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Models and Algorithms for the Reconfiguration of Virtual Enterprise Information System Structure

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Abstract **– In this article we will consider existing approaches to solving problems of complex object reconfiguration, as well as combined dynamic model and method of reconfiguring, which is viewed as a virtual enterprise information system. Reconfiguration is a process of the complex technical system structure alteration with a view to increase, keep or restore the level of complex technical system operability, or with a view to compensate for the loss of complex technical system efficiency caused by the degradation of its function. The dynamic interpretation of the processes of complex work planning in virtual enterprise integrated information systems allows describing in strict mathematical terms and comprehensive manner the mutual effect of business processes and information processing, storage, transmission (reception) processes in this system.**

Keywords **– Dynamic reconfiguration, complex object, control systems, virtual enterprise**

I. THE STATUS OF RESEARCH PROCESS CONTROLLED RECONFIGURATION OF COMPLEX OBJECTS

Environmental and technological object monitoring and managing systems considered in the project can degrade in the course of their operation under the influence of disturbing factors. In the case when the appropriate methods of revolting influence parrying are exhausted, methods of management reconfiguration of the complex natural and technological objects are used; in the future we shall name them as complex objects (COs).

In this section, we will consider existing approaches to solving problems of CO reconfiguration. A combined dynamic model and method of reconfiguring the CO will be offered in the next section, which is considered a virtual enterprise (VE) information system (IS).

The analysis of existing and projected complex objects of big class systems in significant applications (rocket and space, aviation, naval equipment, complex electrical, electronic and automated systems and complexes for different purposes, etc.) with a dynamically modifiable structure allows us to consider existing several theoretical approaches to solving the tasks of poly-model multi-functional synthesis of structural shape of CO.

In the standard (classical) reconfiguration technology of complex objects (sometimes called a “blind” reconfiguration in [1-3]), failures and violations of the proper functioning of a complex object in order to preserve the most important functions of the specified object or the valid conditions of efficiency “sacrifice” other functions or part of working elements.

The following best options for a “blind” reconfiguration can be detailed among these approaches [4-10].

Option I. The functional elements (FEs) of a CO are standardized multi-functional (homogeneous) computing facilities. Reconfiguration procedure of a CO is the following [9], [10]. The set of tasks is divided into groups of objectives with similar (identical) characteristics. Each group of tasks is solved in one functional element. If the FE fails, its group of tasks passes to the FE, where the tasks with the lowest priority are solved. If it is not possible to solve the tasks of the incorporated groups, the tasks of group with lowest priorities are removed from the solution.

Option II. A more involved procedure of “blind” reconfiguration is represented in [4-6]. In contrast to the case of option I, FE interacts via telecommunication subsystem. Each FE contains the processors, RAM and ROM devices, the appropriate interfaces; it interacts with the external environment (management objects, operators, etc.) using the dedicated hardware and software. CO can contain shared resources (external memory, databases, peripherals, etc.).

Let this system carry out the solution of well-known set of functions (tasks) with specified requirements to the order of their implementation and relationship according to an executable task. Each FE is able to execute one (specialized FE) or a few functions (universal FE) of a set of functions assigned to the system.

For each function a set of complete or simplified algorithms to perform the function is given.

Then the option of reconfiguration of a CO summarizing the proposed approaches in [4-7] can be represented as follows. For the initial state a plan for the distribution of tasks and information flows is implemented considering technological, technical, cost, time, resource, etc. limitations. The tasks envisaged by this plan after the FE is called are according to [5-7]. If a CO passes to another state (in case of the failure of a few FEs), then two strategies are discussed.

Strategy 1 (plan correction) – the tasks and associated information flows over the failed FE are redistributed among the operable functional elements, keeping them fulfilling their own tasks.

Strategy 2 (rescheduling) – in a new condition all tasks executed by the CO are redistributed.

The fault tolerance of CO is ensured by placing in the different FEs the back-up copies of the task algorithms. If a CO comes to a different state the mode of its operation should be changed in accordance with the plan of the task redistribution and dataflow for this state that involves the activation of back-up copies of the task algorithms by efficient FE.

Option III. Under options 1 and 2 above when solving the task of reconfiguring the functioning of CO it is required to form a great number of intermediate states, in which there may be a CO. In some cases, this set may include, for example, all the states of CO, the transition in which leads to loss of control of the most responsible objects, or any state that does not allow an interruption in the operation of a CO because of the need to reconfigure it in case of FE failure, or, as a rule, all the states the probability of a transition to that from the initial state is not less than specified (in the simplest case – all states). As mentioned above, it is possible and feasible to represent the task of reconfiguring the CO under the action of random perturbations using the approaches of the two-stage or multi-stage stochastic programming [11-13]. In other words, the development of the initial distribution plans and plans for the redistribution of tasks and the flow of information is carried out jointly, so there is the choice of initial allocation plans in such a way that subsequent redistribution enables the efficient use of the resources of CO needed to compensate for adverse impacts [11-13].

