Digital Twins of Activities: Role of Information Actions

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***Abstract*—The article considers concepts and models for digital twins of activities and methods available to use such digital twins. Emphasis is made on modelling of information actions as a part of activity and information use in the activity. Authors show that there is a multidisciplinary gap between the need to model application of information for further activity in systems (when creating digital twin of activity) and available theoretical means for the modelling of application of information while performing activity. Models suggested can be used to create models for digital twin of activity, which represents an information application for activity. As a result, the digital twin of activity, represented by such models, can be used to synthesize activity characteristics and information actions for systems functioning in various conditions. To build models required, diagrammatic models of information application for activity in systems are suggested. Diagrammatic models suggested can be used for further creation of new formal models of activity and formal models of information technologies applications to fulfill successful activity. Suggested models can be applied to build digital twins of the activity. Such twins allow representing and, then, enhancing activity based on information collected and to enhance information application for activity. This could further allow us to solve problems related to digital transformation planning of various activities, system engineering problems, computer aided design and manufacture problems, information activities synthesis problems.**

I. Introduction

The concept of digital twin (DT) was first introduced by David Gelernter's in his book "Mirror Worlds" [1] in 1993 and later formalized in 2002 by Michael Grieves from the University of Michigan and developed in his works till modern days [2], [3]. For example, in the form of intelligent DT [4].

DT use allows us to solve a variety of problems of system engineering, model-based system engineering, life cycle management, sustainable development in various areas, including aerospace, defense, healthcare. It allows us to use modern concepts of the Internet of Things (IoT), Industry 4.0 and Industrial Internet of Things (IIoT) [5] means more effective and efficient and to use DT as a means for decision-making and experiments, for computer-aided design and computer-aided manufacturing [6].

Machine learning and simulation techniques can be effectively combined with DT use, providing better effects of DT use [7].

However, the digital twin has traditionally had a characteristic of passiveness [4]. The digital twin has been described as a repository of product information. Information is populated in the digital twin and consumed from it. The digital twin could be questioned by its users to use information in order to replace wasted physical resources.

As a result, Grieves recently suggested [4] the Intelligent Digital Twin (IDT). It has these characteristics:

- Active;
- Online;
- Goal seeking;
- Anticipatory.

We suggest the concept of a digital twin of the activity. It can be effectively combined with IDT, because it is active, online, goal oriented, anticipatory.

Moreover, information application [8], [9] explained as a purposeful change of the activity and thus, can be explained by the digital twin of the activity.

It could be used to reflect information actions and to solve problems related to information and information actions application.

Among such problems are activity automation problems, information action synthesis problems.

II. Digital Twin of the Activity

A digital twin is a dynamic virtual model of a system, process or service [6].

It is defined by Defense Acquisition university [10] as an integrated multi-physics, multiscale, probabilistic simulation of an as-built system, enabled by Digital Tread, that uses the best available models, sensor information, and input data to mirror and predict activities/performance over the life of its corresponding physical twin.

As well, it was defined [11] as a physics-based dynamic computer representation of a physical object that exploits distributed information management and virtual-to-augmented reality technologies to monitor the object, and to share and update discrete data dynamically between the virtual and real products.

Following this definition, we will define a digital twin of the activity (DTA) as a dynamic computer representation of a human organized activity that exploits distributed information management and virtual-to-augmented reality technologies to monitor this activity, and to share and update discrete data dynamically between the virtual and real activity. Based on the definitions given, we have formulated the main requirements to DTA:

- DTA model should include dynamical interrelations between the virtual and real activity: activity object, activity subject, activity environments, information processed during activity.
- As it stated in [11] "digital twin has to be associated with an object that actually exists: a digital twin without a physical twin is a model". The same is true for DTA.
- DT exists at a time, so DTA, as DT variant, shall have mechanisms of updating it over time. Such mechanisms can be based on cyclograms, graphs of synchronization, timing diagrams [12].
- When modelling activity for DTA all possible information activities realizations and corresponding activity traces shall be taken into account. It means the model should be the model of the set of possible activity realizations over time, not a single activity model.
- Information action models and models of information action results shall be described by DTA models. Mechanisms to update them over time should be suggested.
- Next, DTA shall have mechanisms to link activity, its environments, possible information application to change action in varying environments, and possible, as a result, outcomes of activity in varying environments with model of the activity.
- DTA with mechanisms mentioned and its model of the activity, effectively, can be considered as DT of the higher level [13], in this sense, DTA should reflect not one (realized), but all possible changes to activity environments, systems, ways to react.
- DTA program code and data used should be synchronized with DTA model and changing activity [14].
- DTA should be adaptable. Its model, information actions and software used should be able to adapt to the possible changes in activity performed [15]. DTA should be able to use the model of possible activities and information obtained to update and adapt reactions, and then – to realize new or updated possible activities according to its updated model. In this regard, possible future activity traces should depend on and adapt to results obtained by the physical twin (in the result of realized activity trace) at each moment of its life circle.

