

DOI: 10.15276/hait.03.2020.7

UDK: 65.012.3

## INFORMATION MODELS AND METHODS OF THE STRUCTURAL CRISES CONSEQUENCES OVERCOMING IN THE EDUCATIONAL SPACE

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### ABSTRACT

Information models are developed and methods for eliminating the consequences of global structural crises in the educational space are proposed. The content of the article is a continuation of the previous work of the same authors on information technologies for the search for anti-crisis solutions in the management of complex dynamic systems. The aim of this work is to increase the efficiency (speed, minimize costs) of anti-crisis solutions to eliminate the consequences of structural crises in complex educational systems. Depending on the type of complex object, its initial structure, depth and severity of damage, temporary, financial and other resources available to the manager of the process of restoring a complex object, there are three main principles of construction (optimization) of this process: first principle – one-time design and further replacement (transformation) of the “damaged” part of the structure of the object, pre-selection of the replacement option for a fee (target function) at the design stage; mathematical method developed for this approach – methods of convergence and divergence; second principle – step-by-step design and discrete replacement (transformation) of the “damaged” part of the site structure of the object with discrete calculation of the reward (target function) and adjustment of the recovery plan after each site; the mathematical method developed for this approach is the method of percolation of functionality; third principle – step-by-step design and discrete replacement (transformation) of the “damaged” part of the site structure of the object with continuous calculation of the reward (target function) on fuzzy initial data and constant adjustment of the recovery plan; the mathematical method developed for this approach is the Markov decision-making process. On the example of a higher educational institution, a structural anti-crisis model of the educational process is proposed. Using an example of a separate discipline, an anti-crisis model of the restored element of the educational process was created and a method for the quick restoration of such an element with minimal losses for the process as a whole was developed. A lecture is chosen as a typical element of the educational structure at a university. Using the example of a systemic external crisis that arose during a pandemic, an information technology was developed to overcome such a crisis with the optimization of an anti-crisis solution using model convergence. The final parameters are proposed that fulfill the role of target functions when choosing optimal solutions to crises. Practical tests of information technology for the search for anti-crisis solutions in managing complex dynamic systems in higher education were carried out, in particular, in the preparation and implementation of anti-crisis measures during the teaching of the planned discipline “Higher Mathematics”. The technology was used in anti-crisis restructuring of the educational process during quarantine of the coronavirus. As a result, the following results were obtained: the participants in the educational process interacted through communication tools built into the Learning Management System (LMS), email, instant messengers (Viber, Telegram), conferences (MS Teams, ZOOM, Google Meet, Skype, etc. mode according to the curriculum delivered lectures and practical exercises in full.

**Keywords:** information technology; educational space; consequences elimination; structural crises; element of higher education

For citation: Oborskyi H. O., Saveleva O. S., Stanovska I. I., Saukh I. A. Information models and methods of the structural crises consequences overcoming in the educational space. *Herald of Advanced Information Technology*. 2020; Vol.3, No.3: 185–198.

DOI: 10.15276/hait.03.2020.7

### 1. INTRODUCTION

There is a large group of objects, that can be related to complex systems, which consist of many interacting constituents (subsystems), wherefore they acquire new properties that are absent on

subsystem level and properties that can not be reduced to subsystem level properties [1]. Reaction of such systems to outer requests can be complex and sometimes unpredictable, such as crises that can happen during their functioning [2]. Concerning choices of solutions for compensation of such crises with possible methods [3] – problems that can occur, like availability of time, resources, ideas, executor’s e.t.c. require models and methods, which call for

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accounting of interactions of such objects with aggressive environment.

Examples of such systems are technical [4–5], organizational [6] and social [7] objects. This article describes informational models and methods of elimination of structure crises outcomes in educational field: universities, colleges, schools e.t.c. [8].

## 2. ANALYSIS OF RECENT PUBLICATIONS REGARDING THIS STUDY

We will distinguish for analysis separate conceptual groups of general direction of “accumulation and elimination of structure crises outcomes in educational field”.

They consist of:

1) composition of anti-crisis models of complex educational systems:

- space-time environment of complex educational systems [9–12];
- structural analysis of educational process [13–15];
- models of specialists training in university [16–20];

2) crises in functioning of complex educational systems:

- outer attacks on educational systems [21–23];
- latent [24–25], multiplicative crises [26];
- critical crises [27–28] and surprise crises [29];
- activities of educational systems after eradicating crises outcomes [30];

3) models and methods of complex educational system recovery on simple subsystem level:

- self-recovery in dynamic systems [31–33];
- optimal recovery and criteria for it [34];
- recovery of complex systems in uncertain conditions [35–36].

To use benefits of informational technologies in search and implementation of anti-crisis solutions during sudden damage done to complex systems to the fullest, we should create corresponding models for damaged objects and crisis problems inside them [16–18].