It should be noted that to increase the flexibility of operation of the COs, redundancy is introduced into all their structures in advance, which allows formulating and solving the management tasks of these structures (including their reconfiguration). However, during the “blind” reconfiguration, next operations are generally not fulfilled: accounting and analysis of current tasks performed by CO, their characteristics and functions; analysis and estimation of the current state of the CO in general; real-time calculation, evaluation and analysis of CO goal abilities and technical and information possibilities for reasonable reallocation of CO functions between its runnable elements and subsystems.

Thus, in relation to modern CO reconfiguration it should be seen not only as a technology of CO structure management to compensate for the failures, but also as a management technology consigned to improve the survivability of CO with structural and functional redundancy and operating in a dynamically changing environment. Further in contrast to “blind” reconfiguration, this technology will be referred to as “structural-functional” reconfiguration.

Structural-functional reconfiguration of CO, on the one hand, aims to change the topology of the system and its subsystem performance technical characteristics, to compensate the impact of various destructive effects; on the other hand, it implies a flexible reallocation of goals, objectives and functions performed by the system among non-failed components, taking into account the admissibility of CO operation with quality indices worsened in the specified limits.

It is necessary to solve the problems of the development of models and methods of structural-functional planning of CO (today this significantly affects the ability of prevention and containment of various emergency and critical situations). Thus, there is a contradiction between the need to improve the structural-functional reconfiguration of CO planning process as the basic function of management, on the one hand, and the lack of theoretical and methodological study of the process, on the other.

II. Review on Reconfigurable Control Systems

Over the past two decades the growing demand for reliability in industrial processes has drawn increasing attention to the problem of fault detection and isolation (FDI), but only a few studies have been dedicated to the related fault-tolerant control (FTC) problem. A fault (abrupt or incipient) is any kind of malfunction or degradation in the plant that can lead to a reduction in performance or loss of important functions, impairing safety. Therefore, FTC can be motivated by different goals depending on the application under consideration; for instance, safety in flight control or reliability, or quality improvements in industrial processes [14].

Although FTC is a recent research topic in control theory, the idea of controlling a system that deviates from its nominal operating conditions has been investigated by many researchers. The methods for dealing with this problem usually stem from linear-quadratic, adaptive, or robust control. The problems to consider in the design of a fault-tolerant controller are quite particular. First, the number of possible faults and, consequently, actions, is very large. Second, the occurrence of a fault can make the system evolve far from its normal operating conditions and can lead to a drastic change in the system behaviour. It is often a rapid change, and the time for accommodation is very short. Furthermore, correct isolation of the faulty component is required to react successfully; it is a rather difficult problem in the case of closed-loop systems. Finally, FTC is a multivariable problem, with strong coupling between the different variables.

Various approaches to fault-tolerant control have been suggested in the literature [15]. From the application viewpoint, flight-control systems have represented the main area of research, and only a few studies have been devoted to industrial processes. One of the main goals of this article is to show that these approaches are appropriate to such systems.

Fault-tolerant control systems are characterized here by their capabilities (alter the occurrence of faults) to recover performance close to the nominal desired performance. In addition, their ability to react successfully (stably) during a transient period between the fault occurrence and the performance recovery is an important feature. Accommodation capability of a control system depends on many factors such as the severity of the failure, the robustness of the nominal system, and the actuators’ redundancy.

Actually, fault-tolerant control concepts can be separated into “passive” and “active” approaches. The passive approach uses robust control techniques to ensure that a closed-loop system remains insensitive to certain faults. When redundant actuators are available, methods dealing with this approach are also called reliable control methods [16], [17], [18]. In the active approach, a new set of control parameters is determined such that the faulty system reaches the nominal system performance. It is important to precisely define the degraded modes that are acceptable with regard to the required performance parameters, since the capability to alter the occurrence of faults as well as conventional feedback control design may result in unsatisfactory performance, such as tracking error, instability, and so on.

Fault-tolerant control systems (FTCSs) can be classified into two types [19]: passive (PFTCS) and active (AFTCS). In PFTCS, controllers are fixed and are designed to be robust against a class of presumed faults [20-25]. This approach needs neither fault detection and diagnosis (FDD) schemes nor controller reconfiguration, but it has limited fault-tolerant capabilities.

In contrast to PFTCSs, AFTCSs react to the system component failures actively by reconfiguring control actions so that the stability and acceptable performance of the entire system can be maintained. In certain circumstances, degraded performance may have to be accepted [26]. AFTCSs are also referred to as self-repairing [19], reconfigurable [27], restructurable [28], or self-designing [29] control systems by some researchers. From the viewpoint of functionality in handling faults, AFTCSs were also named as fault detection, identification (diagnosis) and accommodation schemes by other researchers [30]. In such control systems, the controller compensates for the impacts of the faults either by selecting a pre-computed control law or by synthesizing a new one online. To achieve a successful control system reconfiguration, both approaches rely heavily on real-time FDD schemes to provide the most up-to-date information about the true status of the system.