The article provides the concept and models of digital twin of activity (DTA) regarding information technology (IT) application for such activity. Based on this concept and models, methods can be built to solve a variety of urgent practical problems based on DTA regarding IT application.

Among them, foremost, problems caused by the necessity to model interrelations between a system and its environments during activity, so – to model information application during activity. Such problems are sustainable activity planning and digital transformation planning.

Schemes of information application for activity are suggested. Based on such schemes, we suggest building diagrammatic models of information application for activity. Some examples of such models are explained.

Models suggested are based on information application for activity [16].

III. Information Application for Activity in Systems

Information application for activity in systems value measured as system functioning effects correspondence to the changing demands. There are long-standing problems of information value explanation and modelling. They take the forms of IT paradox [17], [18], information value problem, IT performance problems [19], [20], information systems (IS) success [21], IS effectiveness, IS evaluation, IS benefit determination [22], information system functionality performance evaluation [23], digital economy measuring [24]. Current state of research on the IS Success Model discussed at [21]. IS evaluation and benefit determination state of research can be found in [22]. List of most known theories concerning IS success, adoption and utilization of IT and similar areas reviewed in [25]. Among them:

- DeLone & McLean IS success model;
- Technology acceptance model;
- Diffusion of innovation theory;
- Resource based view;
- Unified Theory of acceptance and use of technology (UTAUT);
- Motivational theory;
- Technology, Organization, Environment (TOE);
- Information processing theory;
- Expectation-confirmation Model of IS;
- Bagozzi, Dholakia and Basuroy (BDB) model;
- Theory of Planned Behavior (TPB);
- Gorry and Scott Morton framework of management information system;
- Technology to Performance Chain (TPC) model;
- Nomological net model;
- Expectancy Theory;
- Social exchange theory;
- Theory of effective use;
- Porter's value-chain activities framework;
- Institutional theory;
- Technology adoption model;
- Theory of Reasoned action (TRA);
- Wixom & Watson framework;
- Theory of effective use;
- Limayem et al.'s IS continuance model;
- Strategic orientation of business enterprise (STROBE) framework;
- Burton-Jones and Straub dimensions;
- Clark's model;
- Integrative model of IT value.

Major part of works are based on an evaluation of Information System success, researched by DeLone and McLean

[26]. They proposed 180 traits of Information Systems, which they classified in six main categories:

System quality: measurements of IS itself;

Information quality: measurement of IS output;

Information manipulation: recipients' handling of IS output;

User Satisfaction: recipients' response to handling the IS output;

Individual influence: effects of information on recipients' behavior;

Organizational influence: effects of information on organizational performances.

In this article, the last category has been elaborated. The hypothesis of the research is that the effects of information can be investigated on the base of predictive system-theoretic, cybernetic mathematical models and methods, in contrast to heuristic, structural and expert models discussed in [21], [22], [27]. In [28] IS success value estimation literature reviewed. A clear demand for a value orientation is found. A framework for Value-Oriented knowledge management systems decision support is presented. Majer [29] critiques DeLone/McLean's model. He notes that contribution to overall system success is not modelled as needed. It remains unclear to what extent the individual variables in the categories contribute to the overall success of the application of an information system. Also, it is unclear how individual variables influence or depend on each other.

Further, he notes missing consideration of environment. The model is limited to the most direct influences of the application of an IS and thus neglects environmental variables. The environment has to be measured or at least controlled in order to render results of IS success comparable. Examples are: the organization's strategy, the organizational structure, the tasks which are supported by the IS, the fit between tasks and IS as well as the human aspect, e.g., the quality of services provided by IS or IT personnel or departments or individual characteristics of the users.

Organizational impact. This category almost exclusively comprises financial measures, which are inappropriate to assess the influence of the application of IS as Majer states. Additionally, with the advent of group support systems and the emphasis on work groups, teams and communities, it is suggested to include another construct in between individual and organizational impact: workgroup impact. Majer analyzed Ballantine alternatives to the DeLone/McLean model [30] and stated that even though the model represents a brave attempt to respond to a great part of the critique against the DeLone/McLean model, it still lacks operationalization and raises more new question than it answers.

