Analytical Research on System Capability and Information Technology Use Capability: Problem Statement Examples

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***Abstract*—System dynamic capability (DC) is a system's ability to integrate, build, and reconfigure competences to address rapidly changing environments. Information technology (IT) capabilities (IC) are defined as the ability to mobilize and deploy IT-based resources in combination with other resources and capabilities. Here, it is suggested to estimate the indicators of DC and IC based on models and methods to estimate the potential of a system (which has such DC and IC) analytically. More precisely, it is suggested to estimate DC or IC by the results of their use. Such results are those parts of a system's potential that are obtained due to given DC and/or IC use. System potential was defined as a system's ability to achieve changing goals in its changing environments. With the use of models and methods built for solving a system's potential problems, it is possible to build functional models in order to estimate a system's potential with regard to DC and IC use. As a result of such models and methods, the application of the estimation of DC and IC use indicators becomes possible depending on the parameters and variables of the DC and IC problems to be solved. Use cases of such indicator investigations include choosing optimal IT, IC characteristics, digitalization planning, synthesis of information operation characteristics based on mathematical models of IT use for a system's functioning, and strategic planning based on the analytical investigation of DC use indicators.**

I. Introduction

To achieve changing goals in changing environments, system functioning must be able to change appropriately depending on the environment and to provide changed effects of functioning in such a way that the effects comply in the best possible way with changing environments [7].]. This ability can be achieved by means of dynamic capability (DC) [25] and information technology capability (IC), which first measure environmental states and next change the effects appropriately. . Thus, DC and IC are used as means and routines to change and to enhance in changing environments. Unfortunately, models and methods to analytically estimate DC and IC use quality with the help of predictive models of system functioning in changing environments have not yet been suggested. In this article, it is suggested to estimate DC and/or IC based on the amount of a system's potential DC and/or IC generation. Theoretical models and methods suggested of a system's potential allow the analytical estimation of changing effects in changing environments and the estimation of random measures of effects that comply with changing environmental demands . So it is possible to use these models and methods to estimate DC and IC use quality, usually referred to as "performance" but with another meaning of performance due to change and the process of change. Such an estimation can be done by the effects of DC and IC use, and by these effects, compliance with changing environments can be achieved. As a result, models and methods created for decision problems of a system's potential can be used to estimate DC and IC use indicators analytically. This further allows solving DC and IC practical problems as corresponding mathematical problems (e.g., mathematical programming or operation research problems). Examples of models presented are graph-theoretic model parameters with random values and probabilities. Example models are a system's environmental graph-theoretic models and a system's model with regard to IT use to respond to a changing environment. Research on the roles of DC and IC in the functioning of modern organizations [16]led to the conclusion that "capabilities represent the potential of a firm to achieve certain objectives by means of focused deployment and are considered the building blocks on which they compete in the market." Further, "IT capabilities [are] defined as firms' ability to mobilize and deploy IT-based resources in combination or co-present with other resources and capabilities in order to differentiate from competition." Dynamic capabilities (DC) are usually defined [12] [23] [24] as "the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments," while ordinary capabilities are usually defined as ones that "enable a firm to 'make a living' and as routines or 'zero-order' capabilities, as they enable a firm to continue producing and selling the same product or service in a repetitive pattern." Some authors [12] come to the conclusion "that ordinary and dynamic capabilities are closely associated, that both of them enhance firm performance, and that environmental dynamism reinforces these effects." However, environmental dynamism leads to changes in system functioning as well as to a variety of possible functions in different environments and to transition processes guided by information operations. Thus, in order to account for possible functioning and environmental conditions, we shall estimate their possible changes to enhance the system's potential but not its performance in given conditions . This is reasserted by ways to measure dynamic capabilities used by other researchers. For example, in [15] [16], when measuring dynamic capabilities "sensing, coordinating, learning, integrating, and re-configuring routines" are researched. System potential is an integrative measure, which reflects such routine effects and their compliance with changing environments. The value of a system's potential indicator [4] [5] [6], obtained for different DC (IC), may serve as an indicator of DC (IC) use results. As stated in [15][15], "DC view is considered an appropriate framework to explain how firms can differentiate and compete in a turbulent environment, taking into account that they must evolve and co-evolutionary reconfigure their (IS/IT) operations in order to remain competitive." But DC use is not enough to change system functioning accordingly in such turbulent environments. Information operations according to certain IT are required as well [9] [10] [11] as operations of different kinds, starting from designing new functionality for the system and finishing with transitions from one functioning to another. Some of these operations are informational, and some are not (i.e., material). We will call such information operations fulfillment routines information or digital capabilities (IC). Such routines aligned in possible chains of information and material actions lead to enhancements of the system and its functioning in changing environments. Unfortunately, models and methods to estimate quality indicators of such changing functioning in changing environments, with regard to DC and IC use, are at an early stage. For example, [21] proposed a general modular system theory. This theory states that many systems opt towards modular forms in order to enable greater agility. The general assumption is that many complex systems adapt or evolve in response to changes. IT use is always required to design and realize such responses. Yet despite heavy investments in IT, organizations quite often fail to achieve improvements in their organizational performance due to their inability to align IT with organizational needs. In general, this so-called "productivity paradox" [13] has been greatly attributed to the lack of fit, or alignment, between business strategy and internal resources, including IT. IT flexibility is the degree of decomposition of an organization's IT portfolio into loosely coupled subsystems that communicate through standardized interfaces. Competitive performance refers to the degree to which a firm performs better than its key competitors in changing environments. To estimate competitive performance, it is logical to estimate and compare competitors' potential [19]. The strategic alignment model [16] for IT flexibility and dynamic capabilities can guide decision-makers towards aligning the use of IT resources with their dynamic capabilities and guide IS/IT and business investment to support the process of enhancing firm performance. Performance here is understood as the extension into multiple functioning in multiple possible conditions, in changing environments, with the use of transition processes—thus, actually, with a system's potential. In [16], it is stated that synergies between a firm's IT and organizational resources and capabilities are the foundation of what is called "strategic alignment." One of the findings is that "this is an important insight for business, IT managers and executives because they can look at strategic alignment, with the underlying pillars, i.e., IT flexibility, dynamic capabilities, and a firm's absorptive capacity, as a means (and key toolbox) to drive firm performance and systematically enhance the evolutionary fitness of the firm." Models of a system's potential theory, DC, and IC shall be viewed as possible information and non information operation routines. Change routines and their alternative chains are used to react to a system's environmental impacts in order to change functioning accordingly. Accordingly, means to enhance functioning operate in such a way that functioning effect measures of compliance with demands of the environment become highest [8] [7]. For this purpose, IC, DC, and other abilities to perform action routines shall be used together to fulfill changing functioning in changing environments. The impact of DC and AC use for such changing functioning in changing environments measured by a system's potential change and modeled with analytical predictive models is used to estimate a system's potential. This allows solving DC and AC research problems as mathematical problems in research on a system's potential.