Classic descriptions of educational process models that exist in literature [19–20] excel in their fundamentality, which usually have a long history, are created beforehand (at least before the start of educational process) and contain many components (for example practice, intermediate and final controls, mobile education on exchange with foreign universities and so on). All these components of educational process eventually have positive influence on quality of specialist training.

However, there are some cases, when certain components are discarded (for example during distance learning) which nevertheless do not hinder

with completeness and usefulness of such education and specialists that finished it having all required skills and knowledge. This approach allows you to count on possible conscious losses during crises.

Elements of educational process are discrete [13–15] and are spread in unified space-time environment [9–12], which helps with any transformations in original learning process plan (including replacements and discards).

Note that all attributes of planned learning process can be considered as static, nothing happens spontaneously and discrete models that were once created can be used multiple times.

They can also be used as criteria of successful ending of temporary discrete of learning: learning plan was completed, all elements of control were delivered and marked – semester is finished for the student. Positive total amount of marks (of all learning elements in each and every one of subjects that are planned for the semester) lead to decision of transferring to the next stage.

Completely different conditions can happen during modeling of outer crisis impacts on learning process. Latter can become part of the first, usually fragmentarily.

Structural crises can be described as reactions of complex objects to outer attacks of environment [21–23]. In terms of their origin, they can be divided into latent (hidden) [24–25] and multiplicative (which affect different elements of the system as a whole) [26]. In terms of outcomes of crisis attack, they can be distinguished as critical crises [27–28] and surprise crises [29]. They have one general feature: they can quickly (compared with whole duration of learning half a year or a year are nearly immediate) destroy structural elements of educational process: separate structural units of learning process and/or their connections with each other.

To make and effective decision on level of anti-crisis measure outcomes it is better to have information regarding the state of educational system after eliminating crisis outcomes [30].

These decisions are the most important result of activities of management personnel on institute, university or Ministry of Education level. Their adoption consists of three phases. Decision about formats of education process continuing are embraced during first phase, during second phase possible complex of actions for each separate element of process are chosen, and finally, if there is more than one such complex the most optimal of them should be chosen. The best management activity is considered to be the one, which leads to self-recovery of damaged process [31–33], second type of activities require optimization of object and

crisis that struck it under determined parameters [34], and lastly, during the third case optimization task of activity choosing has to be done in uncertain conditions [35–36].

### 3. THE PURPOSE, OBJECTIVES AND SCIENTIFIC NOVELTY OF THE STUDY

The aim of the work is increasing efficiency (speed, minimization of costs) of anti-crisis solutions for elimination of the outcomes of catastrophic structural crises in complex educational systems.

To achieve this goal, the following tasks were solved:

- on the example of university structural anti-crisis model of educational process was proposed;
- anti-crisis models of structural elements OD educational process – semester and subject, were created;
- method of quick recovery of the elements with minimal time consumptions for learning process as a whole was developed;
- models and methods of measuring the parameters of damage and recovery of educational field, which are based on optimization of choice of recovery solutions that are based on these parameters, were proposed;
- on the example of systemic outer crisis, which happened because of the pandemic, information technology for overcoming such crisis with optimization of anti-crisis solution with the help of model convergence was developed;
- practical tests of the results of the study and evaluation of their technical, economic and social efficiency were completed.

The scientific novelty of the study is embodied in models and methods of anti-crisis solutions searching in conditions of developing crises in life cycle of complex systems:

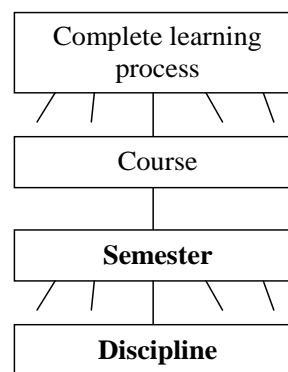
- model of educational process, which consists of elements and connections between them, that work only for achieving their main objective – achieving required level of knowledge and skills, planned for a certain time period, which allows to use it during planning and realization of urgent anti-crisis solutions, got further development;
- was proposed a method of searching, planning and implementation of anti-crisis solutions, which is based on optimization of time required to achieve those solutions during harsh and negative outer structural impacts on educational process, which allows finishing educational plans in sufficient volume for listeners to get qualification without significant social or economic losses.

### 4. MODELS AND METHODS OF OVERCOMING THE OUTCOMES OF STRUCTURAL CRISES IN EDUCATIONAL FIELD

Educational field usually is multidimensional and can be stratified in different directions, depending on crisis phenomenon localization.

For example, crisis border of regions of this field can walk along the river, if educational resources on the opposite coast are not available for students and teachers. These crisis phenomena include problems with transport, electricity, quarantine restrictions and much more, and they do not make up the concept of “approved curriculum” and “approved educational plan”.

