

A CONCEPTUAL FRAMEWORK FOR MODELING COMPLEX ADAPTATION OF COLLABORATIVE NETWORKS

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The paper elaborates methodological basis of collaborative networks (CN) complex adaptation. We consider challenges and underlying principles of the CN complex adaptation. Subsequently, the DIMA-methodology of the integrated CN modeling is considered. The paper ends with the presentation of the five-level CN complex adaptation concept and summarizing DIMA-methodology application in the CN complex adaptation settings.

1. INTRODUCTION

On the modern global markets, collaborative networks (CN) emerge in a decentralized and dynamical way instead of former static hierarchical cooperation and value chains (Camarihna-Matos et al., 2005). The CN 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 CN complexity and uncertainty. Thus, specific modeling and optimization methodologies and techniques are required.

The CN execution is accomplished by permanent changes of internal network properties and external environment. It requires dynamic CN adaptation to the current execution environment and the goals and decisions of the configuration phase. Although the problem of the CN configuration was presented in details in a number of recent papers, the research on CN execution is still very limited.

2. CHALLENGES OF COLLABORATIVE NETWORKS ADAPTATION

Some recent research papers (Camarihna-Matos, 2005, Ivanov et al., 2004, 2005, 2006) have dealt with forming of CN management methodology. According to these works and the system theory basics, the large variety of the issues can be classified into the subclasses of CN analysis and synthesis (Figure 1).

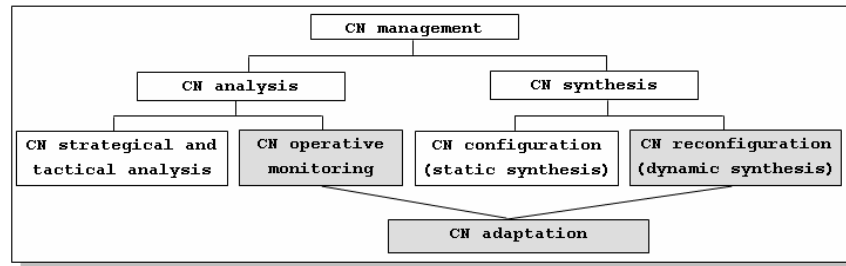


Figure 1. General classification of CN management issues

The most of the CN management issues are multi-disciplinary and cross-linked. In this paper, we pay particular attention to the CN execution. The elaboration of the CN operative adjustment methodology can be based on the conceptual framework of adaptive systems (Bellmann 1972, Casti, 1979). Generally, the adaptation is considered as operative adjustment according to the changing execution environment. However, the CN have particular features, which distinguish them from the technical systems being considered in the classical systems and control theories.

In terms of systems theory, a *complex system* is characterized by uncertain interactions of the elements, distributed goals, and is described by a number of different model classes (Mesarovic and Takahara, 1975, Casti, 1979, Sterman, 2000, Sokolov and Yusupov, 2004). The particular features of CN are mostly caused by their *complexity and uncertainty*, the main sources of which are the following (Ivanov, 2006):

Table 1 - Complexity and uncertainty of CN

Sources of CN complexity and uncertainty	
1	uncertain interactions of partners
2	considerable environmental uncertainty while CN functioning
3	activity of network elements and their free-will interactions
4	high structure and process dynamics
5	combination of centralized and decentralized management resulted in conflicting nondescript multi-criteria objectives of global and local nature,
6	a large number of uncontrolled internal and external factors,
7	considerable cross-linking of various CN management models.

The *uncertain interactions* of partners are the primary cause of the CN complexity and uncertainty. Moreover, additional complexity and uncertainty arise from the *activity of network elements* and their free-will interactions. Besides, operation of

the CN is accompanied by perturbation impacts (*disturbances*), which influence the plan execution and the network environment.

A collaborative network can be *defined as a complex open decentralized system with active independent elements*. The classic adaptation approaches do not consider such types of systems, so that they can be used only as conceptual framework. The usage of their formalizing and modeling techniques requires more detailed analysis.