II. Modeling system and its environment

Let us consider simple example of modelling system's change due to it's environment change. Example consists of system environment model, which produce possible vectors of states, required by the environment and probabilities (possibilities) for such vectors to be demanded (required) by environment. One of such vectors shall be realized as a result of environment functioning. Such vectors and probabilities of their realization can be represented as random vector. Each possible vector of such required by system's environment states lead to separate model of system's functioning under changing conditions. It describes functioning and changes of the system, including transition operations. Such functioning and system's changes (transitions) corresponds to chosen vector of required states. Transitions realization requires information operations. System model allows to estimate effects of operations, including transition operations and information operations and their correspondence to environment requirements, according chosen vector of required states. Such measure is probabilistic measure estimated for each required state of the vector and can be represented as discrete vector of correspondences (each correspondence is element of vector of probabilistic measures). All possible measures of correspondence (for all required by environment vectors of states) can be represented as multidimensional random vector or its characteristics, for example - mean, mode, median. Such random vector or its characteristics may serve as system's potential indicator. Indicator varies depends on capabilities and technologies used to react on system's environment changes. IT used is one (and necessary required) among such technologies. Measure of distance between system's potential indicator value for non-digital IT used and digital IT used as a result of digitalization can serve as digitalization performance indicator [9].

III. System's environmental functioning and its change graph-theoretic model

Consider an example of a complex technical system (CTS) environmental functioning model M^e with the following source data: One real G_0^r and two possible G_1^p, G_2^p goals are specified. These two possible goals can change the actual one in any sequence and at different times. This change is implemented as a result of actions in the environment of the CTS. These action details are unknown, but the probabilistic characteristics of the scenarios for changing the actual goal are known. An example of a CTS environmental model is shown in 1. Scenarios are sequences of actions in the environment that may cause goal changes. Scenarios are shown with bold lines. First, it is assumed that if a goal becomes a real one and thus ceases to be, then this goal cannot become valid again. Second, it is assumed that if a goal change happens, then it is impossible for information operations and CTS to miss this change. Third, it is assumed that goals are changed during time intervals that are significantly bigger than the intervals in which information operations check the actual goals. Scenarios are characterized by the probabilities $p_{00}, p_{01}, p_{11}, p_{12}, p_{02}, p_{21}, p_{22}$, where the indexes show possible transitions between goals due to actions in the environment, corresponding to chains of transition. Deterministic moments of the system's and its environment's state checks are $\mathbf{T} = T_0, T_1, T_2, T_3$. T_0 moment corresponds to the start of functioning. Let us specify possible sequences of demanded environmental states at $\mathbf{T}$ and possibilities for such sequences to be realized: $\mathbf{S}_0 :=< \mathbf{S}^d_{01}, \mathbf{S}^d_{02}, \mathbf{S}^d_{03} >; p = p_{00}$, where indexes represent scenarios (0) and serial numbers (1,2,3) of demanded vectors of states.These demanded vectors of states are:

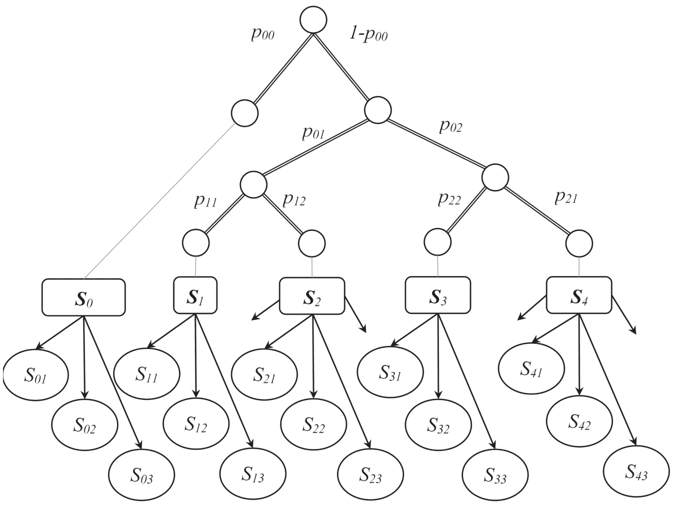

Fig. 1. The example of complex technical system environment model

$$\mathbf{S}_{01} :=< S^d_{00}, S^d_{01}, S^d_{02}, S^d_{03} >;$$

$$\mathbf{S}_{02} :=< S^d_{00}, S^d_{01}, S^d_{02}, S^d_{13} >;$$

$$\mathbf{S}_{03} :=< S^d_{00}, S^d_{01}, S^d_{02}, S^d_{23} > .$$

This is basic sequences of states, which corresponds to situation when the initial (real) goal not changed at moments $T_u \in \mathbf{T}$. This may happen because it not changed at given time frame or due to moment of goal change happened between T_2 and T_3, so changing goal already useless. Elements of these sequences are: $S^d_{00}-$state, demanded at T_0 (always corresponds to initial goal); $S^d_{01}-$state, demanded at T_1 in case goal change have not happen between T_0 and T_1 (so, goal is initial one); $S^d_{02}-$state, demanded at T_2 in case goal change have not happen between T_1 and T_2 (so, goal is initial one); $S^d_{03}-$state, demanded at T_3 in case goal change have not happen between T_2 and T_3 (so, goal is initial one); $S^d_{13}-$state, demanded at T_3 in case goal change happened between T_2 and T_3 and new real goal is G_1; $S^d_{23}-$state, demanded at T_3 in case goal change happened between T_2 and T_3 and new real goal is G_2; Te last two cases corresponds to situations, when goal change already does not affect functioning, because functioning shall end at T_3. Other possible sequences considered are $< \mathbf{S}_1, \mathbf{S}_2, \mathbf{S}_3 >, p = 1-p_{00}$: $\mathbf{S}_1 :=< \mathbf{S}^d_{11}, \mathbf{S}^d_{12}, \mathbf{S}^d_{13} >$ where the indexes represents scenario (1) and serial numbers (1,2,3) of the demanded vectors of states. These demanded vectors of states are:

$$\mathbf{S}_{11} :=< S^d_{00}, S^d_{11}, S^d_{12}, S^d_{13} >;$$

$$\mathbf{S}_{12} :=< S^d_{00}, S^d_{01}, S^d_{12}, S^d_{13} >;$$

$$\mathbf{S}_{13} :=< S^d_{00}, S^d_{01}, S^d_{02}, S^d_{13} > .$$

Note S^*_{13} is the sequence which is part of $\mathbf{S}_{03}$ too. $\mathbf{S}_2 :=< \mathbf{S}^d_{21}, \mathbf{S}^d_{22}, \mathbf{S}^d_{23} >, p = p_{01}p_{12}$, where the indexes represents scenario (2) and the serial numbers (1,2,3) of demanded vectors of states. These demanded vectors of states are:

$$\mathbf{S}_{21} :=< S^d_{00}, S^d_{01}, S^d_{12}, S^d_{23} >;$$

$$\mathbf{S}_{22} :=< S^d_{00}, S^d_{11}, S^d_{12}, S^d_{23} >;$$

$$\mathbf{S}_{23} :=< S^d_{00}, S^d_{11}, S^d_{22}, S^d_{23} > .$$

Note that two arrows from $\mathbf{S}_2$ has not corresponding them ends (ovals) at Figure 1. They correspond to $\mathbf{S}_{24} :=< S^d_{00}, S^d_{01}, S^d_{02}, S^d_{13} >$ and $\mathbf{S}_{25} :=< S^d_{00}, S^d_{11}, S^d_{12}, S^d_{13} >$ which considered impossible. $\mathbf{S}_3 :=< \mathbf{S}^d_{31}, \mathbf{S}^d_{32}, \mathbf{S}^d_{33} >, p = p_{02}p_{21}$, where indexes represent the scenario (3) and serial numbers (1,2,3) of the demanded vectors of states. These demanded vectors of states are:

$$\mathbf{S}_{31} :=< S^d_{00}, S^d_{21}, S^d_{22}, S^d_{23} >;$$

$$\mathbf{S}_{32} :=< S^d_{00}, S^d_{01}, S^d_{22}, S^d_{23} >;$$

$$\mathbf{S}_{33} :=< S^d_{00}, S^d_{01}, S^d_{02}, S^d_{23} > .$$

Here, S^*_{23} is the sequence which is part of $\mathbf{S}_{04}$ too. $\mathbf{S}_4 :=< \mathbf{S}^d_{41}, \mathbf{S}^d_{42}, \mathbf{S}^d_{43} >, p = p_{02}p_{21}$, where indexes represent the scenario (4) and serial numbers (1,2,3) of the demanded vectors of states. These demanded vectors of states are:

$$\mathbf{S}_{41} :=< S^d_{00}, S^d_{01}, S^d_{22}, S^d_{13} >;$$

$$\mathbf{S}_{42} :=< S^d_{00}, S^d_{21}, S^d_{22}, S^d_{13} >;$$

$$\mathbf{S}_{43} :=< S^d_{00}, S^d_{21}, S^d_{12}, S^d_{13} > .$$

Note two arrows from $\mathbf{S}_4$ has not corresponding them ends (ovals) at Figure 1. They correspond to $\mathbf{S}_{44} :=< S^d_{00}, S^d_{01}, S^d_{02}, S^d_{23} >$ and $\mathbf{S}_{45} :=< S^d_{00}, S^d_{21}, S^d_{22}, S^d_{23} >$ which considered impossible. The result of using the complex system environment functioning model M^e is set $\mathbf{S}^r$ of vectors $\mathbf{S}^r_q, q = \overline{1, 15}$ and probabilities p_q of their actualization for CTS at its environment. In the example considered $q = 9$, q corresponds to $i = 2, j = 3$. $\mathbf{S}^r_q :=< S^r_{ij}; i = \overline{0, 4}, j = \overline{0, 4} >$ of possible states S^r_{ij}, required by environment. Each vector $\mathbf{S}_q$ characterized by appropriate possibility p_q of such vector to be actualized by the environment for CTS. Here indexes i, j of $\mathbf{S}^r_q$ states $S_{i,j}$ represent scenarios (sequences of actions and corresponding transitions at environment) serial numbers i and the serial numbers j of demanded vectors of states according such scenarios at moments T_u. Each of $\mathbf{S}^r_q, q = \overline{1, 15}$ vectors used as the "given condition" to build separate complex system model.

IV. THE SYSTEM FUNCTIONING AND ITS CHANGE GRAPH-THEORETIC MODEL

The possible result of using the CTS model are sets $\mathbf{S}_j^s$ of possible CTS states $\mathbf{S}_j := s_{uj}, u = \overline{1, U}$ for T_j. As well, model use provide measures w_{uj} and possibilities p_{uj} for CTS states s_{uj} to realize at T_u. The measures $w_{uj} := p(s_{uj} \sim S_{ij}^d)$ for CTS environment requirements and CTS states correspondence according $\mathbf{S}_q^r$ at T_u, that is - S_{qiu}^r at the same moment T_u (S_{iu}^d)) when s_{ui} counted. Here "$\sim$" shall take form of one of inequality/equality operations. i.e. "¿,=,¡" and their combinations. The example model M_{qa} of the CTS is calculated for the one vector $\mathbf{S}_q^r$ of required states and fr the one set I_a of possible information operations characteristics from the set of possible characteristics of technological information operations $\mathbf{I} = I_a, a = \overline{1, A}$ and thus, depending one of A IT used. $\mathbf{S}_q^r =< S_{qij}^r >$ taken from the set of possible sequences of the states $\mathbf{S}_q^r$, required by the environment. This vector is $\mathbf{S}_9^r$ at example shown: $\mathbf{S}_9^r = \mathbf{S}_{23} :=< S_{00}^d, S_{11}^d, S_{22}^d, S_{23}^d >$; It means during first information operation at moment T_1 system functioning must be adapted (that means conversion of the system shall be performed) to achieve goal G_1. Next, at the moment T_2 conversion of system shall be performed to achieve the goal G_2. The system will stop functioning at the moment T_3. Because of q varies separate CTS and its functioning model built for each q but the one model considered in example. We need all models ($q = 15$) in order to estimate system potential indicator. As well, we need to measure w_{ju}, p_{ju} depending possible IT characteristics used to perform $A_0^i ... A_3^i$ and so - depending this information technological operations characteristics used to create appropriate prescriptions for the conversion and further, for the target operations. This IT characteristics are $I_a : a = \overline{1, A}$. Depending I_a and $\mathbf{S}_q^r$ different models M_{qa} built and as a result different s_{uj} realized. So, once all that models built we will add q and a indexes to results of modelling and will get multidimensional array $\mathbf{W}_{[Q,A,J,U]}$, which allows to get w_{qaju}, p_{qaju} for each $\mathbf{S}_q^r \in \mathbf{S}^r$ and $I_a \in \mathbf{I}$:

$$\mathbf{W}_{[Q,A,J,U]} =< w_{qaju}, p_{qaju}, u = \overline{1, U}, j = \overline{0, J}, \quad q = \overline{1, Q}, a = \overline{1, A} > . \tag{1}$$

The example of complex technical system's model used to estimate (1) shown at Figure 2. At this Figure, $w_1^m - w_5^m$- the workplaces to perform technological non-information operations (TNIO or material technological operations); w_1^i, w_2^i- Workplaces to perform technological information operations (TIO); $A_1^m - A_5^m$- Technological non-information operations; A_1^i, A_2^i- Technological information operations; S-system; E^s- environment of the system; $\hat{t}$- random value t;

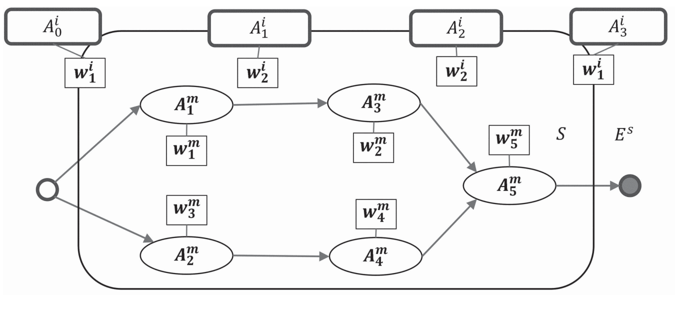

Fig. 2. The example of complex technical system model

The information technological operations parameters (designated by upper index i), are characterized by the left and right margins of the respective random values:

$$\begin{aligned} A_0^i &\sim< t_0^i, c_0^i >; t_0^i =< 1, 3 >; c_0^i =< 1, 2 >; \\ A_1^i &\sim< t_1^i, c_1^i >; t_1^i =< 1, 4 >; c_1^i =< 2, 3 >; \\ A_2^i &\sim< t_2^i, c_2^i >; t_2^i =< 1, 2 >; c_2^i =< 1, 3 >; \\ A_3^i &\sim< t_3^i, c_3^i >; t_3^i =< 1, 3 >; c_3^i =< 1, 2 >; \end{aligned} \tag{2}$$

It is supposed that all actions (information 2 and non-information) effects are the Beta- distributed random values. The calendar schedule of technological non-information operations has a vector form and contains prescriptions to start 5 non-information actions:

$$<< A_1^m, T_1 >, < A_2^m, T_2 >, < A_3^m, T_3 >, \quad < A_4^m, T_4 >, < A_5^m, T_5 >> . \tag{3}$$

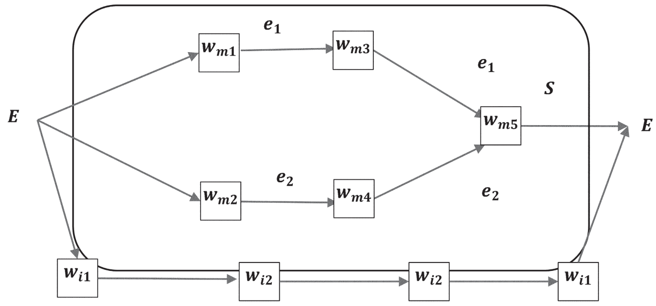

Fig. 3. The example of information and non-information technological routes of the complex technical system

In (3) $T_c, c = \overline{1, 5}$- the calendar moment of A_c^m beginning. The technological route has a form of one information route $w_1^i - w_2^i - w_1^i$ and two non-information routes chains: $< w_1, w_3, w_5 >$ to produce and and assemble part 1 - p_1, and $< w_2, w_4, w_5 >$ to produce and and assemble part 2 - p_2. Parts assembled at workplace number 5 - w_5. The required states of the $\mathbf{S}_2 3$ sequence, for which complex technical system model was built are: S_{00}^r- the initial state checked at $T_0 = 0 :$ $\hat{C}_{00}^r = 0, \ \hat{R}_{00} = 0; S_{01}^r$ - the first state checked at $\mathbf{T}_1$: $\hat{C}_{01}^r, \ \hat{R}_{01} =< \hat{R}_{011}, \hat{R}_{013} >$. After checking, the goal changed to G_1, so conversion planned and required states required changes accordingly. S_{12}^r- the second state checked at $\mathbf{T}_2$: $\hat{C}_{12}^r, \hat{R}_{12} =< \hat{R}_{121}, \hat{R}_{123}, \hat{R}_{122}, \hat{R}_{124} >$. After the checking the goal changed to G_2, the conversion planned and states required changes accordingly. S_{23}^r - third state checked at T_3 : $\hat{C}_{23}^r, \hat{R}_{23} =< \hat{R}_{235} >$. The network of technological non-information (material) operations is shown at Figure 4. This is typical representation of operations, for example, for the project management, but expanded. Exactly, the model of CTS functioning expanded with use of waiting operations D_1, D_2, D_3, D_4, D_5. The waiting operations used, particularly, to account for the calendar plans fulfillment, to represent possible waits (delays) and the states of workplaces during each moment of CTS functioning. Next, such model expanded with technological information operations chain in the network specified. The technological information operations performed on workplaces w_1^i, w_2^i. Workplace w_1^i used to receive and send reports from/to environment and not capable of altering the CTS functioning but workplace w_2^i is capable to alter CTS functioning and not used to receive/send reports to/from environment 3. The network of technological information and non-information operations with waits is shown at Figure 5. The CTS model created allows to specify: $\mathbf{S}_j-$ the set of the possible CTS states under condition that the vector S_{ij}^r of states, required by CTS environment at T_j is fixed; Each CTS state is associated with b_s^s- $s-$th branch at the tree T_{ij} of possible branches of the simultaneously performed technological operations. It created for the fixed S_{ij}^r. Each branch b_s^s associated with the set of U information and non-information technological operations and waits for operations, $b_s^s \sim A_{us}, u = 1,\bar{U}$, each one performed (or waits) at the workplace w_u. This allows to compute the states of CTS, which corresponds to b_s^s. Such tree T_{ij} fragment is shown at 6. The fragment built under condition that technological information operation is performed. Other fragments has the same structure and corresponds to the cases when other technological information operations performed. As a result, the complex tree built based on its fragments. It shown at Fig. 7.