Active educational plans are represented as hierarchical structures, which can be presented as such (*Fig. 1*).



*Fig. 1. Hierarchical structure of studying process*

We will choose two «primary» elements of hierarchical structure for composition of anti-crisis models: “Semester” and “Subject”, as they are the most vulnerable to crisis damage and it is easier to compensate the damage on their sublevel. For this, we will create structural logic models of these elements.

#### 4.1. Elementary structural anti-crisis model of sub-system “Semester”

Usually, educational process during the semester consists of two main types of interaction between teachers and students: teaching and knowledge control. Latter does not refer to quick anti-crisis activities and does not require quick recovery in case of sudden structural damage done to its algorithm [37–38].

That is why this study emphasis on first subprocess – teaching. As known, studying process in university is certainly discrete – it consists of separate elements, which from the point of final objective – completion of studying – have binary nature: subject is studied, syllabus is completed and practical tasks defended e.t.c. Because of this, the

most informative mathematic models of this process are tables, diagrams and Boolean algebra formulas [39], or models, which are built upon discrete percolation gratings [40].

Creation of logical schema is usually called as logical schema synthesis [41]. For each disjunction (logical sum), there is an element “OR” and the amount of inputs is determined by amount of variables in disjunctions. For each conjunctions (logical multiplication), there is an element “AND” and the amount of inputs is determined by amount of variables in conjunctions. For each negation (inversion) there is an element “NOT”.

With the help of the first, we will show how the models of planned studying process are built, while the second are irreplaceable for optimal anti-crisis decisions searching.

At first, let us review truth table of studying discrete “Semester”, which is observed by dean’s office of corresponding faculty: transition of students to the next stage only after forming logical true in the output of truth Table (Table 1).

The meaning of the table can be also expressed in the form of logical schema (Fig. 2).

Schema portrays:

- $D_1$  – first complete (lectures + laboratory works + practical lessons) subject within the semester;
- $D_n$  –  $n$ -th complete subject within the semester;
- $P_1$  – first incomplete(for example only with practical lessons) subject within the semester( for example PE);
- $P_m$  –  $m$ -th incomplete subject.

According to logical schema, student transfers to the next semester or finishes his studying in university only after full and successful studying of all complete and incomplete subjects of the semester.

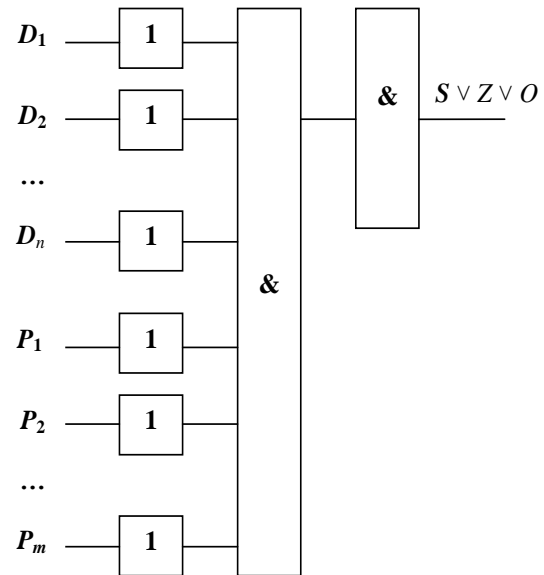


Fig. 2. Logical schema of the element “Semester”

Knowledge and skills that were acquired by the student are confirmed and decision of his further studying is settled (transfer to the next semester S, end of studying Z, dropping out O):

$$(D_1 \wedge \dots \wedge D_n) \wedge (P_1 \wedge \dots \wedge P_m) = S \vee Z \vee O. \quad (1)$$

#### 4.2. Elementary structural anti-crisis model of sub-system “Subject”

Creation of logical schema for the element “Subject” starts with definition of the logical function that should be implement (Table 2).

Meaning of the table can be described like this. Subject is fully mastered by the student, if he successfully passes visit control: he have listened full course of lectures and done all laboratory and practical tasks, which are foressen by the syllabus, and also passed corresponding tests and exams. Corresponding to Table 2 logical schema can be seen on Fig. 3.

