Digitalization Effects and Indicators Estimation

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***Abstract*—The article provides models to describe formation and to estimate effects of digitalization. Models provided on the example of digital technologies use in technological systems. As a result, it is possible to estimate effects and indicators of digitalization predictively with use of analytical mathematical models. Models constructed with use of conceptual models, based on graph theory, probability theory and technical systems efficiency theory. These models allows descriptions of changes in material operations due to information operations use. Information operations required to perform a reaction to environment change and to provide better effects of material operations in changing environments. It is possible to use constructed models to estimate the digitalization effects, its performance, efficiency, and effectiveness indicators. As well, it is possible to use such models for the estimation of dynamic capability indicators and indicators of system potential of technological systems, which modernized with use of digital technologies. The estimation and analysis of digitalization operational properties indicators mentioned above obtained by plotting the dependences of information technology use operational properties indicators predicted values due to the digitalization against the variables of the digitalization problems needed to solve.**

I. INTRODUCTION

The research of the use of information technologies traditionally implemented based on performance, efficiency, effectiveness, dynamic capability, system potential indicators with regard of IT use [1-6]. Such properties suggested designating as operational properties. Under operational properties of the objects under study extensive class of properties of various objects understood, such that these properties characterize the results of the activity with these objects [7,8]. Therefore, the operational properties form the basis of the quality of objects under research. These properties manifested at the boundary of the object in which the activity implemented and of the environment. Operational (or, alternatively, pragmatic, praxeological) properties are estimated with use of effects (i.e. main results) of activity at the boundary. Effects used to estimate measure of these effects compliance with the requirements of the environment. Requirements of the environments specified according changing goals perceived in a changing environment. Activity in changing environment implemented by humans or actuators (devices under humans' control) with use of certain information operations. At least such information operations conducted using humans (senses, speech). Modern information operations conducted using digital technologies. Information operations considered as special elements of activity whose objectives are to obtain information about system and environment states and to generate information about future functioning, but not to exchange matter and energy. Information operations implemented in accordance with certain information technology – traditional or digital. Information technology objective is to describe the use of information operations in possible circumstances.

The mechanisms of the formation of activity effects and next, the subsequent formation of operational properties regarding the use of information operations, especially operations, performed with modern (digital) information technologies (IT), have not been studied in enough detail. Such study, if conducted in sufficient details, shall make it possible to predict the effects of activity characteristics with mathematical models. Such prediction shall be made in the form of functional dependency from the variable characteristics of the digital information operations use during system functioning. In this case mathematical problems of evaluation, analysis, and synthesis [8,9] of information technologies use. Unfortunately, there are no suitable models and methods available for analytical description of the effects of information operations in sufficient details. Such details shall describe further use of the effects, produced by information operations to change material operations. That is why operational properties of digital information technologies use not yet measured analytically, on predictive mathematical models. This, in turn, caused by the absence of a widely accepted concepts of causes and effects of digital information operations, and next – of digital information operations effects use for material effects change. Particularly, cause and effects relationships not explained for material effects that obtained by material operations, such that these material operations depend on the information operations under study. Material effects of such operations vary depending the implementation of the causal relationships between environment changes, further information, and subsequently material operations fulfilment. These causal dependencies examined in article based on technological system example. Technological system defined as system which functioning described by operations description in system documentation.

According concept suggested, digital information operations cause changes in material (non-information) operations through change of prescriptions to perform operations. This change than leads to material effects change. That is why it is necessary to develop the concept of information and material actions causal dependencies and the concept of effects formation due to such causal dependencies [10]. The development of the concept of such dependencies, as it follows from literature analysis, causes conceptual difficulties. As a result, further difficulties with mathematical modelling of effects formation due to digital IT use arises. Thus, further research directed to the description of the causal dependencies between information and material actions and between information and material effects as a result. Such dependencies description allows then analytical predictive description of digital IT use effects using suggested mathematical models. Developed predictive mathematical models describe formation of information operations usage effects, including material effects changes because of the information operations effects with use of analytical dependencies. Such analytical models were not presented in known literature. Such model's objective is analytical evaluation of digital information operations use performance, efficiency and effectiveness indicators depending on digital operations use characteristics. Such models also used to evaluate other operational properties, especially the system potential and dynamic capability regarding IT use. In this case, system potential and dynamic capability indicators measured considering the necessary use of information operations.

