THE FORMALIZATION AND INVESTIGATION OF PROCESSES FOR STRUCTURE-DYNAMICS CONTROL MODELS ADAPTATION OF COMPLEX BUSINESS SYSTEMS

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ABSTRACT

Dynamics and globalization of modern markets force the business integration and building of various collaborative business structures (e.g., supply chains). The issues of modeling and optimization of such complex business systems are cross-linked and multi-disciplinary.A challenge is a combined formation of the supply chain structural-functional configuration and the information infrastructure for implementation of interactions and coordination in supply chains. A important point of such simultaneous formation consists in ensuring of the business-processes continuity, information availability, and system catastrophe-stability. The paper lays the special focus on the structural and parametric adaptation of models describing structure-dynamics control processes in the supply networks.

1. INTRODUCTION

Nowadays the greater evolution of business conceptions, which have consolidated advanced organisation principles and modern information technologies, takes place. Supply Chain Management (SCM) can be classified under these conceptions (e.g. Chandra and Kamrani 2004, Kuhn and Hellingrath 2002, Tayur et al. 1999). One of the SCM challenges is a combined formation of the supply chain structural-functional configuration and the information infrastructure for implementation of interactions and coordination in supply chains.

A important point of such simultaneous formation consists in ensuring of the business-processes continuity, information availability, and system catastrophe-stability. To ensure that the static network configuration and dynamic network reconfiguration (system recovery planning) must be considered combined.

The problem of network reconfiguration arises when essential deviations in actual work processes exist. The network execution is accomplished by permanent changes of internal network properties and external environment. It requires dynamic network adaptation in accordance with the current execution environment and the goals and decisions of the configuration phase. Although the problem of the network configuration was presented in details in a number of recent papers (Teich, 2003, Camarihna-Matos, 2005, Ivanov et al., 2004, 2005, 2006), the research on network execution is still very limited.

The SCM modeling and optimization issues are cross-linked and multi-disciplinary. They differ from those in the classical control theory and operations research by highly specific features of the SCM complexity and uncertainty (Ivanov et al., 2006). So specific modeling and optimization methodologies and techniques are required. This paper focuses on the problem of dynamical adaptation of the supply networks. Section 3 outlines study addressing supply networks structural and parametric adaptation in the framework of structure-synamics control. Sections 4 lay the special focus on the structural and parametric adaptation of models describing structure-dynamics control processes in the supply networks as well as on the formal statement of structural and parametric adaptation problems for supply networks models.

2. SUPPLY NETWORKS STRUCTURAL AND PARAMETRIC ADAPTATION IN THE FRAMEWORK OF STRUCTURE-SYNAMICS CONTROL

The problem of complex business systems (CBS) structure-dynamics control (SDC) includes tasks of three main classes:

– *Class A problems* (problems of structured analysis, problems of CBS structure-dynamics analysis under or without perturbation impacts);

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– *Class B problems* [estimation (observation) problems, monitoring problems, problems of CBS structural state identification];

– *Class C problems* (problems of control-inputs selection and problems of CBS parameters selection, i.e., multi-criteria control problems for CBS structures, modes, and parameters, and multi-criteria problems of CBS structure-functional synthesis).

In (Sokolov et al. 2004, 2005) the problems of the class A were considered in detail, while the problems of the class B do not belong to the scope of this paper. Here we consider a formal description and solving algorithms for the class C problems.

In a general case the formal statement of CBS structure-dynamics control problem can be written as follows.

We are given: customer requirements, technical, and technological constraints, determining variants of CBS SDC at the operation phase; vector of CBS effectiveness measures.

We should determine: $\vec{u}_{pl}(t)$, $\vec{v}\left(\vec{x}(t),t\right)$, and $\vec{\beta}_{\Theta}$ meeting the constraints and returning optimal value to the general effectiveness measure $J_{\Theta}^{(ob)} = J_{\Theta}^{(ob)}\left(\vec{x}(t),\vec{y}(t),\vec{\beta}_{\Theta},\vec{u}(t),\vec{\xi}(t)\right)$.