Table 1. Truth table of logical schema of studying element “Semester” of educational process

Type of class Variant	Subject $D_1$	Subject $D_2$	...	Subject $D_n$	The end of studying in the semester $S_i$
Start of studying	0	0	0	0	0
1	0	0	...	1	0
2	0	1	...	0	0
3	0	1	...	1	0
4	1	0	...	0	0
5	1	0	...	1	0
6	...	...	...	...	
End of studying	1	1	...	1	1

Table 2. Truth table of logical schema of element “Subject” of educational process

Type of class Variant	Lecture, LK	Laboratory work, LR	Practical lesson, PR	Credit, Z
1	0	0	0	0
2	0	0	1	0
3	0	1	0	0
4	0	1	1	0
5	1	0	0	0
6	1	0	1	0
7	1	1	0	0
8	1	1	1	1

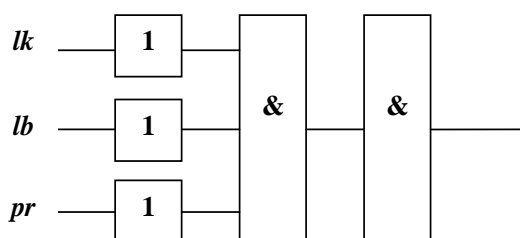


Fig. 3. Logical schema of study element “Subject”

Present on schema:

- *lk* – cycle of lectures within one subject;
- *lb* – cycle of laboratory works within one subject;
- *pr* – cycle of practice lessons within one subject.

During the final test knowledge and skills, acquired by student are confirmed and subject is credited for him *z*:

$$(lk \wedge lb \wedge pr) \wedge z = d . \quad (2)$$

### 4.3 Models of damage and recovery in education environment structure and measuring their parameters

Structural models that are shown on Fig. 1, Fig. 2 and Fig. 3 have one similarity – they are stable and have not changed for decades. Education expenses are usually used for its parametric upgrade: construction of new buildings, purchase of new laboratory equipment and materials, modern computers and software for them, training of professors and teachers and much more.

Everyday life, sport and wellness of students is improved. Serious changes to the structure of studying process are very rare. They usually can only be provoked by catastrophic crises: natural disasters, wars, pandemics and other, which can

limit the movement of people and hinder connections between university and students.

With these conditions, there is a problem of compensating halts, which happen because of crises; moreover, this compensation can be done with different means: repairs without changes in original structure, replacement of “damaged” structure for one that is functionally equal (shunting), transition to completely new approaches of educational process e.t.c.

Such compensation most of the times expects choosing methods and means to provide it, which requires ability to change amount of expenses for one or another method, and not only financial, but also time, energy, materials and so on.

While choosing arises the problem of optimization, staging and solving of which depends on chosen models of educational process.

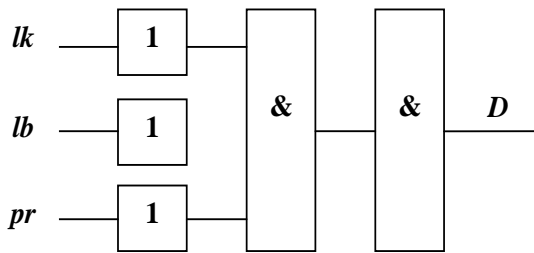
While working on this study there were used logical models, fractal models and graph models. They can help with evaluations of crises compensation variants and with choosing the “best” one out of them.

#### 4.3.1. Logical models [41]

Let us take a look at these models more thoroughly.

Examples of using logical models for showing damages and recovery in educational field structure is shown on Fig. 4

It is obvious that without finishing all laboratory works syllabus will not be considered fully finished and this subject cannot be credited (Fig. 4). With logical modeling, quantitative value of syllabus “damage” complexity can be done in discrete units, connected to amount of «retired» elements and amount of new elements that are required for compensation.



**Fig. 4. Logical schema of study element “Subject” after failing to finish required by the syllabus laboratory works**

4.3.2. Fractal models

Direct discretion of studying process logic models (Fig. 1, Fig. 2, Fig. 3 and Fig. 4) can show us fractal features.

The simplest fractal – geometric figure, which has self-similarity property, meaning that it consists of several parts, each of which is similar to the whole figure [42–43].

Important attribute of fractal is fractal dimension. Since models (Fig. 1, Fig. 2, Fig. 3 and Fig. 4) look like broken lines on  $k$ -dimensional space, their geometric dimension is always integer and equal to  $k$ .

No change to the structure of studying process without adding elements with new parameters can change its geometric dimension, which means that latter cannot be used as the measure of this change.

Unlike geometric, Hausdorff dimension is

fractional and its value is very sensitive to changes in fractal structure (Fig. 5).

To analyze stability of network operation it is usually required to explore its vulnerability, or to find “tight” places, consecutive usage of which can lead to network malfunction.

To solve these problems different approaches can be used, one of which is creating attack graph for original network [44].

4.3.3. Graph models

Attack graph for the network with set technology – oriented graph, which describes all possible sequences of actions, which can result in disturbance of normal network functioning. These sequences of actions are called attack routes. In case of recognition of situation as dangerous, measures for suppression of attack routes should be undertaken (changing channel capacity, installing protective shields e.t.c.). Described task of informational network research to find its “tight” places – network operation during Dos-attacks (service denial) was modeled.