There were standing attention to operationalize DeLone/McLean model [31] and to model adoption and development of IT [25], [32], but such efforts are based on qualitative or expert estimation. There is a trend among researchers to build models to explain IS success through dynamic business and IT alignment [33], [34] but these attempts use qualitative and expert estimates too.

There is a gap between the need for predictive modelling of IT adoption, IS use at its design / adoption stage and available predictive mathematical models and methods, which can explain IT/IS use during design. Predictive mathematical modelling of dynamic IT adoption, dynamic business and IT alignment, IS success dynamic models (IS/IT application) based on system theory, cybernetics and agile process models of system functioning could greatly improve the ability to build needed mathematical models and to explain IS/IT application.

This article suggests directions and first steps to overcome the existing gap. To model IS/IT application for action in systems, schemas of information application for actions in systems are suggested. The purpose of these schemas is to show how information is applied and transformed into measured effects of actions in systems. Schemas can be built by experts in system functioning and/or by use of process log files recorded. Information applied in systems to change the system functioning if such changes are possible and reasonable. That is why researchers pay attention [33] to dynamic aspects of IS/IT application. Unfortunately, the changes of system functioning are not investigated in details, which are required to build mathematical models for explanation of changes and their results' formation for system success. Mathematical models of such changes are only investigated [8], [33], [35], [36]. The use of "Big Data" and log-files to build such models is at the research stage yet [37], [38]. Causes and effects of such changes are not investigated in the needed depth to build quantitative mathematical models of changes.

Causes considered as information [39], obtained or transmitted because of information actions of various kinds. Among such actions are [40]–[43] measuring, checking, monitoring, testing, identification, research, investigation, intelligence, and predictions. Such actions produce various kinds of information which may cause necessity, reason, or possibility of purposeful change. Such purposeful changes due to information application led to complex system functioning entropy decrease (fewer possibilities after choice made) and simultaneously, the increase of correspondence of such system results functioning to changing demands (due to functioning realized according to better choice, by information available). Changes are realized based on one or a few approaches [44]–[47] to deliver the adaptation and flexibility. Purposeful changes took the form of choosing further possible way of actions and so, choosing appropriate outcomes too (predicted states and events among possible states). Due to choosing such way of actions, the entropy of possible states because of functioning is effectively limited, but it leads to a possible increase in flexibility of functioning because of better correspondence of purposefully changed state characteristics to the changing conditions. Once purposeful changes are chosen among possible ones and fulfilled according to the approaches used, the events and states happening may be recorded in the change logs or in other databases, information vaults which can be further used as a "Big Data" source.

Data mining and process mining methods [38] allows the building of process traces and process models based on processes log-files. Such models can be further used to enhance processes to achieve better effects and better agility. Process enhancements may happen in various forms. It was shown that the major ways to enhance processes are providing their flexibility and adaptability [36], [43].

Such enhancements may be realized as purposeful changes through declarative, imperative, case handling, agent-based, aspect-oriented, variant approaches [46] and other possible approaches to delivering adaptation and flexibility to processes. To describe adaptive and flexible processes, change mining from change logs suggested [38].

General way of IS/IT application for actions in systems can be described as cause – and effect chains started with obtaining information and next, caused by information actions, events, and states in the form: "information action – information obtained – new possibilities discovered – choosing the way for change i.e., by using new opportunities – fulfilling the change chosen – checking the results – possible record in change log". Not all stages of these chains of cause-and-effect relationships between actions, events, and states are described in modern process-aware information systems, and not all actions, states, and events are recorded in modern change logs. However, models of such chains of cause-and-effect relationships are required to solve many urgent practical problems, for example, information technology design, systems digital transformation planning.

As well, such chain description, actions, states, and events recording are required to build models of the described chains based on big data about chain elements and their relations to be collected in the future. For example, to be recorded in a new type of change logs, or "information application actions, events, states logs" which can help to automate the modelling of information application for actions in systems, and to solve the mentioned practical problems based on the models built. However, such models, methods of their creation, use, automation, and software for using models of information application for action in systems have not yet developed as needed. This led to the gap between the need to solve several urgent practical problems using mathematical models and methods, and mathematical models available to decide such problems. To overcome this gap, the author proposes schemas to model chains of cause – and effect relations of actions, states, and events.