Therefore, the main goal in a fault-tolerant control system is to design a controller with a suitable structure to achieve stability and satisfactory performance, not only when all control components are functioning normally, but also in cases when there are malfunctions in sensors, actuators, or other system components (e.g., the system itself, control computer hardware or software).

III. METHOD OF DYNAMIC RECONFIGURATION

Reconfiguration is a process of the complex technical system (CTS) structure alteration with a view to increase, keep or restore the level of CTS operability, or with a view to compensate for the loss of CTS efficiency caused by the degradation of its functions [43-61].

Typical technology of CTS reconfiguration under the condition of a single-resource failure includes the following main steps: Step1 – fixing an analysis time and place of a resource failure, interruption of the task that used the defective resource, passing the task to another resource with or without retention of intermediate results; Step2 – removal of the defective resources from the CTS configuration, making an attempt to use reserve resource of the same type or of another type with similar functionality; Step3 – removal of connections with the faulty resource, prohibition on its use, as for the faulty resource itself, making an attempt of its recovery.

If a task of a high priority uses the faulty resource than it can conflict with the tasks of the resource it is passed to, so it can be needed to preempt or to abort tasks of lower priority according to the service procedure.

The described technology is usually implemented in modern CTS at a micro-level, which is at the level of CTS elements and blocks. Special hardware and software modules are used. This reconfiguration sometimes is named blind reconfiguration, as the following operations are not fulfilled:

- accounting and analysis of tasks, their characteristics, and functions;
- analysis and estimation of the current state of CTS as a whole;
- real-time calculation, estimation and analysis of system's goal abilities for reasonable reallocation of CTS functions among its runnable elements and subsystems.

In a real situation, a single-resource failure can cause failures of some other resources or can reduce their efficiency. Therefore, a substitution for a faulty resource may necessitate completely new efficient configurations of CTS.

The following intermediate conclusions can be considered now:

- firstly, besides the compensation of failures, the reconfiguration can be used to improve the operating efficiency of modern CTS;
- secondly, to implement the proposed concept it is necessary to construct such formal tools that can join together the processes of CTS reconfiguration and the processes of CTS use at different phases of system life cycle.

The presented considerations have led us from a narrow traditional interpretation of CTS reconfiguration to a wide interpretation within a new applied theory of CTS structure dynamics control. Developing of this theory is one of the main aims of our investigations in the project.

IV. MODEL AND ALGORITHM OF COMPLEX PLANNING OF THE WORKS IN THE VIRTUAL ENTERPRISE INFORMATION SYSTEM

Virtual enterprises (VEs) are the organizations that are created from the geographically distributed independent multi-profile partners (real enterprises), united into a common organizational and technical structure based on the information and telecom technologies for the time of execution of the common order [32 - 34].

The main purpose of VE is to use some resources provided by the individuals and legal entities in a timely and effective manner to enable each party involved to make profit during the solution of the common production task. Comprehensive analysis of the processes of creation and functioning of the modern integrated industrial and transportation enterprises (IITE, including VE) shows that these organizations as the management objects are characterized by structural dynamics. Thus, during their designing and application it is required to be capable of promptly solving several important tasks of the structural and functional synthesis of their appearance. Such tasks, primarily, include: partner selection tasks (for example, manufacturers and suppliers of the component parts and finished goods); order configuration tasks; order placement tasks; configuration tasks on the transport network and information and technological resources [32], [33].

The major subsystem of any VE is its integrated information system (IIS) that is created based on the operational configuration (structural and functional synthesis) of IS, providing the functioning of both real enterprise, engaged in temporary cooperation, and their interaction during the industrial operations. It should be noted that structural dynamics caused by various reasons (objective, subjective, internal, external, etc.) [35] is characteristic of both IIS and VE. Figure 1 graphically illustrates the possible scenario variants of structural dynamics if applied to modern IS.

Previous research showed that for the purposes of improving (maintaining) the IIS operability and capability level or ensuring the best conditions of the degrading of such systems it shall be required to manage their structures (including the IIS structure reconfiguring management). At the present time, there are various variants of IIS dynamic management. These primarily include [35]: changing of ways, purposes of IIS operation, their contents, sequence of execution under various conditions; relocation of separate IIS elements and subsystems; redistribution and decentralization of functions, tasks, management algorithms, information streams between the IIS levels; utilization of flexible (shortened) IIS management technologies; reconfiguration of IIS structures in case of their degrading.