There is an algorithm, which is used to find routes that lead to dangerous conditions [40]. Critical amount of arcs, deleting of which leads to inability to achieve dangerous situations, are chosen from multitude of found routes elements. Thus, amount of activities, required for increasing the level of network security is formed.

Structure of the part of studying process logical schema	Geometrical dimension	Hausdorff dimension
	2	1,21
	2	1,16
	2	1,24

**Fig. 5. Sensitivity of Hausdorff dimension to the changes done to educational process model**

#### 4.4. Methods of structural crises compensation in educational processes

Replacement of element, connection or several elements and connections is a part of transformation of original “skeleton” of initial complex object – educational process. As was mentioned before, we are interested in such replacement after serious damage done to the object, connected to irresistible structural crisis which threatens functionality of educational process as a whole, for example inability for students and teachers to be present in educational institution.

Technology of choice is a part of informational technology, because it uses models, based on processes, searching, collecting, storing, processing, providing and delivering of information methods and means to carry out these processes and methods.

Depending on educational process type, its original structure, depth and severity of damage, time, financial and other resources, which are at the disposal of education recovery process manager, there are three main principles of creating (optimizing) of this process:

- one-step design and subsequent replacement of “damaged” part of educational process structure, preliminary choice of replacement variant using the method of brute force on objective function during design phase; mathematic methods, which are used for this approach – convergence and divergence methods [45–47];

- step by step design and discrete replacement of “damaged” part of educational process structure with discrete accurate calculation of objective function and correction of recovery plan after each site; mathematic method, which is used for this approach – percolation (flow) method [40];

- step by step design and discrete replacement of “damaged” part of educational process structure with continuous calculation of objective function with inaccurate inputs and constant correction to the recovery plan; mathematic method, which is used for this approach – Markov decision process [49–50].

##### One-step principles of educational processes recovery

Such principles can be named parallel, because variants of replacement of “damaged” part of complex educational process structure are developed beforehand, after that they are “presented” one by one to the convergence (fusion) method object and values of objective functions for each variant are calculated, for example probability of achieving the result, time, cost e.t.c. (Fig. 6).

Onwards, values of objective functions are ranked and delivered to recovery managers to make the final decision and to implement it.

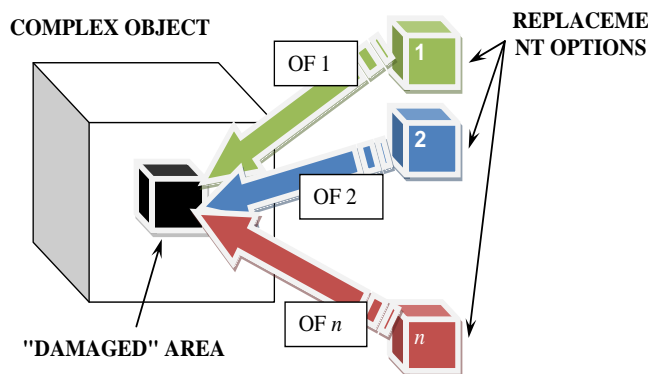


Fig. 6. Example of anti-crisis solutions optimization using consecutive fusion (convergence)

##### Step by step determined principles of educational process recovery

These principles are counted as consistent.

Recovery starts immediately after damage and moves towards working state of the object along one of the percolation grid edges, providing the first step of optimization process for objective functions (Fig. 7). Picture show the starting point A (current state of damaged object) and final point B (recoverable state, i.e. the state in which the object should be without any damage).

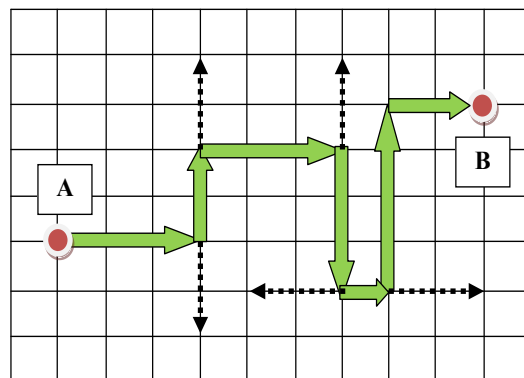


Fig. 7. Example of decision-making optimization using percolation models of the “flow” of the objective functions (green arrow – “optimal” direction, dotted – suboptimal)

Each grid node – achievable intermediate states. Wherein each intersection of objective function grid node is calculated from the beginning and further direction of movement is determined by the calculations. Objective functions are seemingly flowing on edges and nodes of percolations grid. During realization of such adaptive principle movement of recovery process is determined and discrete and final result is closer to optimal than in aforementioned method of simple search.

Step by step stochastic principles of complex objects recovery. During this situation movement of structural damage recovery process along the percolation grid is realized, however the choice of direction is based on random values of calculated objective functions.

