full-redundant system on 5 nodes

n	$F_{10}(n)$	C_{10}^n	$R^*(n) = f(n)$
0	1	1	1,0
1	10	10	1,0
2	45	45	1,0
3	120	120	1,0
4	205	210	0,976
5	222	252	0,881
6	5	210	0,024
≥ 7	0		0

Similar results can be obtained if to make NI HB *r*-tuple and assign the branches in a graph with the resistance level *L* (analog of the system of channel redundancy). In this case we should use the formula from **[8]**. But it will not change the basic principle: the higher is the redundancy level measured by vector *F*, the higher is the level of system survivability in respect to NI of wide spectrum.

Functional survivability and principles of analysis

A qualitative leap from structural survivability to the functional one is made as a consequence of substitution of a binary function of operability in the tasks of structural survivability by the level of tolerable loss of efficiency. Let the system be specified by a basic property which defines its performance (for example: in electric power systems this property is available power, in gas systems it is the capacity of a gas pipeline system). Then we can fix the level ε, in percentage of a maximum value of emergence, when we say that if the system efficiency becomes lower than ε in percentage as the result of NI, it means that the system lost its survivability.

Therefore, **functional survivability** is the ability of the system to keep its emergence at the level not lower than ε of the maximum value under NI, or to restore the required level quickly after NI. For instance, in the theory of civil defense there is a principle of technological reserved quota ε=30%, when non-core consumers are de-energized, and all the energy is brought for domestic needs of people. There is also the level of emergency reserved quota ε=10%, when not all citizens get electric power, but only separate important centers of consumption (hospitals, maternities, etc.). And a scientific mission of estimating and assuring of functional survivability is to distribute SA and allowable redundancy, to set the algorithms of system configuration in the way which will make it possible to minimize the probability of technological and emergency reserved quotas in cases of NI of wide spectrum. A more detailed description of ε-criterion is given in papers [9, 13, 15 – 17**]**.

When NI is point, we are in a discrete space of NI states. There is no such space if we estimate the variants of areal affection, when there is NI of continuum spectrum. Likewise, passing from structural survivability to the functional one, we lose a discrete space of the system states, it becomes continuous and uncountable. Instead of a logical function of operability we deal with the **algorithm** of assurance of survivability under NI. This algorithm is a kind of a black box having a NI model at the entry, and a resulting effect at the exit. If the entry is a continuum spectrum of impacts, the exit is a continuum spectrum of resulting.

The first that comes to mind in this case is trying to simplify the task, to substitute a continuous space of states by a discrete one. For instance, in [17] we note that a single NI takes a certain quantum of allowable capacity form the system, and the task of a large electric power system is to redistribute the loading and make up the occurred deficit. With the increasing NI, the system starts degradation, its reserves of allowable capacity become exhausted, and one day we will occur at the level of technological reserved quota; and it is necessary to estimate the probability of such negative scenario.

Having begun to deal with the task we discovered that we can substitute a continuous space of states by a discrete one, fixing the certain level ε in the analysis. Actually, ε-criterion is similar to the fixed frequency we scan the system at, specifying a complete set of its operable states. Making the enumeration of states space intent (for instance, using the branch and bound method), may significantly reduce the scope of operations; and *NP*-completeness of the task is still here.

Then we can rewrite formulas (9) and (10) as follows:

$$R^*(n, \varepsilon) = f(n) = F_N(n, \varepsilon) / C_N^{\,n} , \qquad (12)$$

where $F_N(n, \varepsilon)$ is the number of operable states of the system of N elements, exposed to n-tuple point NI, on the assumption that the survivability of such system is described by ε-criterion. Besides we can easily pass from an active strategy of NI to a passive strategy – it will not change the analysis principle significantly. The main thing is to estimate the level of functional redundancy, which does not depend on the applicable strategy of NI, as it is being formed in the space of discrete system states specified in an algorithmic way. And then the function of survivability can be estimated with consideration of the strategy, based on the formed vector F.