This study aimed to bridge the gap between the need to solve research problems of operational properties indicators estimation regarding IT use based on predictive analytical mathematical models as it stated in [11-14] and the lack of the necessary concepts and methodology for solving such problems as mathematical problems of estimation, analysis, and planning by operational properties indicators [15-22] with regard of digital IT use. It is assumed that systems under study are technological ones so all actions performed are described in documentation. Estimation is limited to the case when possible chains of events in the course of system functioning are known and events in such chains are linked with cause-effect relation.

II. Use of Information Technologies: Basic Concepts, Principles, Assumptions and Modeling Suggestions

The use of IT illustrated on the example of such complex system that operations of this system are technological. It means that operations of such system specified by descriptions of technological operations in the technical documentation. Such system named the complex technological system (hereinafter CTS). According this technological assumption about the system functioning, not any action in the system considered but only technological operations. It further asserted that the states of the beginning of CTS operations, the modes of performed technological operations and the possible resulting states of each operation described in the technical documentation for the CTS. The essence of changes in material operations due to the information operations is that different states of the system and the environment can implement and different requirements can accommodate by environment. These states and requirements can lead to CTS reaction on environment change. This reaction results in the change of course of CTS functioning. For such change information operations required of different kind. That is, environment change can lead to changes in information operations. First, to detect and measure changes. Subsequently, information operations (of decision kind) can cause changes in operations following them. It assumed that the number of changes in operations is finite. Changes described by list and modes of technological operations. CTS reacts on environment changes with use of information operations to fulfill changes of CTS functioning. As a result, CTS becomes like "living" system, which reacts on environment change. Effects of "living" system functioning differ depends on information operations characteristics – i.e. depends on how it is "living". How it is "living" is described by finite number of modes in information and material technological operations chains. Which depends on environment impacts.

Finite number of modes of technological operations specified in the CTS technical documentation. Thus, chains of operations can be modelled depending environment impact. Accordingly, knowing the possible changes in the environment and caused by environment impacts modes of information operations we can build a model of possible CTS states due to chains of environment impacts and further information operations. These chains than lead to different prescriptions to perform material operations and consequently, to different modes of the implementation of these material operations. Next, various modes of such material operations result in changed effects. Finally, these changes cause change in effects compliance to effect requirements of the changing environment. The difference in effects compliance to changing environment demands depending IT used to realize needed "living" and as a result, compliance, may serve as IT use performance indicator. Therefore, (digital) information operations effects are making CTS where they used "living" system. That means information operations allows carrying out material actions in the changing environment with modes of operations that are differ from those which planned before environment change and its impact on CTS. These modes can better adapt to changing environment conditions and may provide better results. Because of number of possible environment states is limited, as well as number of operation modes, it is further asserted that the possible number of chains of information and caused by them material operations is finite as well. As a result, we can model these chains with use of finite discrete algebraic models. For example, graph theoretic model. Before building such graph theoretic model of information operations use, therefore – of IT use describing these operations, it is necessary to perform conceptual modelling of possible finite sequences of environment states and then – caused by them information and material operations. In sequences of such operations and caused by them states there can be alternative relationships and states [23-29] caused by various kinds of alternatives (alternatives of environment changes, alternative decisions). It is further assumed that such alternatives are known, their number is finite and that a measure for the possibility of such alternatives to be realized (if applicable) known. As a result, to model possible sequences of relations between states, their alternatives, information and non-information actions and their subsequent formalization, labelled finite trees used.

III. Formalizing INFORMATION TECHNOLOGIES use

The method of formalization consists of assigning the main concepts and relations between them to graph theoretical objects. To implement such formalization, the graph-theoretic model of the main concepts of the problem is used. Such model was constructed with use of knowledge representation software. It is proposed to use constructed model to instantiate graph theoretic objects – i.e. vertices and arcs. Conceptual model serves as meta-model f graph theoretic objects. Conceptual model than makes it possible to correctly instantiate the parametric models by parameterization of the graph-theoretic model according conceptual model elements mapping with database records. Then functional models can be constructed by specifying and explicating the functional dependencies between the explicated parameters and variables. As a result, labelled graph theoretic model built, which imitate possible chains of states and operations in environment and system while traversing the graph theoretic model performed and computation of functional dependencies realized wile traversing graph theoretic model. As a result, effects characteristics computed on graph theoretic model. Using these characteristics of effects problems of evaluation, analysis, and synthesis by operational properties, mainly system potential indicators, would be solved. Provided formalization of the dynamic capability or system potential research problems can be represented as construction of graphs and their labels based on conceptual model.