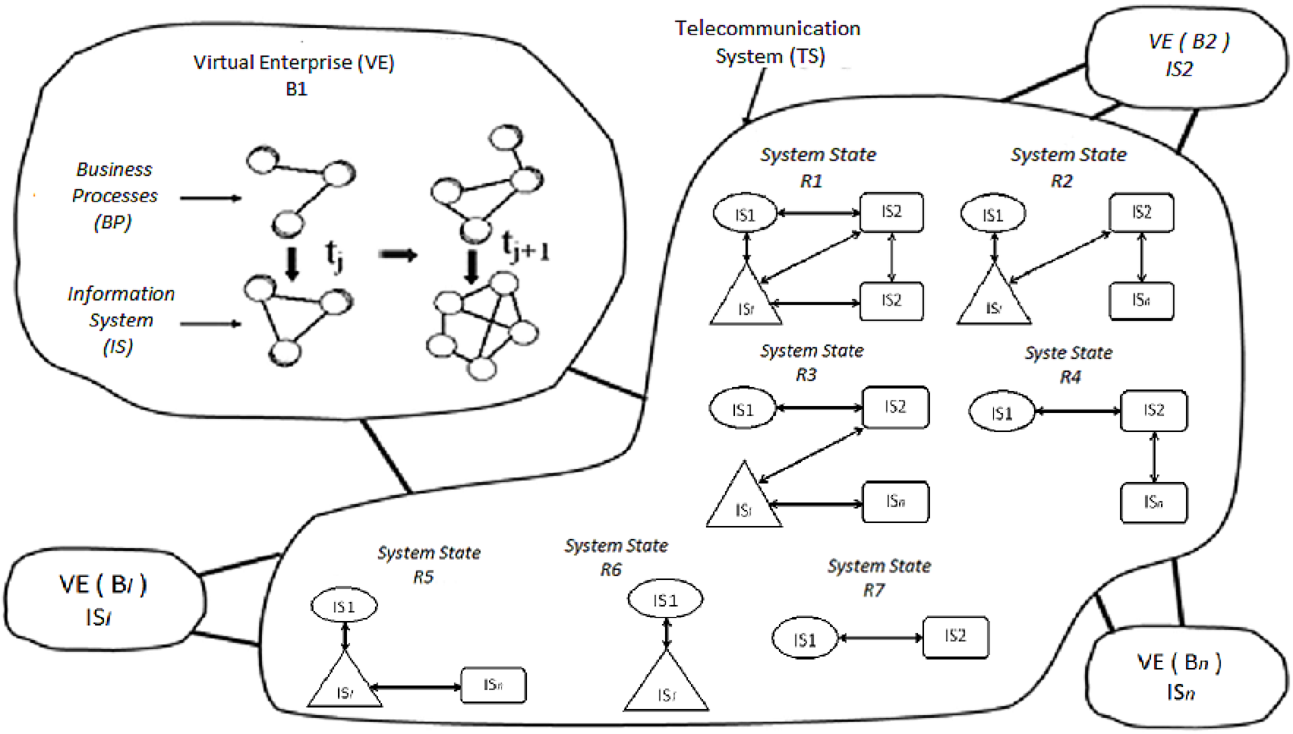

Fig. 1. Possible scenario of structural dynamics applied to modern IS

Structural dynamic management (SDM) tasks on IIS are attributed by their contents to the structural and functional synthesis of IIS appearance and generation of the relevant development management programs [35–40]. This article reviews one of the IIS SDM tasks in connection with the operative generation and implementation of the planning technology for business processes (BP) of VE and the work performed in IIS to ensure qualitative implementation of BP.

A. *Task Setting*

The process of operation of the modern VE IIS is described by the high intensity of change of both VE BP execution conditions and composition of the tasks in connection with the implementation of the relevant information processes.

To ensure that VE IIS fulfils all the tasks set under the specified conditions it shall be required to develop flexible ways of application for each IIS to allow prompt redistribution of the aims, functions and tasks solved (algorithms) among the VE IIS elements, subsystems, levels subject to the observed situation. Such tasks primarily include: reception, transmission, storage, processing, generation, planning and management tasks of both VE as a whole and its IIS.

When redistributing such tasks between the software and hardware complexes, located in the VE IIS nodes, alongside with the evaluation and analysis of the VE IIS application efficiency, it shall be required to perform the matching of the selected BP implementation methods in the relevant VE subsystems with the target and information and technological capabilities (TCs and ITCs) of VE IIS each time. The mentioned feature of BP automated management (AM) process arrangement is connected with the fact that each BP in the respective VE node shall have the corresponding structure of the information subsystem of this node, included in the VE global IIS and, as a result, its own variants of arrangement of the information streams within the management circuits, implemented in the given hardware and software architecture of IIS.

In formal terms, the task of selection (synthesis) of both BP structure of the specific VE and the task of operative structural and functional VE IIS synthesis and the relevant distribution (redistribution) of each BP management functions between the VE IIS levels are close in their content to the task of structural and functional synthesis of complex system, when both system functioning optimization and simultaneous distribution of the functions in the system nodes and their composition selection are performed. Additional feature of the task in question (in comparison with the variant, described in [38, 39]) is that its solution must be performed promptly under conditions of tight time limits, connected with the process of designated VE IIS application.

The task of prompt distribution (redistribution) of management functions may be solved at various stages of implementation of such BP. For the purposes of certainty in this article we shall review the case, where the task in question is solved at the stage of planning of the VE IIS application, during which the simultaneous preliminary distribution of BP management functions between the main VE IIS elements and subsystems and the generation of the management programmes take place.