The elaborated methodological basis of the CN complex adaptation contains the following main parts:

- conceptual model of the CN design and execution (Ivanov et al., 2006),
- conceptual framework of CN complexity and uncertainty analysis (Ivanov, 2006),
- system of categories and figures of CN analysis and synthesis under the terms of uncertainty,
- methodological framework of decision making under integrated risk modelling in CN,
- methodological framework for the embedding of risk factors into the CN modelling,
- methodological framework of the the CN complex adaptation
- mathematical models and algorithms of CN adaptation.

In this paper, we consider the methodological basis of CN complex adaptation. Section 3 considers the underlying principles of CN complex adaptation methodology. In section 4, the principles of the DIMA (Decentralized Integrated Modeling Approach)-methodology are discussed. The paper ends with the presentation of the concept of five-level CN complex adaptation and short description summarizing DIMA-methodology application in CN complex adaptation settings.

3. THE CN COMPLEX ADAPTATION UNDERLYING PRINCIPLES

Based on the conceptual framework of the CN complexity and uncertainty analysis, the following underlying principles of the CN complex adaptation can be defined.

- Not only original objects, but also *dynamics of their interactions, environment, and models* are subjects of planning. Planning process is interpreted as *continuous control of system dynamics under the terms of uncertainty*,
- Results of planning are not only ideal operations model, but also a set of the *CN execution scenarios, models, algorithms*, intended for system functioning support in case of disturbances and deviations,
- There is a certain period of time between the decision making about the CN, adjustment and the launch of the execution. Practically it leads to the parallel existing of the "old" CN and the new (reconfigured) one. It requires the *simultaneous synthesis of both new CN and the programs of the CN adjustment* based on the adaptation principles with the forecasting models for describing the CN functioning in the adjustment period,
- All the CN management phases (planning, monitoring, analysis, and adjustment) must be considered as a whole based on the unified methodological basis. This basis should ensure the *CN models cross-linking and inter-corresponding* as well as the adaptation of the processes and models to the *current execution environment*,
- The CN management problems differ from those in classical control theory and operation research by highly specific complexity and uncertainty features. That is

why the classical modeling techniques of the systems theory, control theory and operations research do not suit to the CN modeling because of insufficient complexity and uncertainty consideration. They must be enhanced by combining with the multi-agent paradigm, fuzzy-logic and evolutionary algorithms.

The presented challenges of the CN modelling let to draw a conclusion that a *multi-disciplinary integrated modelling framework* is needed (Camarinha-Matos and Afsarmanesh, 2004, Ivanov et al., 2005, 2006). The widespread agent-based frameworks can be considered only from the simulation point of view. The agents are implemented as a result of some partial heuristics. They do not have any grounded theoretical background, which would cover all the CN modelling aspects. The control theory frameworks have well-elaborated theoretical backgrounds, but they were developed for the technical systems and do not take into account the *goal-oriented (active) behaviour* of enterprises. The analytical frameworks of the operation research are not flexible enough and unsuitable for the large-scale problems. So these frameworks must be enhanced by the advantages of each other.

4. DIMA – AN INTEGRATED APPROACH OF THE CN MODELING

In the DIMA-methodology, various modeling approaches are not set off with each other, but considered as a united modelling framework. The multi-agent ideology is considered as a basis for the *active elements modelling*. The control theory serves as a *theoretical background* of systems analysis and synthesis. The general scheme of the DIMA-methodology is shown in Figure 2.