First, conceptual models built. They created in such a way multiple instances of conceptual models elements – for example, states and transitions, can be created (instantiated). Instantiation done in such a way states of CTS in their chains at model instantiated imitate states changes in real system in a given circumstances. Next, algebraic graphs are constructed based on instantiated models. Then the graphs are labeled by variables and parameters, according rules defined by conceptual model. Next graph theoretical models are built in which functional dependencies are assigned to its elements. Finally, functional dependency labels explicated using programming language constructions. As a result, graph-theoretic model created allows imitating real functioning in real circumstances and given IT used with sequences of computations performed according functional dependencies specified on graph. This property of the models enables imitation by analytical computations because of possible sequences of states and computations performed by computer are linearized in the sequences which imitate chain of causal relationships of states and operations (transitions) during real functioning. Such graph-theoretic models shall be connected graphs without loops. So such model can be traversed to calculate all the required expressions based on functions specified as the labels for graphs transitions. The calculations can be performed by traversing the graph in depth (width) with the calculation of the functional relations during traverse. Based on labelled graph-theoretic models suggested it is possible to generate a functional and program language code models which describe a finite sequence of functional expressions for the calculation of the system's potential indicators. Then such indicators can be computed depending on the variables of the mathematical problem of digitalization.

IV. System functioning with IT use Formal model Example

Let us introduce an algebraic structural model of the CTS functioning. It describes the elements and structure of the system workplaces (WP): Let us denote: $e_{jk} - k -$th element on $j -$th WP, according to the technical documentation; $e_{jk} \in E_j$, where $E_j -$ workplace $j = \overline{1,J}$; Realizations of states of WP in appropriate sequences, corresponding (imitating) real functioning fulfilled in accordance with concept model created. At a given moment t, part or all the WP are functioning. If WP functions than technological operation (TlOp) is performed with it. TlOp, implemented on the WP according to one of the possible modes. Mode of operation can be predefined or set by information operation. TlOp can begin only once the specified initial state of the WP is reached. Mode of operation description is part of such state. TlOp can lead to different states as a result of TlOp realization, depending on the environment conditions and mode of operation performed. The set of states of $E_j -$th WP at each moment forms a state of the whole CTS:

$$Q(t) = \bigcup_{j=\overline{1,J}} Q_{E_j}(t). \tag{1}$$

System states $Q(t)$ at the moment t as in (1) are checked at the boundary of the system for compliance with its environment demands. A mathematical model of states at the CTS boundary is built as an algebraic model of CTS states sequences on the CTS boundary and transitions between such states. It is assumed that the number of such states on the boundary is finite. These states on the boundary shall comply to states demanded by environment so these states are checked for compliance. The algebraic model can be represented as a tree. Then, from the constructed algebraic model, a functional model of CTS states and its environment states as well as their compliance is generated. This model unites the model of states at the boundary of the CTS and the model of the environment states. It is the model that allows calculating CTS potential indicators based on already constructed models.

It is further assumed that the number of states at the boundary of the CTS as well as states demanded by its environment is finite. Thus, transitions between states number is finite too. Information operations are needed to check states at the boundary. The results of these information operations are a compliance measure of the CTS and the environment states. The model of such information operations on the border sequence can be used to determine the CTS potential indicators.

Few classes of relations are used to represent CTS states change. Such relations between CTS states are modeled as arcs, hyper arcs, and nested graphs at the tree of states – depends on semantic of relations. Transitions are a special class of relations that are associated with the mode of operations in this tree. Other classes are joint realizations relation class of states and relations class of transitions between states. The first class describes possible implementation of TlOp on several WP at the same time. The second class of relations describes the completion of TlOp by one of modes and transition to one of the alternative states of TlOp termination due to one of possible environment impact. Some classes of relations, namely transitions, require input (initial) and output (final) states of different kind (information, non-information). Sequences of states and transitions checked on the CTS boundary for compliance with environment states. This is done with verification operations. Verification operation is information operation and it is part of a branch of the tree. It is assumed that the number of such sequences, that is – number of tree branches is finite. Let us denote this number as L. So, the number of elements of the set of all possible sequences of CTS states is L:

$$C^{CTC}: \ |C^{CTC}| = L.$$

The sequence of states is such that for different initial states before testing and states on the boundary different modes of implementing verification information operations (TIO) corresponds. TIO mode defined by the state before TIO start, according IT used, and the plan of operations. If the state before TIO starts, the information technology, and the plan of operations are known, then the mode of TIO is known too. The mode to execute the TIO for verification states on the border of the environment may depend on the environment state changes. Modes of environment operations, which lead to certain environment states, are not known for sure, but the state sequences, resulting from these operations, transitions between environment states as well as the measure of the possibility of implemented transitions are known. As a result of sequences of environment states transitions and as a result of caused by each sequence modes of implementation of the CTS operations, we can get a sequence of pairs of states on the boundary due to operations of environment and the system – i.e. the “living realization”. In each of such pairs one state is the state of environment, another one is the state of CTS. The compliance of such states can be measured as probabilistic measure of compliance. Possibility of actualization of each pair can be obtained as well. Exactly, in the sequences of states described each pair of states on the boundary corresponds to different branches of the tree of environment states and different branch of the tree of CTS states. Branches actualization possibilities can be computed and used to estimate possibility (probability) of appropriate pair of states actualization.

It is assumed that the actions and states of the environment do not depend on the CTS operations. As well, it is assumed that the CTS states depend on the sequence of environment states. As a result, the specified sequences of the environment states can be considered without environment states interrelations with CTS states. Thus the sequences of environment states can be modelled as a tree of possible sequences of environment states. Such tree is constructed before a tree of CTS states. In the tree constructed, edges correspond to the transitions of environment states. Those transitions happen due to actions in the environment. The states considered are the states of the environment on the border of the environment with the CTS. Let us denote the number of such sequences of the states of the environment as M. Next, let us denote set of possible sequences of environment states as a result of some modes of environment actions as C^{Cp}. Thus, $|C^{Cp}| = M$ and the elements $c_m^{Cp} \in C^{Cp}$ are modelled with the branches of the tree of environment states $m = \overline{1,M}$. Let us construct functional model of the environment. For this, sequences $c_m^{Cp} \in C^{Cp}$, associated with the branches parameterized with branches elements characteristics. Thus, parameterization performed for states, then for state transitions. Next, parameterization of sequences of states performed. The parameterization includes assignment of probabilities of states as well as transition actualizations probabilities. Further, functional dependencies are assigned to transitions. Such dependencies associated with transitions and formalize dependencies of the parameters, the measures of the probability of the states and the dependent variables of the states. A mathematical model of the environment allows further constructing a mathematical model of CTS for given environment changes and next, models of environment states compliance. Such compliance is measured on the boundary of environment and CTS by relating corresponding states with use of the appropriate TIO of states verification. Compliance relations are determined between the nodes of the CTS states tree and the nodes of the environment states tree. The state of the CTS during its functioning depends on the states of the environment and such a dependency in the study of the potential cannot be neglected. That is why modes of implementation of the verification TIO on the boundary of the CTS are associated with one and only one branch of the tree of possible states of the environment. The model of the CTS and its compliance with environment states demands can be constructed as a result. It allows computing the CTS dynamic capability and potential indicators.

Branches of the CTS state tree are constructed under the assumption that the branch $c_m^{Cp} \in C^{Cp}$ of the environment tree is given, that is $|C^{CTC}(c_m^{Cp})| = L_m$. Let us assume that the branch $l \in \overline{1,L}$ is built for $c_m^{Cp} \in C^{Cp}$, i.e. $l_m \in \overline{1,L_m}$. This means that a relationship is defined between $c_m^{Cp} \in C^{Cp}$ and the corresponding it $C^{CTC}(c_m^{Cp})$. Thus a new tree can be constructed that includes a branch $c_m^{Cp} \in C^{Cp}$ before the root of the $C^{CTC}(c_m^{Cp})$ tree. The resulting model is model which describes set of all branches. It is used to create the functional model of CTS and then the model needed to calculate the CTS potential indicators. It is assumed that the number of states in the state tree branch $l \in \overline{1,L}$ can be variable. It can happen because of the number of operations and so – transitions and accordingly, the number of resulting states could vary. It varies, in turn, because of the impact of the environment. As well, even under the same environment impact, the duration of the state transitions and the duration of the sequences of actions on different WP vary as well. So, the number of required state verifications at the system and environment boundaries may vary. Let us designate the number of these states as Q_l for a given branch $l \in \overline{1,L}$ of the given tree. Each state verified on the CTS border $q_l \in \overline{1,Q_l}$ corresponds to the implementation of the verification TIO by the specified mode. So, the state corresponding to this mode is $q_l \in \overline{1,Q_l}$. Any of the state's sequences:

$$\hat{S}_{l.q} =< \hat{y}_{1.l.q} ... \hat{y}_{k.l.q} ... \hat{y}_{K.l.q} > . \quad (2)$$

verified at the boundary of the CTS and its environment is fully described by the effects of functioning. Effects as in (2) are counted for the time the state check starts. $\wedge -$ symbol of randomness [31]. Each state is compared with the environment state, which specifies the requirements values as in (3):

$$S^{\partial}_{l.q} =< y^{\partial}_{1.l.q} ... y^{\partial}_{k.l.q} ... y^{\partial}_{K.l.q} > . \quad (3)$$

Next, a probability or possibility measure $P_{l.q}$ of the state's $\hat{S}_{l.q}$ compliance with the requirements $S^{\partial}_{l.q}$ of the environment represented as in (3) can be defined as:

$$P_{l.q} = P(\hat{A}_{l.q}) = P(< \hat{y}_{1.l.q} r_l y^{\partial}_{1.l.q} ... \\ ... \hat{y}_{k.l.q} r_k y^{\partial}_{k.l.q} ... \hat{y}_{K.l.q} r_K y^{\partial}_{K.l.q} >) , \quad (4)$$

r_k in (4) is the required relationships between the predicted values of the effect's characteristics and their required values (e.g. <,>) according demands of the environment. The probability or possibility measure of compliance as in (4) is calculated using a functional model of states compliance on the boundary of the CTS and the environment and then, random effects compliance to effects demands.

$P(\hat{A}_{l.q}) -$ the probability or possibility of an event $\hat{A}_{l.q}$. This even is: when verification of the state $\hat{S}_{l.q}$ done for one of the possible branches of the tree, performing a single verification TIO by the defined mode the required by the environment characteristics of the effects will be achieved by CTS. This event means that the result of the verification TIO is the required intermediate goal of the CTS functioning achieved. The measure of compliance for the implementation of the entire sequence of branch verification TIO $c^{Cp}_m \in C^{Cp}$ can be than constructed. It is associated with whole branch of $C^{CTC}(c^{Cp}_m)$ and it can be calculated as the probability of a complex event $\hat{A}_l$. This event is that all the intermediate goals are achieved in the given environment conditions. Each event $\hat{A}_l$ probability is defined as in (5):

$$P(\hat{A}_l) = P(\bigcup_{q \in \overline{1,Q_l}} \hat{A}_{l.q}) . \quad (5)$$

With the assumption that the probabilities of states compliance for each of the verification TIO are conditionally independent in their sequences (6) is true:

$$P(\hat{A}_l) = \prod_{q \in \overline{1,Q_l}} \hat{A}_{l.q} . \quad (6)$$

Let the probability of $\hat{B}_{q,p}$, consisting of the event that transition $a_{q,p}$ will be executed defined as in (7):

$$\hat{B}_{q,p} = (\hat{S}_{l.q}, \hat{S}_{l.\mathrm{p}}) : \exists a_{q,p} : q, p \in \overline{1,Q_l} , \quad (7)$$

be equal to $P_{q,p} = P(\hat{B}_{q,p}) \sim a_{q,p}$. That means that the probability $P(\hat{B}_{q,p})$ is associated with the transitions $a_{q,p}$ as in (7). Then the probability of a branch implementation $v_l : l \in \overline{1,L}$ of the tree $C^{CTC}(c^{Cp}_m)$ is defined as in (8):

$$P_l = P(\bigcap_{a_{q,p} \in v_l} \hat{B}_{q,p}) . \quad (8)$$

In the case that these events of transition executions are conditionally independent too (9) will be true:

$$P_l = \prod_{a_{q,p} \in v_l} P(\hat{B}_{q,p}) . \quad (9)$$

So now, as a scalar indicator of the CTS potential ψ or dynamic capability indicator under condition of given IT use, we can take the expected probability or possibility that the following event will happen: whatever branch $c^{Cp}_m \in C^{Cp}$ and corresponding branches of $C^{CTC}(c^{Cp}_m)$ are implemented, there will be compliance between the expected (CTS) and required (by environment) states. This means that whatever changes in the environment happens, required information and then, material operations will conduct in such a way that the changing goals of the CTS (due to environment changes) will be achieved – i.e., effects will comply to demands and (10) is probability of such event:

$$\bar{\psi} = P(\hat{C}) \approx \sum_{l \in \overline{1,L}} (P_l \cdot P(\hat{A}_l)) . \quad (10)$$