At the stage of operational management (plan implementation stage) the previously obtained management effects may be adjusted by input of previously planned reserves and based on the change of the previously composed plan of management function distribution and technological operation execution, or when reconfiguring the relevant VE IIS structures.

When setting a task to promptly plan the function distribution in VE IIS, we shall assume that the following sets are known to us: $A = \{A_i, I \in N=\{1,...,n\}\}$ – a business process set required to be implemented in any subsystem (node) of VE IIS within the given time slot $T = (t_0, t_f]$. BP and relevant management function implementation ensures successful achievement of the targets, set before the VE within the T time slot. Speaking about the management functions we shall, firstly, denote the aim setting, planning (long-term, short-term), operative management, control, accounting, evaluation and VE IIS condition, situation analysis and coordination functions. To set $A = \{A_i, I \in N\}$ the set of information and technical operations $D^{(i)} = \{D_{\delta}^{(i)}, \delta \in K = \{1,...,s_i\}\}$ is directly connected, the execution of which ensures successful BP implementation A_i, i=1,...,n; as well as the set of main VE IIS elements and subsystems (nodes), we shall designate it as $B = \{B_j, j \in M=\{1,...,m\}\}$; we also introduce to the review the set of technical complexes (TC) $C^{(j)} = \{C_{\lambda}^{(j)}, \lambda \in L = \{1,...,l\}\}$ (for example: servers, workstations, etc., with the relevant software and mathematical and information means (SMM and IM)), included in subsystem B_j. Based on these TCs this or that specific BP management function (functions) may be implemented in B_j.

Let us assume that the matrix function $E(t) = ||\varepsilon_{ij}(t)||$, elements of which are the Heaviside functions, is known to us. In this case let $\varepsilon_{ij}(t)=1$, if the space and time and technical restrictions allow implementing within B_j subsystem the A_j function within t time slot; otherwise let $\varepsilon_{ij}(t)=0$. Let the information interaction of TC in VE IIS be performed via the duplex communication channels (phone, telegraph, radio channels).

Figure 1 shows, for example, seven possible structural conditions of VE IIS, in which this system and its elements in the process of designated application may exist. The arrows in Fig. 1 show the variants of information interaction of these elements between each other. The above-mentioned variants correspond to the various ways concerning the application of VE IIS, various space locations of its elements and subsystems in relation to each other.

Problem description of operative planning of implementation and distribution of management functions between the TC and VE IIS is aggregated as follows: it is required (with consideration of the above-mentioned source data of the known space and time, technical and technological restrictions) to find the best variants of assignment of the management functions to its elements and subsystems, variants of process operation execution plans to ensure the implementation of the management functions for each of the given structural conditions $R_1, R_2,..., R_{\chi}$ of VE IIS and to perform the ordering of the above-mentioned structural conditions of VE IIS in the order of priority. The task of priority setting shall be performed using the system of parameters, describing the target and information and technological capacities of VE IIS, its structure and technological features.

Generated task is attributed to a multi-criteria selection task class in case of the end set of alternatives, which may be the structural conditions of VE IIS.

B. *Combined Algorithm of Solution of Work Complex Planning Task in the Virtual Enterprise Information System*

Algorithm of the set task solution includes the following steps.

Step 1. Using the analytical (simulation, analysis and simulation) models of each of the given structural conditions $R_1, R_2,..., R_{\chi}$ it is necessary to perform the optimal BP and the relevant management function distribution between the subsystems (nodes) of VE IS, planning of the process operation execution to ensure the successful BP implementation and calculation of the VE IS capability parameters. Therefore, the following may be selected: total number of management functions implemented in its subsystems in T time slot, total BP number within the given macroconditions, total number of process operations executed in T time slot, total duration of implementation of all the given management functions in T time slot. In case of consideration of uncertainty factors, these parameters have either probability and statistical or uncertain and possibility interpretation [41], [42].

For the quantitative evaluation of the above-mentioned parameters, we shall review the following model, the basis of which is the dynamic interpretation of the management function redistribution processes in VE IS and processes of execution of the relevant process operations [35–37], [40]:

$$\dot{x}_i^{(\phi)} = \sum_{j=1}^{m} \varepsilon_{i\,j}(t) u_{i\,j}^{(\phi)}; \;\; \dot{x}_{i\delta\,j}^{(0)} = \sum_{\lambda=1}^{l} b_{i\,\delta\,j\lambda} u_{i\,\delta\,j\lambda}^{(0)}; \;\; \dot{y}_{i\,j}^{(\phi)} = v_{i\,j}^{(\phi)} \quad (1)$$

$$\sum_{j=1}^{m} u_{ij}^{(\phi)} \left[\sum_{\alpha \in \Gamma_{i1}} \left(a_{\alpha}^{(\phi)} - x_{\alpha}^{(\phi)} \right) + \prod_{\beta \in \Gamma_{i2}} \left(a_{\gamma}^{(\phi)} - x_{\gamma}^{(\phi)} \right) \right] = 0 \qquad (2)$$