It is also a consistent decision-making for fully observable environment with Markov (stochastic) models of transition and additional rewards (Fig. 7).

Method works as a mathematic basis for decision-making in situations, where inputs and results are partly random and partly in control of decision maker.

Quadruple tuple  $(S, A, P (...), R (...))$  is given for determining Markov decision process, where:

- $S$  – finite set of educational systems states,
- $A$  – finite set of impacts done to educational system( mostly in a form of set  $A_s$ , available in a state  $s$ );

•  $P_a(s, s') = Pr(s_{t+1} = s' | s_t = s, a_t = a)$  – probability of impact on educational system  $a$ , in a state  $s$ , leading during time  $t$  to the state  $s'$ ;

•  $R_a(s, s')$  – reward after transferring to the state  $s'$  from the state  $s$  with transfer probability  $P_a(s, s')$ .

#### 4.5 Method of reliability assessment of the information, transferred by communication channels using conditional entropy

Aforementioned principles and methods can be useful in practice only when information, received from the models based on these methods is reliable. After all, anti-crisis decision-making is done in critical conditions, especially for the time. That is why reliability of primary information and decision efficiency are interesting for us.

During the study, we used methods of information reliability evaluation, similarly to the method of reliability measurement of information, transferred by communication channels using conditional entropy.

For a first-order Markov source (one in which the probability of selecting a character is dependent only on the immediately preceding character), the entropy rate is:

$$H_1(S) = - \sum_i p_i \sum_j p_i(j) \log_2 p_i(j), \quad (3)$$

where  $I$  is a state (certain preceding characters) and  $p_i(j)$  is the probability of  $j$  given  $I$  as the previous character.

Using special and overall conditional entropy, we can fully describe information losses during data transfer in channel with obstacles. For this we will use so called channel matrix. Conditional probability

$p(b_j|a_i)$  of receiving symbol  $b_j$  with symbol  $a_i$  being sent is used to described losses from source side.

Channel matrix will look like this

	$b_1$	$b_2$	...	$b_j$	...	$b_m$
$a_1$	$p(b_1 a_1)$	$p(b_2 a_1)$	...	$p(b_j a_1)$	...	$p(b_m a_1)$
$a_2$	$p(b_1 a_2)$	$p(b_2 a_2)$	...	$p(b_j a_2)$	...	$p(b_m a_2)$
...	...	...	...	...	...	...
$a_i$	$p(b_1 a_i)$	$p(b_2 a_i)$	...	$p(b_j a_i)$	...	$p(b_m a_i)$
...	...	...	...	...	...	...
$a_m$	$p(b_1 a_m)$	$p(b_2 a_m)$	...	$p(b_j a_m)$	...	$p(b_m a_m)$

Obviously diagonal rates describe correct reception, and the sum of all elements in a column shows probability of receiving symbol on receiver side –  $p(b_j)$ .

Losses, which fall on transferred signal  $a_i$ , are describes using special conditional entropy:

$$H(B|a_i) = - \sum_{j=1}^m p(b_j|a_i) \log_2 p(b_j|a_i). \quad (4)$$

In this case, to calculate losses during all signal transfers overall conditional entropy is used:

$$H(B|A) = - \sum_i p(a_i) H(B|a_i). \quad (5)$$

$H(B|A)$  means source side entropy; similarly  $H(A|B)$  is receiver side entropy: instead of  $p(b_j|a_i)$  we use  $p(a_i|b_j)$  everywhere( summing line elements we can receive  $p(a_i)$ , and diagonal elements mean probability of receiving the same symbol that was sent, or correct transfer probability).

Mutual entropy or union entropy is used for calculation of entropy of interconnected systems (entropy of joint appearance of statistically dependent messages) and is denoted as  $H(AB)$ , where  $A$  means transmitter and  $B$  – receiver [44].

Interconnection of transferred and received signals is described by joint event rate  $p(a_i|b_j)$ , and for full description of channel characteristics only one matrix is required:

	$b_1$	$b_2$	...	$b_j$	...	$b_m$
$a_1$	$p(a_1b_1)$	$p(a_1b_2)$	...	$p(a_1b_j)$	...	$p(a_1b_m)$
$a_2$	$p(a_2b_1)$	$p(a_2b_2)$	...	$p(a_2b_j)$	...	$p(a_2b_m)$
...	...	...	...	...	...	...
$a_i$	$p(a_ib_1)$	$p(a_ib_2)$	...	$p(a_ib_j)$	...	$p(a_ib_m)$
...	...	...	...	...	...	...
$a_m$	$p(a_mb_1)$	$p(a_mb_2)$	...	$p(a_mb_j)$	...	$p(a_mb_m)$

For more general case, when we describe connection of systems, matrix does not have to be square shaped. Obviously, sum of all elements of the



column  $j$  gives us  $p(b_j)$ , sum of the line  $i$  gives  $p(a_i)$ , and sum of all elements of matrix is equal 1.