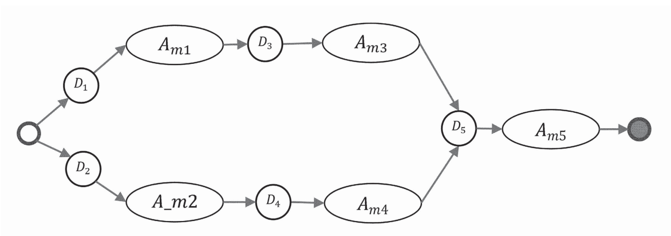

Fig. 4. The example of technological operation network with delays

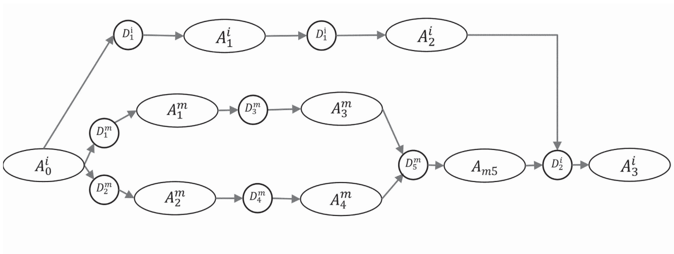

Fig. 5. The example of technological operations network with delays and technological information operations

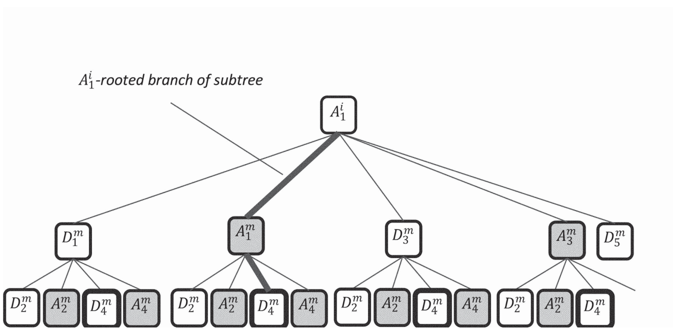

Fig. 6. The fragment of tree of initial technological operation network cuts

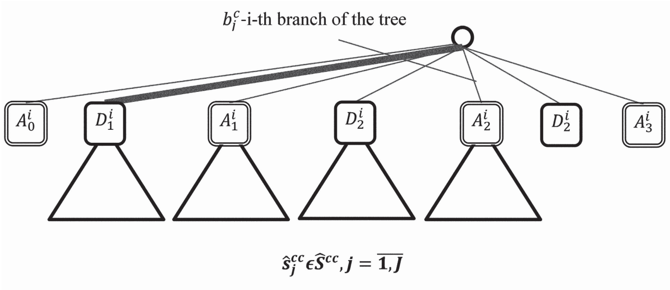

Fig. 7. Complex tree

The trees built allows to specify and further, to compute the possible states of CTS during its functioning to reach the requirements, specified by S_{ij}^r. The computation performed base on the ability to form states of the CTS based on the states of $w_u \sim A_{us}$. Let us designate such state of the CTS as $S_s^s \sim b_s^s$. As well, the models of possible states allows us to generate the correct conversion technological operations and the corresponding them technological operations in case the requirements was changed. The conversion operations depends on the state $S_s^s \sim b_s^s$ and the states required by the environment when CTS is in this state, One case in example, shown in bold at 6 and related to 7 corresponds to the implementation of the D_1^i wait and A_m1 operation at the start of checking the compliance of the system and the environment states and the D_4 wait to start A_{m4} technological non-information operation. In this case, the conversion is to bring workplace w_1 to its original state, and then to fulfill conversion (readjustment) of w_1 to reach the new requirements according the new goal G_1. For w_4, it is necessary to perform a readjustment. The information technological operation A_1^i for the purpose of conversion must return as a result the information about the network of conversion technological operations to perform and the calendar plan for their implementation, as well as the network of further technological operations to reach the G_1 ("target" operations) and the calendar plan for their implementation. Such situation of alternating the functioning due to the environment change, corresponding information operation results and the further conversion and target operations start named cutting. Its example is shown at Figure 8. The conversion technological operations suggested not interrupted for simplicity. As well it is supposed that before the new network of operations will be performed all conversion operations shall end. After the information technological operation A_2^i finished and required information obtained the conversion and further, the target operations should start on the third and fourth workplaces according to the specified calendar plan. These target technological operations can also be interrupted when the next state check is performed at T_2. Corresponding example of the converse technological operations is shown at Figure 9. They ends with the technological information operation A_3^i which check new state of the workplaces and start the "target" technological operations. The corresponding network of technological information and non-information operations with the waits shown at Figure 10. Note this network generated under few conditions: first, under the condition of S_{qij}^r fixed which is $q = 9, \mathbf{S}_2$ and S_{23}, next, under the condition of I_a fixed and so, as a result, S_u^s fixed, which built for $< A_1^i, A_1^m, D_4^m >$ and so under the condition of I_a,and as a result, A_1^i characteristics fixed. This fixation cause the appropriate M_{aq} and next, networks of the converse and the target technological operations.