$$\sum_{\lambda=1}^{l} u_{i\delta j\lambda}^{(0)} \left[\sum_{\nu \in \Gamma_{i\delta 1}} \left(a_{i\nu j}^{(0)} - x_{i\nu j}^{(0)} \right) + \prod_{\mu \in \Gamma_{i\delta 2}} \left(a_{i\mu j}^{(0)} - x_{i\mu j}^{(0)} \right) \right] = 0 \qquad (3)$$

$$\sum_{i=1}^{n} u_{ij}^{(\phi)}(t) \le 1;\ \forall j;\ \sum_{j=1}^{m} u_{ij}^{(\phi)}(t) \le 1; \forall i;\ u_{ij}^{(\phi)}(t) \in \{0,1\} \qquad (4)$$

$$\sum_{j=1}^{m} \sum_{\lambda=1}^{l} u_{i\delta j\lambda}^{(0)}(t) \le 1, \forall i, \forall \delta;\ \sum_{i=1}^{n} \sum_{\delta=1}^{s} u_{i\delta j\lambda}^{(0)}(t) \le 1, \forall i, \forall \delta; \qquad (5)$$
$$u_{i\delta j\lambda}^{(0)}(t) \in \{0, u_{ij}^{(\phi)}\}$$

$$\nu_{ij}^{(\phi)} \left(a_{isj}^{(0)} - x_{isj}^{(0)} \right) = 0;\ \nu_{ij}^{(\phi)}(t) \in \{0,1\} \qquad (6)$$

$$x_i^{(\phi)}(t_0) = x_{i\delta j}^{(0)}(t_0) = y_{ij}^{(\phi)}(t_0) = 0 \qquad (7)$$

$$x_i^{(\phi)}(t_f) = a_i^{(\phi)}; \left(a_{i\delta j}^{(0)} - x_{i\delta j}(t_f) \right) y_{ij}^{(\phi)}(t_f) = 0; y_{ij}^{(\phi)}(t_f) \in \mathbf{R}^1 \qquad (8)$$

$$J_0 = \sum_{i=1}^{n} \sum_{j=1}^{m} \nu_{ij}^{(\phi)}(t_f);\ J_1^{(j)} = \sum_{i=1}^{n} \nu_{ni}^{(\phi)}(t_f);\ J_2 = T - \sum_{i=1}^{m} y_{nj}^{(\phi)} \qquad (9)$$

where $x_i^{(\phi)}(t)$ is the variable, the value of which at t time slot equals the current duration implementation of BP A_i in the subsystem B_j for the situation, when $u_{ij}^{(\phi)}(t) = 1$; $x_{i\delta j}^{(0)}$ is the variable, describing the condition of process operation execution $D_{\delta}^{(i)}$; $y_{ij}^{(\phi)}$ is the variable, which is equal to the duration of the time slot since the moment of completion of the implementation of BP A_i in the subsystem B_j till the moment $t=t_f$; $a_{\alpha}^{(\phi)}, a_{\alpha}^{(0)}, a_{\gamma}^{(0)}, a_{i\nu j}^{(0)}, a_{i\mu j}^{(0)}$ are the given values (edge conditions), values of which shall be (or may be) possessed by the relevant variables $x_i^{(\phi)}(t)$, $x_{\alpha}^{(\phi)}(t), x_{\gamma}^{(\phi)}(t)$, $x_{i\nu j}^{(0)}(t), x_{i\mu j}^{(0)}(t)$ at the end of the planning time slot in the time slot $t=t_f$; $u_{ij}^{(\phi)}$, $u_{i\delta j\lambda}^{(0)}$, $\nu_{ij}^{(\phi)}$ are the management effects, where $u_{ij}^{(\phi)}(t) = 1$, if BP A_i is implemented in the system B_j, $u_{ij}^{(\phi)}(t) = 0$ otherwise; $u_{i\delta j\lambda}^{(0)}(t) = 1$, of the process operation $D_{\delta}^{(i)}$ is performed at TC $C_{\lambda}^{(j)}$, $u_{i\delta j\lambda}^{(0)}(t) = 0$ otherwise; $\nu_{ij}^{(\phi)} = 1$, if BP A_i has been implemented in subsystem B_j, $\nu_{ij}^{(\phi)} = 0$ otherwise; Γ_{i1}, Γ_{i2} — set of numbers of management functions, which directly precede the management function A_i (in accordance with TCM elements and subsystems of VE IS) and are logically connected with them with "AND" and "OR" operations respectively; $\Gamma_{i\delta 1}$, $\Gamma_{i\delta 2}$ — set of numbers of process operations $D_{\nu}^{(i)}$ and $D_{\mu}^{(i)}$, which directly precede the operation $D_{\delta}^{(i)}$ and are logically connected with them with "AND" and "OR" operations, respectively.