Diagrammatic models presented used for further formalization through creation (based on the diagrammatic models suggested), the graph-theoretic models, labeled graph-theoretic, probabilistic graph-theoretic, and functional models. Examples of such models can be found in [48]–[51].

Such models allow the mathematical modeling of information application for actions in systems. Modeling the use of related information technologies for actions in systems becomes possible. Such modeling objective could be the quality of information actions application for actions in systems indicators estimation. Next, such indicators could be used for information actions synthesis. Indicators of the quality of information actions application for action in the system can use previously developed indicators of the system potential [52].

IV. Schemas of IS/IT application for actions in systems

System actions are divided into two main groups. It is effect execution actions and information actions. They differ in their goals: effects, execution actions intended to obtain changes in substance and energy, and information actions designed to obtain information changes.

Effect execution action is an action made by humans, organized by humans, or – under their control to obtain the material results demanded by humans. Such effects manifested due to the exchange of energy and substance according to the human's desire, or/and under human's control, or/and according to the human's plan performed. Such exchange shall be considered in time and space. According to the concept suggested, for such an action to be executed and effects obtained, information of various kinds is required. Such information is required due to human actions' nature, which requires the operation and/or exchange of various facets of reality reflection to conduct the action successfully.

For the successful execution of actions, humans need to be sure: to begin the action with required objects of the required quality, which set in required relation with other objects of interest; to begin the action in certain conditions, represented as requirements to descriptions and measurements of the objects used in the action, and to prescribe the information required to act; to check the states during action execution and their conformance to action prescriptions; to provide required impacts on objects and their relations during action fulfillment, according to checked states and relations of the objects used for action; to predict effects of action execution and their correspondence to requirements; to move effects received for the possible use in other actions or by other humans, through space and time.

Such requirements meet with information processing during action execution. They classify into three main classes: obtaining descriptive information about objects of action, about their relations and characteristics, receiving, operating, and sending information from/to the information sources, using the information to provide required impact on objects, and their relations during action fulfillment, described by this information. Subsequently, three kinds of information for the execution of action effects are distinguished. Furthermore, three kinds of information actions are distinguished. Such information actions (or – in general, information processing) classified as the processing of information to obtain one of three kinds of information mentioned. These kinds of information (to be obtained by corresponding information action) are: descriptive, prescriptive, predictive information.

Predictive information processing differs because it does not necessarily produce information about particular action objects used for effects execution. It makes higher-level information. Predictive information is general information about why effects manifest and how – not only in specific action

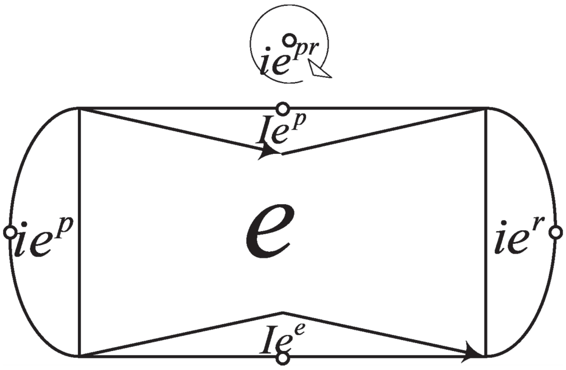

Fig. 1. Effect execution action structure schema.

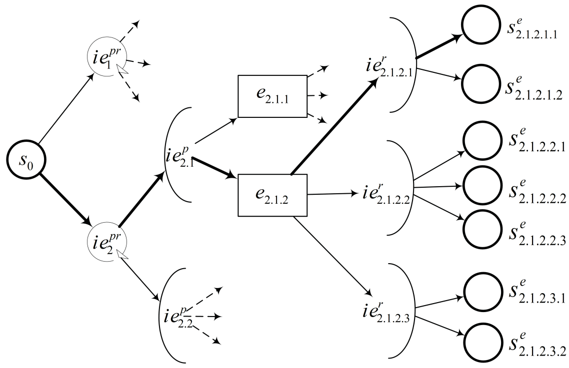

Fig. 2. The application of information for effects execution action schema.

execution cases and on the objects and information used for that. There could also be other higher-level types of processing information, which do not necessarily reflect t he e ffects of actions. Such higher-level information processing is a kind of information processing for obtaining explanations, rules, peculiarities, and prediction of the use of object results formation, general laws of nature functioning, their descriptions, and so, prediction formation of different action fulfillment, different human requirements' formation rules, as well as, probably, other levels of explanations. Such explanations are formed as knowledge about different ways of human and nature activities and other phenomena' formation, their details of the actions of humans and nature.