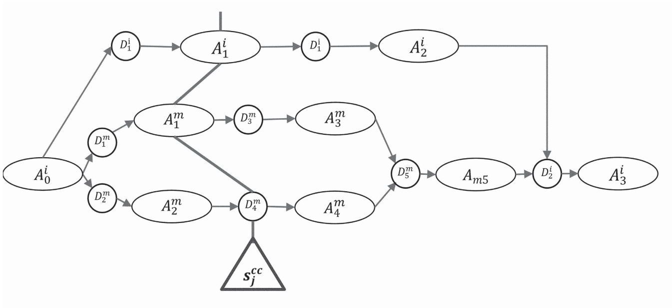

Fig. 8. The example of cutting

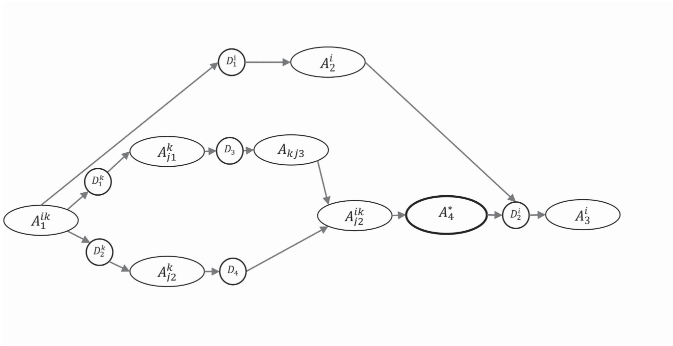

Fig. 9. The example of converse operations network

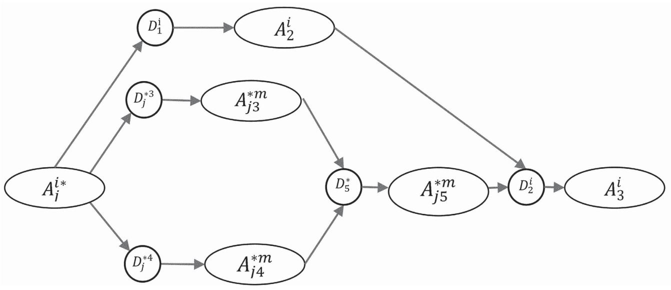

Fig. 10. The example of network of technological operations after converse

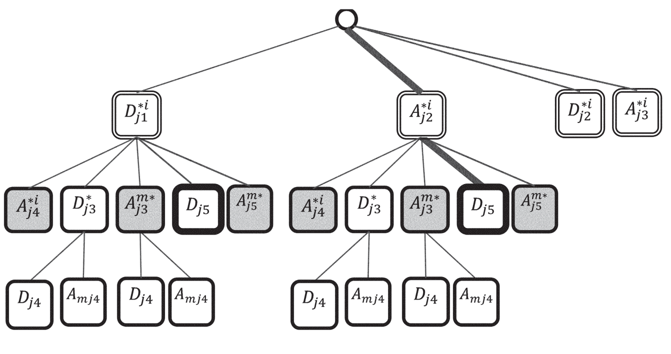

Fig. 11. Tree of technological operation network cuts for after converse operations

The fulfillment of the new target technological operations network, according the required states $\mathbf{S}_{23}$ interrupted again at T_2. Let us consider the example corresponding to the implementation of the CTS state $s_h^s(s_u^s)$ from the set of possible states $\mathbf{S}_h^s(s_u^s)$. Such states obtained again, by the same routine to built the appropriate tree of possible technological operations and the waits at the CTS functioning after the interruption in the specified conditions of CTS environment $\mathbf{S}q$ and after the technological information operation with characteristics defined by the IT I_a used specified. The set of possible states is determined by this operation results. That is prescriptions (plans, orders) assigned for execution when A_4^i finished which depends on state of CTS during the technological information operation performing. So the states of CTS during the alternated functioning depends on the previous states of the CTS, as well as on the states of the environment. The appropriate tree of possible branches of simultaneous technological operations performing after the first interruption is shown at Figure 11. The example case of the second interruption at T_2 considered (shown in bold) corresponds to the implementation (at the moment T_2 when the system and the environment states are checked for compliance) of following technological operations: waiting D_{j5} for the start of the assembly A_{j5}^m technological operation (the last technological non-information operation in the calendar plan). It is assumed that in this case, the conversion technological operations are not needed, i.e. set of the conversion technological operations is empty. That is because the technological operation on the fifth workplace w_5 not started yet, and the remaining places have already been restored to their original state. Therefore $w_1 - w_4$ are supposed no longer needed to achieve the new goal G_2. In this case, the information operation A_{hk1}^i for the purpose of conversion should immediately return an empty set after its start, next it shall call the information operation A_{h2}^i which prepares the beginning of the target technological operations. The A_{h2}^i information operation should end immediately (since the state did not change) and the ${A_h}^m{}_5$ (new, according G_2 goal) product assembly technological operation should start (probably, with wait D_{h5}) on the fifth workplace w_5. It is assumed that this technological operation is no longer interrupted. After it is completed the final information technological operation $A^i{}_{h4}$ starts without waiting. The appropriate (final) network of the technological operations is shown at Fig. 12.

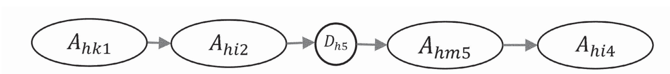

Fig. 12. Last part of the operation network after the second interruption and the second converse operations

As a result of the series of conditional states and their changes due to information and non-information technological operations effects i.e. the random moments $\hat{T}_u$ of states s_u realization, costs $\hat{C}_u$) spent to realize the states s_u and numbers $\hat{\mathbf{R}}_u$ of the parts produced can be computed. Next, $\hat{T}, \hat{C}$ the random variables and the random vector $\hat{\mathbf{R}}$ of the produced items can be computed for each CTS functioning, represented by M_{qu}. Such computation is made base on the given suggestion $\hat{T}, \hat{C}$ are distributed according the Beta distribution and $\hat{\mathbf{R}}$ distributed according the Binomial distribution. It is further assumed that for the large networks the resulting effects distribution form the Gauss distribution for $\hat{T}, \hat{C}$ and the Binomial distribution for $\hat{\mathbf{R}}$.