The probability $P(\hat{C})$ of the event specified by (10) can be represented as a random variable $\hat{\psi}$, not its expected value $\bar{\psi}$. $\hat{\psi}$ discrete distribution $f_{\hat{\psi}}(l)$ could be described by the vector of pairs as in (11):

$$f_{\hat{\psi}}(l) = (P_l, P(\hat{A}_l)) . \quad (11)$$

This vector of pairs can be used as the CTS potential indicator in vector form as in (12):

$$\Psi =< f_{\hat{\psi}}(l), l = \overline{1,L} > . \quad (12)$$

Presented indicators (10), (12) describe the different characteristics of the CTS potential or dynamic capability, given that the functioning of the CTS is terminated. But system potential indicators can be constructed for any moment during functioning as well. Various CTS potential indicators can be used, for example, in case of optimism or pessimism criteria use. Such indicators make sense of the various characteristics of the probabilistic measure of compliance of the predicted effects characteristics (CTS) with the requirements, caused by environment in different circumstances. With this compliance measured at the boundary of the CTS and its environment at different moments the appropriate changes in the CTS that are caused by the environment changes can be measured. The mathematical model of such compliance on the boundary is the basis of further construction of the mathematical model of the CTS potential and dynamic capability estimation and then – analysis and synthesis by system potential indicators. To obtain a mathematical model of the system potential estimation based on the specified model, it is necessary to construct models that reveal the values: (2) and (3) with parametric and then functional graph-theoretic models use. Such model building can be interpreted as a special kind of recursive graph extension. Under such extension of graph-theoretic models it is understood a construction operation of models, such that as a result of these operations required graph constructed. In such required graph the element of the model, which is associated with parameter or variable, is calculated based on the traverse of the graph model. With the use of the proposed graph-theoretic models in the form of hierarchical trees the properties associated with the elements of the trees are described by replacing the node of the original tree with a composite tree. Functional dependencies on the trees must be specified in such a way that by traversing models specified and by computations of functional dependencies during traverse it will be possible to calculate the values of indicators. Then, for example, indicators of digitalization success can be estimated as the measure of distance between system potential indicators values before and after the digitalization conducted.

V. AUTOMATION APPLICATIONS TO ESTIMATE OPERATIONAL PROPERTIES INDICATORS WITH REGARD OF IT USE

Creation of multiple nested graph theoretic models, their multiple alternatives for each possible chain of environment states, possible chains of environment impacts on CTS can be quite tedious task. To automate creation of such multiple graph theoretic models and their further extension, parameterization, adding functional dependences and finally, expressing dependencies with program language texts few automation application was created. Among them application based on known ARIS toolset extension and application based on using internet technologies (Browser, HTML/Java) and meta-programming techniques. ARIS toolset extension (Fig.1.) based on hierarchical extension of ARIS diagramming technologies.

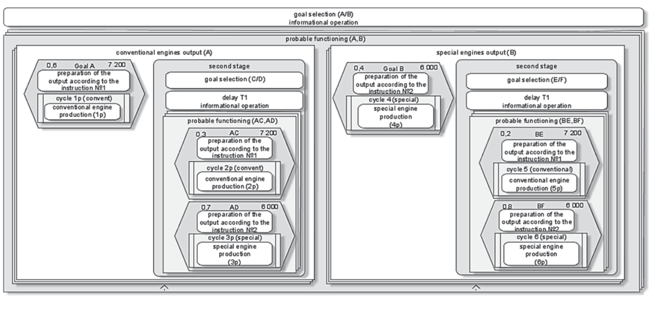

Fig. 1. ARIS extension for operational properties estimation automation

The difference with traditional ARIS models is that, nested parameters and functions used to represent model. Diagrammatical models are transformed into parametric graph theoretic models through adding parameters and variables to ARIS diagrammatic models. Database of parameters used for this purpose. In the example considered, diagrammatic models were created with ARIS toolset modernized so as to use nested diagrams and additional language elements to reflect functional details of outcome trees of states and transitions. Next, parameterized models are transformed into functional diagrammatic models through adding formulas to ARIS models elements. Then, nested diagrammatic models are transformed into program or for example, into Microsoft Excel spreadsheet. As a result operational properties indicators estimated. Internet based extension use HTML to store data about graphs (Fig. 2.) and Java (Fig. 3.) to systematically add details about parameters, functions and computations. Graph structure and data entered represented by HTML page (Fig. 2). Graph theoretic models in form of HTML tree text are transformed into parametric graph theoretic models through adding parameters and variables to HTML with use of Java meta models. Java code (Fig. 3) represents transitions between states of graph-theoretic model.