This article does not consider processing information of these higher levels' kinds yet. It is subject to future research. As noted previously, information processing during effect execution actions should be distinguished in time and in space. For this reason, various kinds of synchronization models are provided. In Fig. 1), the effects execution action represented with a rectangle in the center with oval segments attached, which represents the information processing part of the effects' execution action, and the circle outside which represents the attached effect prediction information operation: ie^p- execution prescriptions information (Ie^p) processing can be performed before the start of the execution process. This kind of information processing is shown as an oval part. Its result consumed during the action is shown as a triangle with direction to action.

ie^r-effect execution monitoring and reporting information (Ie^e) processing can be performed after the finish of the execution process. This kind of information processing is shown as an oval part in the end of action. Its result (Ie^e) formed during the action and its end. Such a result is shown as a triangle with direction outside action. e- effects execution action, between ie^p and ie^r; Information processing for executing an action is required [16] in the case when the action is either new or it shall or could be changed at or after the action start. ie^{pr}-effect execution prediction information (Ie^{pr}) processing can be performed at any time, with or without effect execution action. This kind of information processing is shown as a circled arrow, effects execution action. This information processing can consume all kinds of information before considered. Its results can be consumed during any information processing considered before.

If an action is new, information about its various aspects shall be obtained to fulfill an effect execution action. If such information is already known and received before the action starts and is not subject to change, other information is unnecessary. If an action shall or could be changed at its start, information to fulfill an effect execution action still required, like in the new action case.

As a result, information processing could be classified based on the information processing for effect execution actions classification suggested, as the five main ways of information processing for effect execution action, and their combination for the first level of information use. Among these, two information processing kinds are, in fact, information "in" processing and information "out" processing – i.e., information processing "on the border" to effect execution action objects. The other three kinds are descriptive, prescriptive, and predictive information processing. However, descriptive information processing is related to sensing information processing because descriptive information could be obtained through sensing information processing and from other sources outside the action considered, for example, through information exchange. Similarly, prescriptive information processing is related to actuating information processing because such information is used by actuators but can be processed not only by actuators. Thus, among the three kinds of information processing to effect execution action, two caused by the other two related information processing on the border.

V. Examples of IS/IT application for actions in systems

The IS/IT application for effects execution action fulfillment, illustrated by the schema in Fig. 2). In the figure, one of the possible trails (process realization case) is shown with bold lines. Depending on information operations ie modes and results Ie different actions e performed and as a result, different states s due to functioning realized in the end. To reflect this variability at workflow diagrams, depending

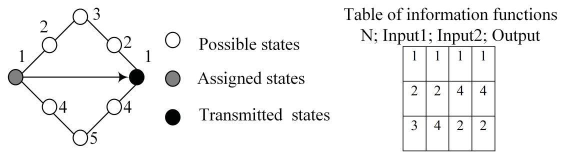

Fig. 3. The application of information visual representation .

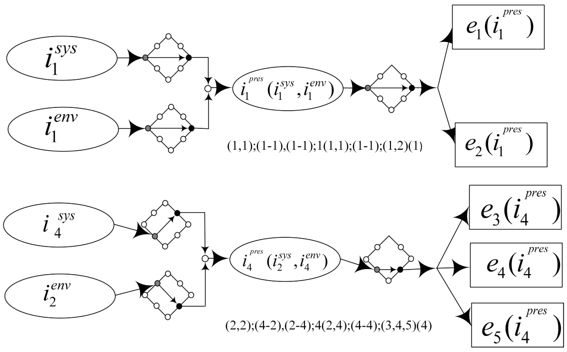

Fig. 4. Representing process trails.

on information application, it is suggested to use 2 typical constructs shown in Fig. 3. It is ”diamond” like figure, which shows choosing and transmission of information and tabular function like figure, w hich s hows t he i nputs a nd o utputs of information through information actions. General information function suggested depicting as an action sign with attached information function in the form $(i^o(i^i_1, i^i_2))$. Here, i^o- output information, i^i- input one. Other kinds of figures, reflecting appropriate information application, shall be developed. in Fig. 4 use of suggested elements of the workflow diagrams explained by two examples. Information functions are shown as action, which fulfill a n i nformation f unction. T wo traces are shown in the example. Traces can be recorded with use of chains, shown below each example of trace. In the chains $x(y, z)$ and $(x, y)(z)$ represent function and vector function respectively. Semicolons in order from left to right represent order in cause-and-effect sequences.