The described problem is too complex to be solved in whole. That is why we propose a decomposition splitting the initial problem into tasks of five main subclasses:

– *Subclass C1 problems* (problems of real-time structure-functional synthesis of CBS make-up);

– *Subclass C2 problems* (problems of optimal control programs selection for CBS SDC);

– *Subclass C3 problems* (problems of a control-inputs generation for optimal conditions of control programs execution);

– *Subclass C4 problems* (problems of CBS parameters optimization);

– *Subclass C5 problems* (problems of structural and parametric adaptation of CBS models and algorithms).

Let us consider the main features of the subclasses C5.

Analysis of the main features of the complex business systems (CBS) indicates their peculiarities such as: multiple aspects and uncertainty of behaviour, structure similarity and surplus for main elements and subsystems of the CBS, interrelations, variety of control functions relevant to each CBS level, territory distribution of the CBS components.

One of the main features of the CBS is the variability of their parameters and structures as caused by objective and subjective factors at different phases of the CBS life cycle (Camarihna-Matos et al., 2005). In other words we always come across the CBS structure dynamics in practice. Under the existing conditions the CBS potentialities increment (stabilization) or degradation reducing makes it necessary to perform the CBS structures control (including the control of structures reconfiguration). There are many possible variants of the CBS structure dynamics control. For example, they are: *alteration of the CBS functioning means and objectives; alteration of the order of observation tasks and control tasks solving; redistribution of functions, of problems and of control algorithms between the CBS levels; reserve resources control; control of motion of the CBS elements and subsystems; reconfiguration of the CBS different structures*.

The formal statement and decomposition of structural and parametric adaptation tasks were worked out for models of the CBS structure-dynamics control (SDC). Here the adaptive control should include the following main phases: *parametric and structural adaptation of structure-dynamics control (SDC) models and algorithms to previous and current states of objects-in-service (SO), of control subsystems (CS), and of the environment; comprehensive scheduling of CBS operation (construction of SDC programs); simulation of CBS operation, according to the schedules, for different variants of control decisions in real situations; structural and parametric adaptation of the schedule, control inputs, models, algorithms, and SCS programs to possible (predicted by simulation) states of SO, CS, and of the environment.*

To implement the proposed concept of adaptive control let us consider two groups of parameters for the CBS SDC models and algorithms: *parameters that can be evaluated on the basis of real data available in the CBS; parameters that can be evaluated via simulation models for different scenarios of future events*.

The adaptation procedures can be organized in two blocks (models): simulation system (SIS) external adapter and the SIS internal adapter. When the parametric adaptation does not provide simulation adequacy then the structural transformations can be needed. Two main approaches to structural model adaptation are usually distinguished.

The first approach lies in the selection of a model from a given set. The model must be the most adequate to the SO and the CS. The second approach stands for the CBS SDC model construction of elementary models (modules) in compliance with given requirements. The second approach provides more flexible adjustment of the SO and CS for particular functioning conditions. However, the first one is faster and can be effective if the application knowledge base is sufficiently large. Both approaches need active participation of system analysts and decision-makers who interact with the SIS and consider hard-formalizing factors and dependences within the general procedure of the CBS SDC program selection.

The structural adaptation of the SCS takes a certain period of time, when the following main activities should be done:

– selection or construction (synthesis) of the CBS SDC models meeting given requirements;

– selection or construction (synthesis) of the CBS SDC algorithms for given conditions and given control problems;

– synthesis of software and data ware for given control problems;

– adjustment of the SCS parameters for current and predicted states of the SO and the CS (parametric adaptation);

– *sometimes it is useful to adjust models and algorithms that are not currently used in the CBS control processes.*