Thus, using the limits of view (2) and (3) the possible sequences of management function implementation and process operations are set. In accordance with the limitations of view (4) and (5) in each current time slot the BP A_i may be implemented within the single subsystem B_j (i=1,...,n; j=1,...,m) only and, vice versa, in each subsystem B_j only the single BP A_i may be implemented in each time slot. Similarly with these limitations the similar limitations of the process operations $D_{\delta}^{(i)}$ shall be executed at their execution at TC $C_{\lambda}^{(j)}$.

Using the ratio (6) the conditions are set, under which the activation of the auxiliary management effects $\nu_{ij}^{(\phi)}(t)$ takes place; the ratios (7) and (8) set the limitations of the values of the phase variables within the time slots $t=t_0$, $t=t_f$ (edge conditions), $\boldsymbol{R}^1$ is the set of positive real numbers; J_0, J_1, J_2 are the parameters of BP distribution quality within VE IIS, where J_0 describes the total number of implemented management functions in VE IIS in time slot t=tf; J1 is the parameter, describing the total number of management functions of BP A_i, which has been implemented in subsystem B_j of VE IIS, J_2 is the parameter, describing the time slot duration, when all the required management functions have been implemented in VE IIS. To calculate the uncertainty factors within the generated model it is purposeful to add the simulation model of the process of management function distribution plan to the ratios (1)–(9). In this case, within the generated analysis and simulation complex based on the concepts, methodologies and algorithms of the system modelling the relevant procedures of inter-model matching may be created [35], [36].

Generally, the calculation of the extreme values of TC and ITC parameters of VE IIS based on the suggested model (1)–(9) is aggregated to the solution of task of optimal management of the finite-dimensional differential dynamic system with the mixed limitations. In [35], [36], the specific algorithms of solution of such tasks are described in detail, particularly, their software implementation.

In **step 2** of the generalized algorithm of solution of the task, reviewed in this article, the calculation of the structure and topology parameters of VE IS is performed, to which the following parameters have been attributed [41]: attainability parameter (factor) J_4; structure compactness parameters (structure radius J_5, structure diameter J_6, integral parameter of structure compactness J_7); structure centricity (decentricity) parameters J_8. Calculation of these parameters is performed using the analytical formula in [41].

Step 3. Based on the expert survey, the matrix of the pairwise comparison of the above-mentioned TC and ITC parameters — K_{cp} — is generated.

Step 4. In accordance with the algorithm, suggested in [42], using the K_{cp} matrix the restoration of the relative weights (importance factors) of the parameters, evaluating the variants of the management function distribution for each given structural condition of VE IS, is performed. For this purpose, the search of the eigenvector of this matrix, normalized to one $\vec{\omega}_{\text{cp}}$ and matching eigennumber $\rho_{\max}$, is performed. For this purpose the following equation shall be solved:

$$(K_{\text{cp}} - \rho_{\max}\, I)\ \vec{\omega}_{\text{cp}} = 0, \tag{10}$$

where I is identity matrix.

Then the search of the relative weight of each variant of structural condition ($R_1, R_2, \ldots, R_\chi$) of VE IS by each parameter separately (matrix $K_{\text{отн}}$ generation) is performed. In each column of matrix $K_{\text{отн}}$ the relative weights are specified, which are attributed to the relevant structural condition by the respective parameter. Then the weighted sum of the given parameters with the given factors for each alternative $R_1, \ldots, R_\chi$ is generated. In other words, the search of the resulting sets of weights of each structural condition is performed. Next, matrix $K_{\text{отн}}$ shall be multiplied by vector $\vec{\omega}_{\text{cp}}$:

$$K_{\text{отн}}\ \vec{\omega}_{\text{cp}} = \vec{\omega}^{*}. \tag{11}$$

Step 5. The ordering of the structural conditions is performed. The best structural condition is considered, which has the maximum element of vector $\vec{\omega}^{*}$. Each of the specified elements of vector $\vec{\omega}^{*}$ may be treated as the resulting weight of each structural condition.

The dynamic interpretation of the processes of complex work planning in VE IIS, reviewed in this article, allows describing in strict mathematical terms and comprehensive manner the mutual effect of BP and information processing, storage, transmission (reception) processes in this system.

The proposed research of issues of the work complex planning in the IIS in the common context of management of its structural dynamics allows, **firstly**, directly connecting the common aims, the achievement of which the current BP are oriented to, with the purposes, which are implemented during the IIS structures management, **secondly**, reasonably determining and selecting the relevant sequences of solved tasks and executed operations (actions), connected with the structural dynamics (in other words, synthesize the IIS management technology), and, **thirdly**, purposefully finding the compromise solutions at preliminary distribution of functions of BP management between the main VE IIS elements and subsystems and generation of programmes (plans) of their management. Meanwhile the preliminary ordering of the above-mentioned structural conditions of VE IIS allows promptly fining the programmes to manage its structural dynamics in case of degradation of the above-mentioned system. To this date, several versions of the software prototype to solve the IIS SMD tasks have been developed in various subject areas, which have confirmed operability and effectiveness of the suggested model and algorithmic support.