Overall probability  $p(a_i b_j)$  of events  $a_i$  and  $b_j$  is calculated as multiplication of original and conditional probability:

$$p(a_i b_j) = p(a_i) p(b_j | a_i) = p(b_j) p(a_i | b_j). \quad (6)$$

Using Bayes formula we can calculate conditional probabilities.

Thus, we have all required data to get transmitter and receiver entropy:

$$H(A) = - \sum_i \left( \sum_j p(a_i b_j) \log \sum_j p(a_i b_j) \right), \quad (7)$$

$$H(B) = - \sum_j \left( \sum_i p(a_i b_j) \log \sum_i p(a_i b_j) \right). \quad (8)$$

Mutual entropy is calculated as consecutive sum of lines or columns of all rates of matrix, multiplied by logarithm:

$$H(AB) = - \sum_i \sum_j p(a_i b_j) \log p(a_i b_j). \quad (9)$$

Fault tolerance grade can be reduced to grade of information, stored in complex systems with loaded redundancy (CSLR) and such entropy equation can be used [44]:

$$K_{\ominus} = \sum_{i=n^*}^{n^{**}} [P(i) \log_2 P(i) - (1 - P(i)) \log_2 (1 - P(i))]. \quad (10)$$

Such indicator can also help to estimate technical condition of CSLR with one size free number, which lets to use it in informational model during express assessment. It can also be an indicator for comparing different variants of CSLR or as adjustable parameter in management.

#### 4.6 Practical results of the study and their effecience estimation

As a result of activity of crisis outcome compensation, we got next results:

– based on information, received by questioning students about their possession of communication means and technical ability to interact with the teacher, three options of tasks structuring for independent work of students were developed and terms of execution are set;

– based on information, received by questioning students about their possession of communication means and technical ability to interact with the teacher, considering topics of lectures, 3 options for tests for each module were developed; each option provides knowledge and skills, foreseen by syllabus and helps to evaluate level of studying achievements of students;

– reading the lectures and carrying out practical lessons are brought to remote mode in full capacity according to subject syllabus.

#### 5. CONCLUSIONS

Structural anti-crisis model of educational process is proposed in Institute of engineering and transport of Odessa National Polytechnic University.

As an example of one separate subject – “Further mathematics”, method of quick recovery of such element with minimal losses for the process as a whole is developed.

As an example of systemic outer crisis, which occurred because of the pandemic, technology of overcoming such crisis with anti-crisis decision optimization using convergence models is developed.

Practical tests of study results and evaluation of its technical, economic and social effecience is done in Institute of engineering and transport of Odessa National Polytechnic University.

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DOI: 10.15276/hait.03.2020.7

UDK: 65.012.3

## ІНФОРМАЦІЙНІ МОДЕЛІ ТА МЕТОДИ УСУНЕННЯ НАСЛІДКІВ СТРУКТУРНИХ КРИЗ В ОСВІТНЬОМУ ПРОСТОРИ

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### АНОТАЦІЯ

Розроблено інформаційні моделі та запропоновано методи усунення наслідків глобальних структурних криз в освітньому просторі. Зміст статті є продовженням попередньої роботи цих же авторів, присвяченій інформаційним технологіям пошуку антикризових рішень в управлінні складними динамічними системами. Метою цієї роботи є підвищення ефективності (швидкодії, мінімізації витрат) антикризових рішень для усунення наслідків структурних криз в складних освітніх системах. Залежно від виду складного об'єкта, його початкової структури, глибини і серйозності пошкодження, тимчасових, фінансових та інших ресурсів, наявних у розпорядженні менеджера процесу відновлення складного об'єкта можливі три основних принципи побудови (оптимізації) цього процесу: перший принцип – одноразова проектування і подальша заміна (трансформація) «пошкодженого» ділянки структури об'єкта, попередній вибір варіанта заміни по винагороді (цільової функції) на етапі проектування; математичний метод, розроблений для такого підходу, – методи конвергенції і дивергенції; другий принцип – покрокове проектування і дискретна заміна (трансформація) «пошкодженої» частини ділянки структури об'єкта з дискретним розрахунком винагороди (цільової функції) і коригуванням плану відновлення після кожної ділянки; математичний метод, розроблений для такого підходу, – метод перколяції функціональності; третій принцип – покрокове проектування і дискретна заміна (трансформація) «пошкодженої» частини ділянки структури об'єкта з безперервним розрахунком винагороди (цільової функції) за нечіткими вихідними даними і постійним коригуванням плану відновлення; математичний метод, розроблений для такого підходу, – марковський процес прийняття рішень. На прикладі вищого навчального закладу запропоновано структурну антикризову модель освітнього процесу. На прикладі окремої навчальної дисципліни створена антикризова модель відновлюваного елемента освітнього процесу і розроблений метод швидкого відновлення такого елемента з мінімальними втратами для процесу в цілому. В якості типового елемента освітньої структури в вузі обрана лекція. На прикладі системного зовнішньої кризи, яка виникла при пандемії, розроблено інформаційну технологію подолання такої кризи з оптимізацією антикризових рішень за допомогою конвергенції моделей.