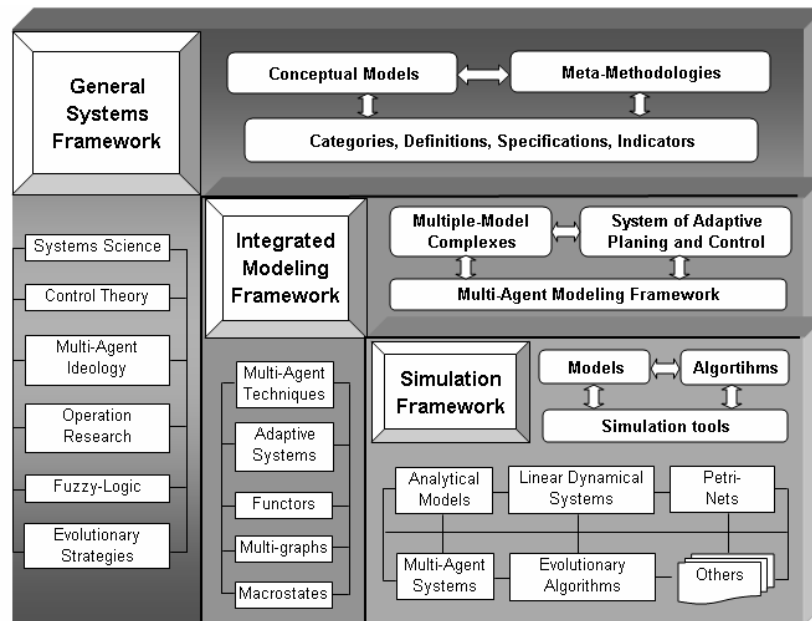


Figure 2. The general scheme of the DIMA-methodology

The main parts of the DIMA-methodology are: the general systems framework, the integrated modelling framework, and the simulation framework (Ivanov, 2006). *The general systems framework* defines conceptual models, meta-methodologies, and set of categories, definitions, specifications, indicators, etc., which are developed as combination of various theoretical frameworks (Ivanov et al., 2005, 2006). The advantage is that the conceptual basics of the CN modelling possess the elaborated in the systems science theoretical background and also takes into account particular features of the CN such as *emergent enterprise behaviour* by the MAS-ideology (*but not the MAS as software!*) using.

The integrated modelling framework defines the rules of the integrated multi-disciplinary mathematical models building. It proposes some constructive methods and techniques of (i) how to combine various model classes and (ii) how to model interconnected the partial CN problems. The main parts of the proposed integrated modelling framework are: *multi-agent conceptual modeling framework*, *multiple-model complex system of adaptive planning and control* (Ivanov et al., 2005, 2006).

The simulation framework integrates building of mathematical models and algorithms, and their implementation as software. Based on the integrated modelling framework, there are built multi-disciplinary models, algorithms, and simulation tools, which allow problem examining and solution in different classes of models, and result representation in the desired class of models (concept of “*virtual modeling*”). As examples of the models and algorithms the problems of the CN design, monitoring, adaptation were considered (Ivanov et al., 2004, 2005, 2006).

The DIMA-methodology represents a multi-disciplinary modeling framework, which meets the CN modeling particular features. The approach creates a unified methodological basis of the CN integrated modeling, from the conceptual level, mathematical modeling up to algorithms and simulation tools. One of the frameworks elaborated on the DIMA basis is CN five-level complex adaptation framework that will be discussed in the next section.

5. THE CN FIVE-LEVEL COMPLEX ADAPTATION

Conventional tools (such as APS and SCEN systems) evince considerable deficiencies (Stadtler, 2004). Their hierarchical functioning principle is not applicable in non-hierarchical approaches based on decentralized management. Their optimization cycle is slow and does not let appropriate taking into account operative oscillations in demand, material availability, lead times, production charges etc. Besides the *parametrical oscillations*, the structural and goal oscillations are to be considered. Various *structures changes*, such as organizational, technological, informational, financial, might let to the situation when initial CN *models* would be no more *representative and adequate*. The clients and network participants' goal changing also cause the models changing (adaptation) necessity. Such model changing is very cost-intensive and must be linked to the other aspects of the CN adaptation. The elaborated concept of the complex CN adaptation is built as a five-level structure. Each level characterizes certain control loop in accordance with the oscillations and deviations appeared (see Figure 3).