The two corresponding strings, representing the two process trail examples of structures: (1,1); ((1-1), (1-1)); 1(1,1); (1-1); (1,2)(1) and (4,2); ((4-2), (2-4)); 4(2,4); (4-4); (3,4,5)(4).

String (1) represents following structure of changes in states, events, transmissions, actions flow (further – c hanges): (two parallel actions performed in environment (number 1), and system (number 1)); ((transition of information number 1 to number 1 happens), (parallel transition of information number 1 to number 1 happens)), action 1 caused by information numbers of pair (1,1) performed; information transmission (1-1) happens; (parallel transition of actions number 1 and 2 started)(as a result of information 1 transmitted). String (2) happens when other information is exchanged. It represents the following structure of changes: (two parallel actions performed in environment (2) and in system (4)); ((transition of information number 4 about system to number 2 happens), (parallel transition of information about environment number 2 to number 4 happens)), action 4 result number caused by information numbers of pair (2,4) received; information transmission (4-4) happens; (parallel transition of actions numbers 3, 4 and 5 started)(as a result of information number 4 transmitted).

Only 2 strings were generated among the possible ones. To generate all strings, all possible realization of information results and then - chains caused by such results shall be constructed. That can be done by traversals of all possible information, generated by possible information actions. Such possible information actions results can be obtained in the example as possible strings in the table (Fig. 3). Such a table represents mapping in the form of “input-output”. This mapping is information action results in a simplified model.

Once the structures of possible strings of changes are considered, we can consider parameterized sequences. Sequences parameterized by probabilities of corresponding events (for example, events of information actions and outcomes), variable stochastic values of effects, obtained because of each of the possible process trails. Such variable stochastic values are functions of stochastic parameters, and function form determined by string of changes. For example, summation of the individual actions’ effects.

These stochastic values attached to strings of changes specified (for example, as distribution types and distributions parameters) such values provide the ability to attach functional dependencies of variables, which depends on these variables (for example, total effects spent or obtained during process trail described by each chain - like time, resources spent, results obtained).

Operating with these values based on structure of changes chains introduced gives the possibility to compute measures of the process trails (process realizations cases) results (under conditions realized) in correspondence to varying demands to these results and under condition of various information operations used (to react on changes realized and so, to obtain realizations of the process effects).

These measures depend on variables and parameters in problems decided and allow introducing indicators (in the form of measures moments and other characteristics) and then appropriate objective functions.

Thus, the sequences of models built are conceptual models in the form of diagram – structural, graph - theoretic model of change sequences – marked graph-theoretic model – functional graph-theoretic model – functional probabilistic model – model of the objective function dependencies of indicators against variables and parameters.

In Fig. 5, the comparison of states obtained with information application to effect execution action and without information application illustrated by trace, selected in Fig. 5. When the information is used (applied) to effect the execution action, only a subset of possible states can be realized, or – subsets of states with probability distribution which differ from the probability distribution of the resulting states when the information was not used. Probability distribution of resulting states

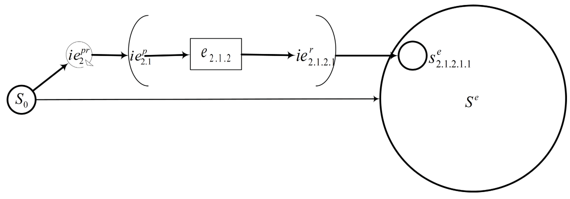

Fig. 5. The comparison of states obtained with information application to effect execution action and without information use.

due to information application parts, i.e. of the action, shall have lower entropy:

$$E(ie) \leq E, E(ie) = -\sum_{s_i(ie)\in S^e} \dot{p}_i(ie)\log p_i(ie) \qquad (1)$$

In (1) $E(ie)-$entropy of the set of possible states in the result of functioning in the case information application parts, i.e. of the effects execution action applied. It reflects the possible changes of action states as a reaction to the changes of the system and its environment states during the effect execution action. In this case, effects execution actions can change because of varying conditions and information applications for effect execution actions. The results of such changes are states which were possible before the conditions changed, but became more preferable than others (now, less possible) in changing conditions. $E-$entropy of the set of possible states as the result of functioning of the effect execution action in the case information is not applied to change the possible states of the effect execution action. In this case, no reaction is possible if conditions changed during action execution. The difference between entropy $E(ie)$ and E, $\Delta(E)$ is that difference which is caused by information application. However, it is not the goal – to decrease the entropy, but the means, by which it is possible to reach the goal. The goal is – to increase the measure of effect correspondence to requirements when conditions changed, and so, the mode of action could be corrected – to reach a better correspondence of effects to the requirements in changing conditions. Thus, entropy may be considered as a "resource", which "used" to increase the correspondence of effects to the requirements in changing conditions.