3. FORMAL STATEMENT OF STRUCTURAL AND PARAMETRIC ADAPTATION PROBLEMS FOR THE CBS SDC MODELS

The general multiple-model multi-criteria description of the CBS SDC problems presented in [Ivanov et al., 2004, 2005] will be used for formal statement of adaptation problems. It is assumed that there are several variants of the CBS SDC models inscribed in the set $\overline{\overline{M}} = \{M_1, M_2, ..., M_\Theta\} = \{M_\Theta, \theta \in \hat{I}\}$, $\hat{I} = \{1, ..., \Theta\}$, moreover the vector $\vec{\beta}$ of the CBS parameters includes the subvector $\vec{\beta}_0$ of the fixed CBS characteristics and besides of it the subvector $\vec{w} = \| \vec{w}^{(1)\mathrm{T}},\ \vec{w}^{(2)\mathrm{T}}, \vec{w}^{(3)\mathrm{T}} \|^{\mathrm{T}}$ of parameters being adjusted through SIS external/internal adapter or defined within structural adaptation.

These parameters can be divided into the following groups:

– $\vec{w}^{(1)}$ is a vector of parameters being adjusted through the internal adapter. This vector consists of two subvectors. The first one $\vec{w}^{(1,n)}$ belongs to the scheduling model, and the second one $\vec{w}^{(1,p)}$ belongs to the model of control at the phase of plan execution;

– $\vec{w}^{(2)}$ is a vector of parameters being adjusted through the external adapter. This vector consists of the subvector $\vec{w}^{(2,n)}$ belonging to the scheduling model and the subvector $\vec{w}^{(u)}$ including parameters of simulation model for the CBS functioning under perturbation impacts. In its turn, $\vec{w}^{(u)} = \| \vec{w}^{(2,o)\mathrm{T}}, \vec{w}^{(2,b)\mathrm{T}}, \vec{w}^{(2,p)\mathrm{T}} \|^{\mathrm{T}}$, where $\vec{w}^{(2,o)}$ is a vector of parameters characterizing objects in service; $\vec{w}^{(2,b)}$ is a vector of parameters, characterizing the environment; $\vec{w}^{(2,p)}$ belongs to the model of control at the phase of plan execution;

– $\vec{w}^{(3)}$ is a vector of parameters being adjusted within structural adaptation of the CBS SDC models.

Now we have the modified multiple-model multi-criteria description of the CBS SDC problems:

$$\vec{J}_\Theta\left(\vec{x}(t), \vec{u}(t), \vec{\beta}, \vec{\xi}(t), t\right) \to \underset{\vec{u}(t) \in \Delta_\Theta}{\mathrm{extr}}\,, \tag{1}$$

$$\Delta_\Theta = \{\vec{u}(t) \mid \vec{x}(t) = \\ = \vec{\varphi}_\Theta\left(T_0, \vec{x}(T_0), \vec{x}(t), \vec{u}(t), \vec{\xi}(t), \vec{\beta}_\Theta, t\right), \tag{2}$$

$$\vec{y}(t) = \vec{\psi}_\Theta\left(\vec{x}(t), \vec{u}(t), \vec{\xi}(t), \vec{\beta}_\Theta, t\right) \tag{3}$$

$$\vec{x}(T_0) \in X_0(\vec{\beta}_\Theta), \quad \vec{x}(T_f) \in X_f(\vec{\beta}_\Theta), \tag{4}$$

$$\vec{u}(t) = \| \vec{u}^{\mathrm{T}}_{pl}(t), \vec{v}^{\mathrm{T}}\left(\vec{x}(t), t\right) \|^{\mathrm{T}}; \tag{5}$$

$$\vec{v}(t)\left(\vec{x}(t), t\right) \in V_\Theta\left(\vec{x}(t), t\right), (6)$$

$$\vec{\xi}(t) \in \Xi_\Theta\left(\vec{x}(t), t\right); \ \vec{\beta}_\Theta \in \mathrm{B}, \tag{7}$$

$$\vec{x}(t) \in X\left(\vec{\xi}(t), t\right), \tag{8}$$

$$\vec{x}(t) = \| \vec{x}^{(g)\mathrm{T}}(t), \vec{x}^{(o)\mathrm{T}}(t), \vec{x}^{(k)\mathrm{T}}(t), \vec{x}^{(p)\mathrm{T}}(t), \\ \vec{x}^{(n)\mathrm{T}}(t), \vec{x}^{(e)\mathrm{T}}(t), \vec{x}^{(c)\mathrm{T}}(t), \vec{x}^{(\nu)\mathrm{T}}(t) \|^{\mathrm{T}} \tag{9}$$