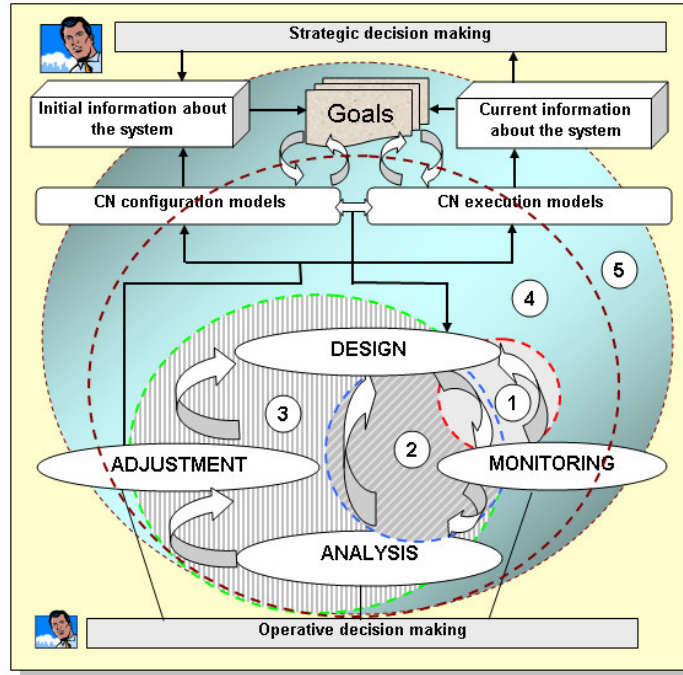


Figure 3. The five-level CN complex adaptation

Table 3 provides a systematical view on the levels of complex adaptation concept.

Table 3 - levels of complex adaptation concept

	Adaptation level	What is adopted?	How can be adopted?	Management horizon
1	Parametric adaptation	CN parameters	Capacities reconfiguration, rush orders, etc.	Operative
2	Structural-functional adaptation	CN structures	Operations reallocation, supplier changing, etc.	Operative-tactical
3	Goal adaptation I	CN goal	Project goal adaptation, e.g. delivery delay	Tactical
4	Model adaptation	CN models	Introduction of new parameters, structures, restrictions and goals	Tactical-strategic
5	Goal adaptation II	CN models and plans	Management goal adaptation (mission adaptation)	Strategic

Particular features of the concept are the control loops 4 and 5 intended for the CN model adaptation and the CN strategic management perspectives adaptation.

6. RESULTS AND IMPLEMENTATION

On the basis of the DIMA-methodology the methodological basis of the CN complex adaptation is elaborated. The main aspects of the CN complex adaptation and the ways of their solution are shown in the table 4.

Table 4 - The main aspects of the CN complex adaptation and the ways of their solution in the DIMA-methodology

The main aspects of the CN complex adaptation	The ways of problems solution in the DIMA-methodology
Interconnection of static and dynamical models	Categorical-functorial conception Structural-mathematical approach
Elements' activity and decentralized management; Personal (subjective) uncertainty	Multi-agent systems Evolutionary algorithms
CN structure dynamics; Simultaneous multi-criteria synthesis of the CN design and the CN execution programs; Simultaneous synthesis of both new (reconfigured) CN and the programs of the CN adjustment	Dynamical alternative multi-graph; Macro-structural macro states; Multiple-model complexes; Theory of structure dynamics control;
Cross-linking and interrelations of all CN life cycle models	Dynamical alternative multi-graph; Multiple-model complexes
Multi-criteria problems definition	General selection multi-criteria structure
Embedding of the uncertainty factors into the CN models	Conceptual frameworks of the risk management and adjustment in the CN

On the basis of the proposed CN complex adaptation framework the methodological framework of decision making under integrated risk modelling in the CN, the methodological framework for the embedding of risk factors into the CN modelling, and a number of mathematical models and algorithms of the CN adaptation were elaborated. Some of the obtained theoretical results are implemented as software SNDC (Supply Network Dynamic Control) and EVCM (Extended Value Chain Management) (Teich, 2003, Ivanov et al., 2004).

7. CONCLUSIONS

The paper presented methodological basis of the CN complex adaptation. We considered the challenges of the CN adaptation and the underlying principles of the CN complex adaptation methodology. The CN adaptation must be based on the *integrated multi-disciplinary methodologies and information systems*. We described the principles of the *decentralized integrated modeling approach (DIMA)*. Subsequently, the concept of five-level CN complex adaptation was presented. The paper ended with the summarizing of the DIMA-methodology application in the CN com-

plex adaptation. The practical relevance of this research lies in the development of the new generation of information technologies for the CN management support, which would make up the deficiencies of conventional APS, SCEM, LES and SCMo systems. The scientific relevance of the work lies in the area of generic model constructions development for the CN design and control, and contribution to advancing of the CN theoretical foundations.

8. ACKNOWLEDGMENTS

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