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Andrejs Romānovs, Boriss V. Sokolovs, Vadims V. Burakovs, Semjons A. Potrjasaevs, Aleksandrs Trufanovs. Virtuāla uzņēmuma informācijas sistēmas pārkonfigurēšanas algoritmi un modeļi

Pielietošanai sarežģītu objektu rekonfigurācijai nepieciešams izskatīt, kā sarežģītu objektu vadības tehnoloģiju pārvaldības struktūru nepilnību kompensācijai, kuru mērķis ir uzlabot sarežģītiem objektiem ilgtspējīgu funkcionalitāti ar papildus struktūrfunkcionālitāti, strādājošu dinamiski mainīgā vidē. Struktūrfunkcionalitātes rekonfigurācija izmaina sistēmas topoloģiju un darbspējīgas šīs tehniskās apakšsistēmas raksturojumu. Tas dod iespēju likvidēt sekas dažādu destruktīvu darbu veikšanai objektā un piedāvā elastīgu pārdali sistēmas mērķa pielietošanai, uzdevumiem un funkcijām starp vadības sistēmas neatteiktajiem elementiem. Pie tam tiek ņemtas vērā pieļaujamās funkcijas pasliktinātie (pieļaujamās robežās) kvalitātes rādītāji sarežģītam objektam. Piedāvātās virtuālās uzņēmuma informācijas sistēmas dinamisko interpretācijas procesu kompleksās plānošanas pārkonfigurēšana un integrēšana, dod iespēju matemātiski precīzi aprakstīt un vispusīgi izpētīt savstarpējo ietekmi starp biznesu procesu un informācijas apstrādes, glabāšanas un pārraides procesiem minētajā sistēmā. Šis pētījums par dinamisko interpretācijas procesu kompleksās plānošanas pārkonfigurēšana un integrēšana sistēmā, tās dinamiskā struktūra kopējā kontekstā dod iespēju: 1) apvienot kopējos mērķus, kuri tiek orientēti uz tekošo biznesu procesiem, ar mērķiem, kuri tiek realizēti, vadot integrētās informācijas sistēmas struktūras; 2) pamatoti noteikt un izvēlēties atbilstošu secību risināmiem uzdevumiem un izpildāmām operācijām (darbībām), kas saistītas ar strukturēto dinamiku (citiem vārdiem, sintezēt vadības tehnoloģiju integrētai informācijas sistēmai); 3) atrast kompromisa risinājumus, izmantojot plānoto biznesa vadības funkciju sadalījumu procesiem starp pamata elementiem un virtuālo uzņēmumu integrētās informācijas sistēmas apakšsistēmām un vadības plānu sagatavošanu. Līdz ar to virtuālā uzņēmuma integrētās informācijas sistēmas iepriekšējā uzskaitīto struktūru sakārtošana dod iespēju sistēmas degradācijas gadījumā operatīvi atrast struktūras vadības dinamikas programmu.

Андрей Романов, Борис Владимирович Соколов, Вадим Витальевич Бураков, Семён Алексеевич Потрясаев, Александр Труфанов. Модели и алгоритмы реконфигурации информационной системы виртуального предприятия

Применительно к сложным объектам, реконфигурацию следует рассматривать как технологию управления структурами сложных объектов для компенсации отказов, направленную на повышение живучести функционирования сложных объектов, обладающих структурно-функциональной избыточностью и функционирующих в динамически изменяющихся условиях. Структурно-функциональная реконфигурация изменяет топологию системы, характеристики работоспособности ее технической подсистемы. Это позволяет ликвидировать последствия различных деструктивных воздействий на объект и предполагает гибкое перераспределение выполняемых системой целей, задач и функций между не отказавшими компонентами системы управления. При этом учитывается допустимость функционирования сложного объекта с ухудшенными (в заданных пределах) показателями качества. Предложенная динамическая интерпретация процессов комплексного планирования реконфигурации в интегрированной информационной системе виртуального предприятия позволяет строго математически описать и всесторонне исследовать взаимное влияние бизнес процессов и процессов обработки, хранения, передачи (приема) информации в указанной системе. Предлагаемое исследование вопросов комплексного планирования реконфигурации в интегрированной информационной системе в общем контексте управления её структурной динамикой позволяет, во-первых, непосредственно связать общие цели, на достижение которых ориентированы текущие бизнес процессы, с целями, которые реализуются в ходе управления структурами интегрированной информационной системы, во-вторых, обоснованно определить и выбрать соответствующие последовательности решаемых задач и выполняемых операций (действий), связанных со структурной динамикой (другими словами, синтезировать технологию управления интегрированной информационной системой), и, в-третьих, осознанно находить компромиссные решения при предварительном распределении функций управления бизнес-процессами между основными элементами и подсистемами интегрированной информационной системы виртуального предприятия и формировании программ (планов) управления ими. При этом предварительное упорядочение перечисленных структурных состояний интегрированной информационной системы виртуального предприятия позволяет при деградации указанной системы оперативно находить программы управления ее структурной динамикой.