$$\vec{y}(t) = \| \vec{y}^{(g)\mathrm{T}}(t), \vec{y}^{(o)\mathrm{T}}(t), \vec{y}^{(k)\mathrm{T}}(t), \vec{y}^{(p)\mathrm{T}}(t), |^{\mathrm{T}}, \\ \vec{y}^{(n)\mathrm{T}}(t), \vec{y}^{(e)\mathrm{T}}(t), \vec{y}^{(c)\mathrm{T}}(t), \vec{y}^{(\nu)\mathrm{T}}(t) |; \tag{10}$$

$$\vec{u}(t) = \| \vec{u}^{(g)\mathrm{T}}(t), \vec{u}^{(o)\mathrm{T}}(t), \vec{u}^{(k)\mathrm{T}}(t), \vec{u}^{(p)\mathrm{T}}(t),^{\mathrm{T}} \\ \vec{u}^{(n)\mathrm{T}}(t), \vec{u}^{(e)\mathrm{T}}(t), \vec{u}^{(c)\mathrm{T}}(t), \vec{u}^{(\nu)\mathrm{T}}(t) \|; \tag{11}$$

$$\vec{\xi}(t) = \| \vec{\xi}^{(g)\mathrm{T}}(t), \vec{\xi}^{(o)\mathrm{T}}(t), \vec{\xi}^{(k)\mathrm{T}}(t), \vec{\xi}^{(p)\mathrm{T}}(t), \\ \vec{\xi}^{(n)\mathrm{T}}(t), \vec{\xi}^{(e)\mathrm{T}}(t), \vec{\xi}^{(c)\mathrm{T}}(t), \vec{\xi}^{(\nu)\mathrm{T}}(t) \|^{\mathrm{T}}; \tag{12}$$

$$\vec{\beta}_\Theta = \| \vec{\beta}^{(g)\mathrm{T}}_\Theta, \vec{\beta}^{(o)\mathrm{T}}_\Theta, \vec{\beta}^{(k)\mathrm{T}}_\Theta, \vec{\beta}^{(p)\mathrm{T}}_\Theta, \\ \vec{w}^{(1)} = \| \vec{w}^{(1,n)\mathrm{T}} \ \vec{w}^{(1,p)\mathrm{T}}; \tag{13}$$

$$\vec{\beta}^{(n)\mathrm{T}}_\Theta, \vec{\beta}^{(e)\mathrm{T}}_\Theta, \vec{\beta}^{(c)\mathrm{T}}_\Theta, \vec{\beta}^{(\nu)\mathrm{T}}_\Theta \|^{\mathrm{T}} = \\ = | \vec{w}^{(1)\mathrm{T}} \ \vec{w}^{(2)\mathrm{T}} \ \vec{w}^{(3)\mathrm{T}} \|^{\mathrm{T}}; \|; \tag{14}$$

$$\vec{\beta}_\Theta = \| \vec{\beta}^{\mathrm{T}}_0 \ \vec{w}^{\mathrm{T}} \|^{\mathrm{T}}; \ \vec{w} = |^{\mathrm{T}}, \\ \vec{w}^{(2)} = \| \vec{w}^{(2,n)\mathrm{T}} \ \vec{w}^{(2,u)\mathrm{T}} \|^{\mathrm{T}}; \ \vec{w}^{(u)} = \} \\ \| \vec{w}^{(2,o)\mathrm{T}} \ \vec{w}^{(2,b)\mathrm{T}} \ \vec{w}^{(2,p)\mathrm{T}} \|^{\mathrm{T}} \tag{15}$$