V. The system potential, information technology and dynamic capabilities indicators research problems examples

The graph-theoretic models presented are used to create the parametric and than functional model of the CTS functioning in the changing environments. That is done through computation of the states s_u which are computed as the sets of effects characteristics based on parameters of the information and non-information actions. The parametric and than functional models composed based on states s_u. Vectors S^s_{qa} of such states obtained for the each vector S^e_q of the environment states and each vector S^s_a of the CTS information technologies capabilities to react on the environment changes. Generally, S^e_q shall include random characteristics of the environment impacts on the CTS elements (such as failures of the CTS elements) and S^s_a shall include not only IC but other capabilities as well, including capabilities to react on the environment changes (DC). As a result of the environment modeling the complex tree T^e_q of the environment states and the transition sequences created. It parametrized with the required states and possibilities and functions, which compute the dependencies between the states on the tree. Models of the possible sequences of the CTS states will be created in the form of the trees of states and the transitions between them for each possible sequence of the environment states from T^e_q. The transitions fulfilled as routines chains, according existing capabilities $a \in A$. As a result, the graph-theoretic model in the form of the complex tree T^s_{aq} built, where a reflects the alternative set of capabilities used to form alternative sequences of the states and transitions in T^s_{aq}. The functional model created based on adding the functional dependencies between characteristics of the CTS states during the states transitions. As a result, based on T^e_q the functional model M^e_q formed where functions used to represent the transitions between the states, i.e. they describe how states characteristics depends on other characteristics in the transitions. Similar way the trees T^s_{aq} form functional models M^s_{qa} in the form of trees with functions between the states. Next, the program model shall be built where the functions represented with the programming code. Thus, the pairs of models, M^e_q, M^s_{qa} obtained. Next, based on this pairs of models the model M^{se}_{qa} of the CTS states and the states of its environment correspondence created. It depends on the CTS environment functioning according S^e_q IC I_a used and DC used. Let us designate DC used as D_c. The number of the model pairs corresponds to QA. They can be formed as the trees composition $\otimes$ in such a way the each branch of one tree combined with all branches of the second one: $T^{se}_{qa} := T^e_q \otimes^q_1 T^s_{aq}$. As a result the complex model M^{se}_{qa} built. It can be transformed into program model by adding program code to tree. At Figures 13, 14 the examples of such addition shown. The Html code which represents the tree shown at figure 13 and the JavaScript, used for the computation inside the Html code, shown at Figure 14. As a result, the values p_{qaju}, w_{qaju} evaluated inside the Html and may be used to compute the CTS potential. To solve practical problems as mathematical (for example, mathematical programming ones) the alternative representation of the modelling results may be used in the form of multidimensional array (1) p_{qaju}, w_{qaju}, where values are evaluated through the functional models formed from the trees specified.

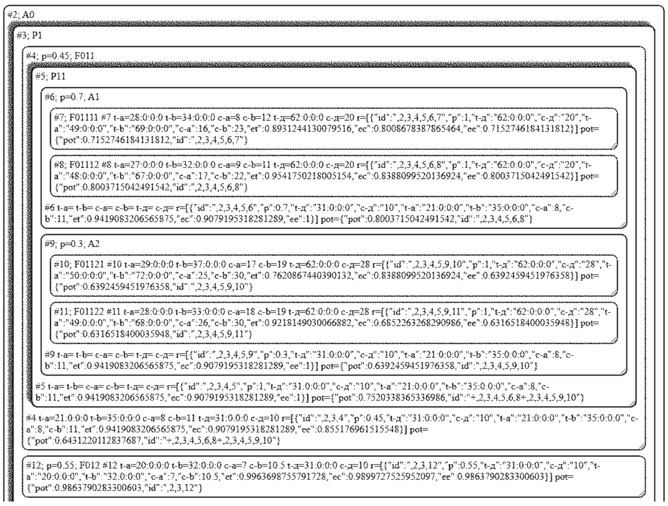

Fig. 13. The HTML page which represents the model in the form of complex tree

```
function cdf(x, mean, variance) {

                        // Cumulative density function
                        // From Numerical Recipes in C 2e p221
                        var x0 = -(x - mean) / (Math.sqrt(2 *
variance));
                        var z = Math.abs(x0);
                    var t = 1 / (1 + z / 2);
                    var r = 0.5 * t * Math.exp(-z * z -
1.26551223 + t * (1.00002368 +
        t * (0.37409196 + t * (0.09678418 + t * (-0.18628806 +
        t * (0.27886807 + t * (-1.13520398 + t * (1.48851587 +
        t * (-0.82215223 + t * 0.17087277)))))))));
                    return x0 >= 0 ? r : 1 - r;

}
function probF(xa, xb, xM, xD, xPr) {
if(xPr <= xa) {
return 0;
}
if(xPr >= xb) {
return 1;
}
return (cdf(xPr, xM, xD)-cdf(xa, xM, xD))/(cdf(xb, xM, xD)-cdf
(xa, xM, xD));
}
function t2s(t) {

                        var s = 0;
                        var r = t || "0:0:0:0";
                        r = r.split(":");
                        for (var j = 3 - r.length; j >= 0; j--)
r.unshift("0");
                        s = ((parseInt(r[0])*24 + parseInt(r[1]))
*60 + parseInt(r[2]))*60 + parseInt(r[3]);
                        return s;

}
```

Fig. 14. Functions inside the model in the form of complex HTML tree

The Values of p_q determined by the CTS environment model. It is worth to notice the environment model may vary for IC, DC used and type of the environments parts (for example, combat environments, information attacks environments, supportive environments) but that is not modelled in this example. In case IC and DC problems considered, p_{qacju}, w_{qacju} formed. These models in the form of the multidimensional arrays can serve as a comprehensive indicators of the CTS potential regarding IT I_a or DC D_c used. This array can be represented as the multidimensional discrete random vector distribution. Such vector elements are the probabilities w_{qacju}

of random effects compliance to the changing requirements of the CTS environment. As well, this discrete random vector distribution may solve as the comprehensive indicator of capabilities, organizational capabilities and dynamic capabilities of the CTS. But, in order to solve practical problems of the CTS potential research based on mathematical models (for example, mathematical programming or operations research ones) the scalar indicator preferable.