Запропоновано підсумкові параметри, які виконують роль цільових функцій при виборі оптимальних рішень криз. Проведено практичні випробування інформаційної технології пошуку антикризових рішень в управлінні динамічними складними системами у вищій освіті, зокрема, при підготовці і здійсненні антикризових заходів під час викладання планової дисципліни «Вища математика». Технологія використана при антикризової перебудові навчального процесу під час карантину коронавіруса. В результаті отримані наступні результати: взаємодія учасників освітнього процесу здійснювалася через засоби комунікації, вбудовані в систему управління навчанням (LMS), електронну пошту, месенджери (Viber, Telegram), конференції (MS Teams, ZOOM, Google Meet, Skype і ін. В дистанційному режимі згідно Учбового плану здійснено читання лекцій і виконання практичних занять в повному обсязі.

**Ключові слова:** інформаційні технології; навчальний простір; ліквідація наслідків; структурні кризи; елементи вищої освіти

DOI: 10.15276/hait.03.2020.7

UDK: 65.012.3

## ИНФОРМАЦИОННЫЕ МОДЕЛИ И МЕТОДЫ УСТРАНЕНИЯ ПОСЛЕДСТВИЙ СТРУКТУРНЫХ КРИЗИСОВ В ОБРАЗОВАТЕЛЬНОМ ПРОСТРАНСТВЕ

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### АННОТАЦИЯ

Разработаны информационные модели и предложены методы устранения последствий глобальных структурных кризисов в образовательном пространстве. Содержание статьи является продолжением предыдущей работы этих же авторов, посвященной информационным технологиям поиска антикризисных решений в управлении сложными динамическими системами. Целью настоящей работы является повышение эффективности (быстродействия, минимизации затрат) антикризисных решений для устранения последствий структурных кризисов в сложных образовательных системах. В зависимости от вида сложного объекта, его первоначальной структуры, глубины и серьезности повреждения, временных, финансовых и других ресурсов, имеющихся в распоряжении менеджера процесса восстановления сложного объекта возможны три основных принципа построения (оптимизации) этого процесса: первый принцип – единовременное проектирование и дальнейшая замена (трансформация) «поврежденного» участка структуры объекта, предварительный выбор варианта замены по вознаграждению (целевой функции) на этапе проектирования; математический метод, разработанный для такого подхода – методы конвергенции и дивергенции; второй принцип – пошаговое проектирование и дискретная замена (трансформация) «поврежденной» части участка структуры объекта с дискретным расчетом вознаграждения (целевой функции) и корректировкой плана восстановления после каждого участка; математический метод, разработанный для такого подхода – метод перколяции функциональности; третий принцип – пошаговое проектирование и дискретная замена (трансформация) «поврежденной» части участка структуры объекта с непрерывным расчетом вознаграждения (целевой функции) по нечетким исходным данным и постоянным корректировкой плана восстановления; математический метод, разработанный для такого подхода, – марковский процесс принятия решений. На примере высшего учебного заведения предложена структурная антикризисная модель образовательного процесса. На примере отдельной учебной дисциплины создана антикризисная модель восстанавливаемого элемента образовательного процесса и разработан метод быстрого восстановления такого элемента с минимальными потерями для процесса в целом. В качестве типичного элемента образовательной структуры в вузе выбрана лекция. На примере системного внешнего кризиса, возникшего при пандемии, разработана информационная технология преодоления такого кризиса с оптимизацией антикризисного решения с помощью конвергенции моделей. Предложены итоговые параметры, выполняющие роль целевых функций при выборе оптимальных решений кризисов. Проведены практические испытания информационной технологии поиска антикризисных решений в управлении динамическими сложными системами в высшем образовании, в частности, при подготовке и осуществлении антикризисных мер во время преподавания плановой дисциплины «Высшая математика». Технология использована при антикризисной перестройке учебного процесса во время карантина коронавіруса. В результате получены следующие результаты: взаимодействие участников образовательного процесса осуществлялась через средства коммуникации, встроенные в систему управления обучением (LMS), электронную почту, месенджеры (Viber, Telegram),

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**Ключевые слова:** информационные технологии; образовательное пространство; устранение последствий; структурный кризис; элемент высшего образования

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Received. 04.08.2020

Received after revision 12.09.2020

Accepted 20.09.2020