Beautiful formulas represented for the case of equally probable NI crash totally, when it comes to preferring one NI to the other. In this case we have to go back to the model by Gorshkov [18] which used to be very popular, with assigning of axiological probabilities of point NI affecting separate elements by the Firshburn's principle [19], [20, p. 83-84], building the systems of preferring of one NI to the other. By applying the Gorshkov's formula we estimate the function of survivability at a certain hold point. Varying the NI probabilities in narrow scope, we estimate the dimensions of optimality subset in a multidimensional field of probabilistic scenarios, when out SA decisions are the best ones. Thus, we test our decisions related to the survivability assurance, for parametric stability [13]. Indeed, ε-criterion may serve as one of the parameters at the verification of the decision for optimality.

Passing from structural survivability to functional survivability сразу takes us out from the area of traditional approaches to the analysis, making it possible to estimate not only technical survivability, but also system resilience, in a wide range of classes and purposes of these systems. Thus we gradually move to the area of mobilization economic resilience.

Connection between technical survivability and mobilization economic resilience

Economic unit is a strongly connected system intended to generate a complex economic effect and covered by the loops of positive and negative feedbacks [20]. Different shocks serve as NI in relation to such objects. These shocks affect the system from the side of the unit's environment. Under NI a unit starts to degrade down to the level distinguished as negative, when it is referred to a failure of achievement of strategic aims, either by the level, or by the time of achievement. A control supersystem generates decisions aimed at the survival of the economic unit and at the keeping of resilience in negative environment. Such decisions are tainted by mobilization.

There is an apparent similarity between technical survivability and economic resilience, and this similarity is observed within the frameworks of the general theory of cybernetic systems developed starting from Ludwig von Bertalanffy and his group [21]. Watching the survivability and resilience from systemic positions, we come to the idea of **vitality** as a basic prototype property of survivability in a general sense, which generates its projections in systems of different types. The idea of Bertalanffy was that all living systems (or systems pretending to be viable) had the property of **equifinality**, when a system inevitable comes to its final state, in different ways, from different initial states. Actually, equifinality is a dynamic resilience, realized in the course of pursuing the achievement by the system of its final aims, its base purpose – to serve, deliver a current, protect, supply. Survivability is inherited from equifinality to the same extent as from vitality; the system is vital if it is equifinal, and vice versa.

The obtained isomorphism of technical survivability and economic resilience leaves a wide room for a mutual migration of methods, models and approaches from one type of application to other types. For example, mobilization resilience copies the principle of NI ε-criterion from functional survivability, in the terms of continuous spaces of NI and system states. Balanced score card serves as the function operability and functional algorithm in the economic system. In reverse, technical survivability may get improved if it loses itself in the economic context, when the analysis of efficiency is supported by an expanded analysis of economic and financial sufficiency of technical decisions for survivability. When it a technical system turns out to have a control supersystem, and a supersystem turns out to have economic context and strategic goals which are introduced to the control supersystem of the respective technical system as basic criteria of performance.

Final purpose of equipment is to serve economic and social systems in standard conditions and under NI, as well. In all cases this service should be developed in stipulated to the extent set forth in advance, with clear expectations, in coordination with the objectives of supersystems.

Conclusion of part 2

The theory of technical survivability shall be developed in the following main directions:

Understanding technical survivability as a general scientific discipline that crosses industrial boundaries. Such vision will be developed when survivability will be observed from systemic cybernetic positions, as a projection of vitality;

Analysis of the experience gained as the result of researches of survivability and resilience carried out in the West. Understanding of how western approaches can be applied in Rissia, why “yes” and why “no”;

Substitution of probabilistic models of survivability by inexplicitly scenary models which do not need any axiologic hypotheses, but simulate expert experience in the terms of impacts and reactions, with consideration of essential information uncertainty. Logic of system performance in these conditions may also be “soft”, it may be estimated with soft computations and measurements in the sense of Zadeh – Dubois – Prada [22, 23];

Passing from the function of survivability to a risk-function. It is necessary to estimate not the survival rate, but risk of failure to achieve a goal;

A more detailed attention to humanitarian aspects of survivability, to a human factor in survivability control. It is necessary to study not only the technical system, but its SA as well;

Development of a conceptual horizontal between technical survivability and resilience. Implementation of economic and financial measures in the tasks of technical survivability. The task of survivability assurance should be considered from the standpoint of investment project development.

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Receive on 30.03.2016