	A	B	C	D	E	F	G
2		N0 Network Operations Data					
3		A01				A02	
4		t_a01	t_b01	c_a01	c_b01	t_a02	t_b02
5		5	9	3	5	5	
6		Network calcultaion by the time of TIO 1				8	And cost demands
7		Ended 01	Lasts 01	Price		Ended 02	Lasts 02
8	Mode	6,6		3,8		6,6	
9	Dispersion	0,64		0,16		0,64	
10	F1	0,985646978				0,985646978	
11	Right border	0,999911583				0,999911583	
12	Left Border	0,006209665				0,006209665	
13	Cutted	0,985644987	0,014355013			0,991894009	0,00810599
14							
15	Measure of corresp	0,92523829					
16	Prob P_0	0,55					
17	potential part P-0	0,50888106			Tree Branches 1-4		
18				Lasts 1 and 2	Lasts 2 1 ended	Lasts 1 2 ended	Both 1 2 ended
19	Probability P-1	0,45		0,000116362	0,00798963	0,014238652	0,97765535

Fig. 15. Excel®spreadsheet with the computation results

It is possible to use any or few characteristics of such multidimensional discrete random vector or some kind of probabilistic mix as the scalar CTS potential indicator $\psi_1(I_a)$ as the function of IC I_a or DC D_c used. For example:

$$\psi_1(I_a) = \sum_{q=1}^{Q}(\prod_{j=1}^{J}\sum_{u=1}^{U}(w_{qaju}(I_a, \mathbf{S}_q)p_{qaju}(I_a, \mathbf{S}_q)))p_q; \quad (4)$$

$$\psi_1(D_c) = \sum_{q=1}^{Q}(\prod_{j=1}^{J}\sum_{u=1}^{U}(w_{qcju}(D_c, \mathbf{S}_q)p_{qcju}(D_c, \mathbf{S}_q)))p_q; \quad (5)$$

where w_{qaju}, p_{qaju} at (4) are taken from $\mathbf{W}_{[Q,A,J,U]}$ at (1) and $w_{qcju}, p_{qcju}, c \in \overline{1,C}$ are taken from appropriate $\mathbf{W}_{[Q,C,J,U]}$. Alternatively, the CTS potential indicators $\psi_2(I_a), \psi_2(D_c)$ with regard of IC and DC use can be evaluated as guaranteed values (based on pessimism criteria) :

$$\psi_2(I_a) = \sum_{q=1}^{Q}(\prod_{j=1}^{J}\min_{\forall u \in \overline{1,U}}(w_{qaju}(I_a, \mathbf{S}_q))p_q; \quad (6)$$

$$\psi_2(D_c) = \sum_{q=1}^{Q}(\prod_{j=1}^{J}\min_{\forall u \in \overline{1,U}}(w_{qcju}(D_c, \mathbf{S}_q))p_q; \quad (7)$$

IC I_a indicator $\Phi(I_a, I_0)$ compared to basic - for example, not digital IT I_0 - can be estimated as difference:

$$\begin{aligned} \Phi_1(I_a, I_0) &:= \psi_1(I_a) - \psi_1(I_0), \\ \text{or, } \Phi_2(I_a, I_0) &:= \psi_2(I_a) - \psi_2(I_0). \end{aligned} \quad (8)$$

DC D_c indicator $\Phi(D_c, D_0)$ compared to basic - for example, not dynamic (zero-level) capability D_0 - can be estimated as difference:

$$\begin{aligned} \Phi_1(D_c, D_0) &:= \psi_1(D_c) - \psi_1(D_0), \\ \text{or, } \Phi_2(D_c, D_0) &:= \psi_2(D_c) - \psi_2(D_0). \end{aligned} \quad (9)$$

Equations 1-9 can be used, similarly, to estimate indicators of the competitive performance, organizational capabilities for the CTS functioning in changing environments. The strategic alignment of IC and DC can be estimated as the difference of aligned DC, IC CTS potential and the CTS potential for not aligned DC, IC. The scalar potential indicator computation by means of Excel®spreadsheet shown at Figure 15. As a result of computations for the given I_a, D_C, $\psi_1 = 0.9631, \psi_2 = 0.0003$. This gives the insight on risks and possible improvements of the IT and DC use.

Let us consider typical practical problem of IC, DC research. Given known historical data **D** about the CTS usage routines in the past (zero-level ones and dynamic) and possible routines of IC **IC** , DC use **DC** in future it is needed to find out which optimal capabilities $C_{dca}^{Opt} = D_d \cup D_c \cup I_a$ where $D_d \in \mathbf{D}, I_a \in \mathbf{IC}, D_c \in \mathbf{DC}$ shall be used and what is the best plan $\pi^{Opt}(C_{dca}) \in \Pi_{dca}$ to use in order to align their usage in the changing environment.

$$\begin{aligned} &\textbf{Given:} C_{dca} \in \mathbf{C}; \mathbf{C} = D \cup IC \cup DC, \Pi_{dca} \in \mathbf{P}; \\ &\textbf{Find:} C_{dca}^{Opt}, pi^{Opt}(C_{dca}^{Opt}): \\ &C_{dca}^{Opt} \in \underset{C_{dca} \in \mathbf{C}}{ArgMax} \Phi(D_c, I_a, D_0, I_a, \pi_0); \\ &\pi^{Opt}(C_{dca}^{opt}) \in \underset{\pi_{jdca} \in \Pi_{dca}}{ArgMax} \Phi(\pi_{jdca}, C_{dca}^{Opt}); \\ &\textbf{Where: } \Phi \in \{\Phi_1, \Phi_2\} \text{ and } \pi_0 \text{ is base plan.} \end{aligned} \quad (10)$$

The problem statement (10) can be used to formulate a number of mathematical problems statements for DC, IC research and related mathematical problems statements - for example, to research DC and IC alignment.

VI. CONCLUSION

The results obtained enable the evaluation of the predicted values of a system's potential depending on IT capabilities and dynamic capabilities used for the system's functioning changes. Such capabilities are required and used because of the need for the system to react to changing conditions of the environment. Corresponding IT capability indicators and dynamic capability indicators can be estimated based on a system's potential indicators. The analytical estimation of such indicators becomes possible depending on the variables and options in the mathematical problems to be solved. This could lead to a solution to contemporary problems in research using predictive analytical mathematical models and mathematical methods. Examples of such research problems are problems related to IT capabilities and dynamic capabilities [2][1]. Possible aspects include choosing the best information routines, choosing IT and information operation characteristics for the optimal implementation of new IT, choosing the best digitalization [27][18][20][26][28][17] scenarios, strategic planning, and modernization and innovation planning. Similarly, the suggested indicators can be used to estimate the indicators of organizational capabilities, dynamic capabilities, and IT alignment [3][22][14]. As a consequence, it makes it possible to overcome the existing gap between the need to solve problems in research on a system's potential, dynamic capabilities, and information technology use capabilities based on mathematical models and methods and the lack of the necessary concepts and methodology for solving such problems as mathematical ones. Further research should allow the estimation of indicators of IT capabilities, organizational capabilities, and dynamic capabilities for CTS functioning in changing environments regarding different types of environments—for example, combat environments, information attack environments, and supportive and collaborative environments.

Acknowledgment

The reported study was funded by RFBR, project number 20-08-00649 and 19-08-00989

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