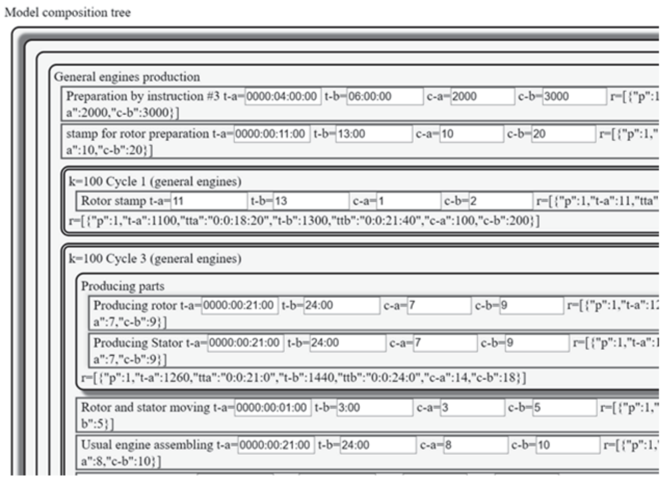

Fig. 2. Browser based extension to automate estimation of operational properties: graph model structure and parameters

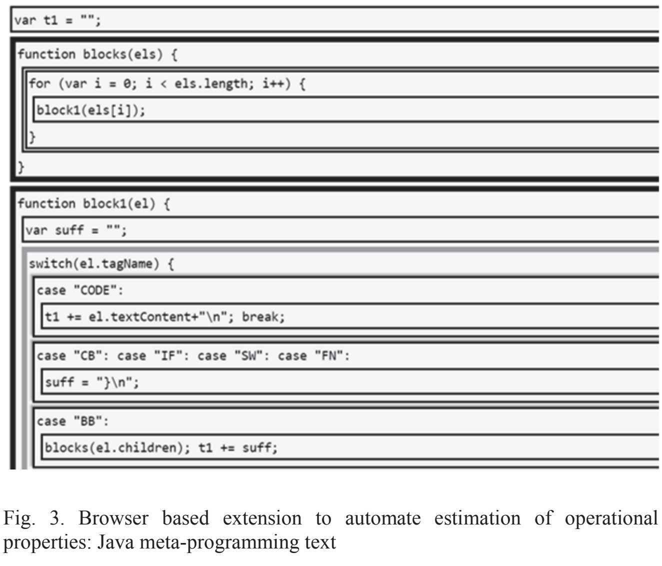

Fig. 3. Browser based extension to automate estimation of operational properties: Java meta-programming text

Parameterized models are transformed into functional diagrammatic models through adding Java formulas to HTML tree model which model nested graphs. Then, HTML interpreted by any browser which supports Java. Operational properties indicators estimated by Java computation based on parameters entered (Fig. 2). As a result, model can run in any device which supports browser and Java. As well, distributed processing of models is possible.

Based on observations of processes results in practice models elements parameters (i.e. probabilities of transitions) can be updated (i.e. model may learn) to make model as precise as possible based on data observed in real situation.

VII. Conclusion

The results obtained enable the evaluation of the predicted values of the system potential and dynamic capabilities indicators depends on characteristics of IT used to change course of system functioning due to environment changes. As a result, digitalization success indicators can be estimated as margin between indicators value before and after digitalization. Analytical estimation of such indicators becomes possible depending on the variables and options in the mathematical problems of digitalization. This could allow a solution to contemporary problems of digitalization research using predictive analytical mathematical models and corresponding mathematical methods (for example, mathematical programming and operations research methods). Examples of such research problems are problems related to digitalization performance, efficiency and effectiveness. Possible applications include choosing the best digital technologies characteristics, choosing IT and information operations characteristics for the optimal implementation of digital IT, choosing best digitalization plans and technologies. It makes it possible, as a result, to overcome the existing gap between the need to solve research problems in digitalization results based on mathematical models and methods and the lack of the necessary concepts and methodology for solving such problems mathematically.

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