The goal of such "resource" as entropy use is to decrease the measure of correspondence $\mu(e, ie)$ of the execution action vector W of effects $W(e, ie)$ to the vector of requirements R to it $R(e, ie)$. We consider both effects and requirements components of W, R as probabilistic values and as functions of time, i.e., as $W(e, ie, t)$ and $R(e, ie, t)$. Such a measure of correspondence can be defined as:

$$\mu(e, ie) = Poss(W(e, ie, t) \bowtie R(e, ie, t)). \qquad (2)$$

At (2) symbol $\bowtie$ means subset of correctly applied relational signs of the effects' correspondence to requirements model: $\{<, \leq, >, \geq, =\}$. Thus, the application of information can cause a system of synchronous interdependent changes:

$$Syn = \mu(e, ie), \Delta E(e, ie). \qquad (3)$$

The third information processing kind, predictive information processing, ie^pr differs from the four kinds considered above. It is information processing of (meta-),ie^M level, $ie^{pr} \in ie^M$ as the author described earlier. Such information processing may use information of all possible kinds and, probably, information from outside the system, to synthesize foresight information to predict future effects. Predictive information can be further used to synthesize new descriptive and prescriptive information, and to synthesize new descriptive and prescriptive information for corresponding information processing. Like with other information processing cases, such information can be used in case the action changes or could be changed. We show such possibility with an external circled arrow which may connect each information processing kind. Information processing ie^M of meta-level kind may lead to various results. One of them is expanding the set of possible states S^e obtained because of effect execution action. Such expansion is possible, for example, due to changing in possible action modes, changing technological possibilities, changed natural laws, and mechanisms used for performing possible action modes. These new possible outcomes of effects execution action results in new set of possible states $S_2^e(ie^M)$ because of ie^M, and it is over set of initial S_1^e: $S_2^e(ie^M) \supseteq S_1^e$.

As a result of updated, due to conducting ie^M, information application ie_2 for effects execution action $e(ie_2)$, with set of possible states $S_2^e(ie^M)$ because of action $e(ie_2)$ fulfilled. The result of such action, $e(ie_2)$ is a state $s(ie_2)$ or set of states $S(ie_2)$ with updated probability distribution $F_S(ie_2)(s)$ on the set S elements s. Because of $S_2^e(ie^M) \supseteq S_1^e$, the following is true:

$$E(ie_2) \leq E_1; E(ie_2) = \sum_{s_i(ie_2)\in S_2^e} p_i(ie_2)\log p_i(ie_2) \qquad (4)$$

Therefore, again, the information application for actions in systems results in decreasing entropy. Now, by enlarging the set of possible outcomes. However, again, such a decrease is not a goal, but it is a mean or 'resource', which is possible to use to obtain the system of changes as a reaction to changing conditions:

$$Syn(ie_2) = \mu(e(ie_2), ie(ie_2)), \Delta E(e(ie_2), ie(ie_2)). \qquad (5)$$

Such a system of synchronous changes caused by the information action of the higher level (actions which change the possible outcomes of other actions in changing conditions). Other possible systems of higher level changes could be considered. Depending on the results of the various kinds of information, processing results (i.e., information of various kinds), required if an action is new or changed mode, or could be changed after a particular action with a certain mode starts, the action will result in different effects. Furthermore, various correspondence of effects to the changing demands will manifest differently.

However, this correspondence is required to obtain the needed quality of the action. Thus, the quality of the effect execution action depends on available entropy 'to spend': the effect execution action of necessary condition, changed as a

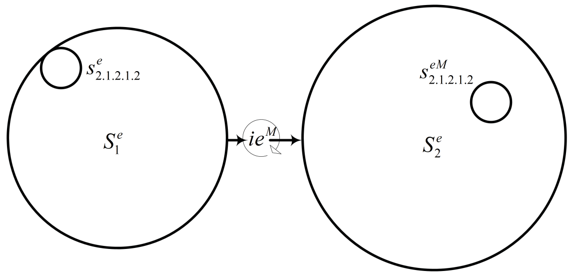

Fig. 6. The schema of possible state set expanding due to information actions of meta-level kind use.

reaction due to changed environment, changed action objects, changed characteristics, or changed relations between objects as well as due to changed goal. As a result, dependencies of the $Syn(ie)$ kind, constructed with use of mathematical models, open the road to choose the characteristics of information operations $ie-$ for example, during IS/IT transformation. Models for building $Syn(ie)$ shall describe a series of effect execution action possible changes, chains of such changes due to different information processing results. Such chains of possible changes and their characteristics could be modeled as effect execution – information action chains.