The formulas define a dynamic system describing the CBS structure-dynamics control processes. Here $\vec{x}(t)$ is a general state vector of the system, $\vec{y}(t)$ is a general vector of output characteristics. Then, $\vec{u}(t)$ and $\vec{v}\left(\vec{x}(t), t\right)$ are control vectors. Here $\vec{u}(t)$ represents the CBS control programs (plans of CBS functioning), $\vec{v}\left(\vec{x}(t), t\right)$ is a vector of control inputs compensating perturbation impacts $\vec{\xi}(t)$. The vector $\vec{\beta}_\Theta$ is a general vector of the CBS parameters.

$$\vec{J}_\Theta\left(\vec{x}(t), \vec{u}(t), \vec{\xi}(t), \vec{\beta}_\Theta, t\right) = \\ = \| \vec{J}^{(g)\mathrm{T}}_\Theta, \vec{J}^{(o)\mathrm{T}}_\Theta, \vec{J}^{(k)\mathrm{T}}_\Theta, \vec{J}^{(p)\mathrm{T}}_\Theta, \vec{J}^{(n)\mathrm{T}}_\Theta, \\ \vec{J}^{(e)\mathrm{T}}_\Theta, \vec{J}^{(c)\mathrm{T}}_\Theta, \vec{J}^{(\nu)\mathrm{T}}_\Theta \|^{\mathrm{T}} \tag{16}$$

is a vector of the CBS effectiveness measures. Its components state control effectiveness for motion, interaction operations, channels, resources, flows, operation parameters, structures, and auxiliary operations. The indices «*g*», «*o*», «*k*», «*p*», «*n*», «*e*», «*c*», «ν» correspond to the following models presented in (Sokolov, 2004): models of motion control ($M_{<g,\Theta>}$); models of operations control ($M_{<o,\Theta>}$); models of channels control ($M_{<k,\Theta>}$); models of resources control ($M_{<p,\square>}$); models of flows control ($M_{<n,\Theta>}$); models of operations parameters control ($M_{<e,\Theta>}$); models of structures control ($M_{<c,\Theta>}$); models of auxiliary operations control ($M_{<\nu,\Theta>}$).

In the equations (2) and (3) the transition function $\vec{\varphi}_{\Theta}\left(T_0, \vec{x}(T_0), \vec{x}(t), \vec{u}(t), \vec{\xi}(t), \vec{\beta}_{\Theta}, t\right)$ and the output function $\vec{\psi}_{\Theta}\left(\vec{x}(t), \vec{u}(t), \vec{\xi}(t), \vec{\beta}_{\Theta}, t\right)$ can be defined in analytical or algorithmic form within the proposed SS; $Q_{\Theta}\left(\vec{x}(t), t\right)$, $V_{\Theta}\left(\vec{x}(t), t\right)$, $\Xi_{\Theta}\left(\vec{x}(t), t\right)$ are correspondingly allowable areas for program control, real-time regulation control inputs, perturbation inputs; B is a area of allowable parameters; $X\left(\vec{\xi}(t), t\right)$ is an area of allowable states of the CBS structure-dynamics. Expression (4) determine end conditions for the CBS state vector $\vec{x}(t)$ at time $t = T_0$ and $t = T_f$ (T_0 is the initial time of a time interval the CBS is being investigated at, and T_f is the final time of the interval).

CONCLUSIONS

We proposed dynamic interpretation of CBS structure dynamics control processes. The proposed interpretation of these processes provides advantages of modern optimal control theory for CBS analysis and synthesis. The dynamic models of structure reconfiguration process allow: - to seek for alternatives in finite dimensional spaces rather than in discrete ones; - to reduce the dimensions of the CBS synthesis and control problems; - to take into account the influence of structures on CBS performance.

The formal statement and decomposition of structural and parametric adaptation tasks were worked out for models of CBS structure-dynamics control (SDC). It was shown that two groups of additional parameters should be included in CBS SDC models for constructive implementation of the proposed adaptation concept: parameters being adjusted on the basis of real data of CBS state and of the environment state; parameters being adjusted via simulation experiments for different scenarios of future events.

Now we use our approaches to formalization for tasks of business continuity planning and disaster recovery planning.

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