VI. Discussion

Current limitations of the concept and models suggested are some schemes recommended for limited cases of modelling of IS/IT application to use with DTA and their discrete nature reflected by graph-theoretical, probabilistic models of unique processes used by authors for modelling.

We consider discrete set of activities as possible ones. Activities of environment are from the discrete set too. Variables are of discrete nature, the time changes in discrete moments determined as a min and max functions composition on the possible duration of activities possible. As a result, the set of moments at which we count variables is discrete. We do not consider any changes inside discrete time intervals suggested. Such discrete character of the model is our assumption, which may overcome with future modelling techniques suggested. Results of activities, though, can be continuous.

To integrate and converge data during DTA life, we suggest real time whenever its possible. Such possibility depends on computational resources, because activity may change faster than the object, modelled by usual digital twin.

We plan to use data to update:

- Activity model parameters (probabilities of sets of activities realizations, possible activities characteristics);
- Model structure (change future possible set and structure of activities);
- Information actions (update input data, decisions planned in various circumstances, update communication of information produced).

In general, DTA can be the probabilistic state machine, or the Petri net or the Markov chain. There are no specific demands to the modelling formalism used, except the ability of the model to reflect possible alternations of activities (including set of activities, their flow, characteristics and goal alternations) due to possible variable conditions.

For modelling example, we used families of alternative stochastic action networks – which are the PERT and the GERT networks extension to describe possible projects alternations and conditional dependencies among actions in variable conditions. Such models do not use assumptions of the Petri net or Markov chains or state machines. For example, they describe unique non-stationary processes with chains of stochastic dependencies among variables, which describe actions results. But the formalism suggested can be used for other modelling paradigms, properly updated to represent probabilistic fulfillment of actions and sets of actions possible alternation due to variable conditions.

Dead – locks should not be possible for kind of modelling formalism example considered, because we use assumption there are no cycles or even contours in chains of alternatives, the model of alternating is tree of probabilistic networks (directed acyclic graphs) fragments. Every state is reachable by one and only one chain of events possible. The minimal number of states is three (one initial and two possible ones to form the simplest tree of two possible alternatives).

It is possible to further enhance DTA concepts, models and methods proposed for application in various areas. Among them virtual commissioning, model-driven process development, robotic process automation, process conformance checking [53].

Further research should be done to overcome the limitations of the suggested models, to model a broader range of various kinds of IS/IT applications for activity and different system functioning models using suggested candidate theory results. Demands for records about information-action-event-state chains observed shall be specified, as well as their use methods. Possible ways to construct indicators based on incomplete data shall be considered. Researchers of IS/IT applications for various kinds of systems should create new types of models, algorithms, and technologies based on models already suggested. Research can be conducted on possible applications of machine learning technologies for DTA models built regarding IS/IT application for activity in systems, based on incomplete, vague, or expert information about activity realizations and applications to predict system response to information actions outside the system under study.

VII. Conclusion

The schemes described, and the mathematical expressions based on them, can be used to build new formal models of activity and models of IS/IT applications for activity. Such models are built through creation, based on the suggested diagrammatic models, first graph-theoretic models, then labeled graph-theoretic, and then functional probabilistic models as well as program code models to compute needed probabilistic and entropy measures of performed activity depending on information collected during action (as physical twin of DTA) and DTA characteristics. This formalization opens the road to the formal description of activity as a series of actions, their possible changes, and possible chains of state changes due to various information obtained and information action results. These chains represent activity traces in DTA depending on conditions released and information processed. Such chains are modeled as information actions – realizations of effect execution actions in chains of changes and corresponding to these events and state chains of changes. These chains may be recorded in the form of log files or other records and used for updating DTA models depending on activity (physical twin) observed characteristics.

Schemes suggested were used to estimate the system's functioning effects, the measure of correspondence to the changing needs, as well as entropy indicators. Both types of indicators are estimated based on probabilistic mathematical models, on trees of information-action-event-state chains, or based on records (for example, log files) about observed activity. Researchers can implement estimations depending on the parameters and variables of the information operations and the corresponding IT/IS characteristics.

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