INTEGRATED MODELLING OF COMPLEX PROCESSES ON BASIS OF BPMN

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ABSTRACT

The description of designed complex of analytical logic-dynamic models supported by corresponding complex of dynamic simulation models developed on the basis of BPMN is offered in this article.

INTRODUCTION

Modern enterprises in such high-technology industries as shipbuilding, aerospace sector, fuel and energy system and the like, represent complex objects (CO) functioning in dynamically changing environments. Specified complexity is caused by the increase in number of composing subsystems and objects, and, respectively, rapid growth in number of internal links that reveals itself in such aspects as structural and functional complexities, the complexity of the choice of behavior, the complexity of decision making, the complexity of development and the complexity of modeling (Sokolov et al. 2006).

INTEGRATED MODELING OF COMPLEX OBJECTS FUNCTIONING

Studying of CO mentioned above requires joint use of diverse models and combined methods, and in some cases methodological and systematic basic concepts, multiple theories and scientific disciplines and conducting relevant interdisciplinary research. In this case to increase the level of relevance and reliability of the prognoses for the development of existing and projected CO it is necessary to carry out preemptive modeling and multi-variant forecasting of different scenarios for the implementation of the life cycles of the objects under review based on the concept of integrated modeling (IM).

Hereafter by IM of CO of any nature (a particular case of which is high-technology enterprises) we will mean the methodology and technologies of multiple-model description of the specified objects and combined use of methods, algorithms and techniques of multi-criteria analysis, synthesis and choice of the most preferable managerial decisions in connection with creation, use and development of the considered objects under various conditions of dynamically changing external and internal environments (Sokolov et al. 2006). The combined use of diverse models, methods and algorithms allows both compensating their actual drawbacks and limitations and, simultaneously, strengthening their advantages.

Moreover, IM of manufacturing processes (MP) of an enterprise is a step to its pro-active control (PaC). Unlike traditionally used in actual practice reaction control focused on rapid response and subsequent prevention of incidents, pro-active control involves prevention of their occurrence by creating in the relevant control system fundamentally new predictive and preemptive capabilities (such as parametric and structural model adaptation for past, present and future events) while forming and implementing control activities based on counteracting not consequences but reasons causing possible abnormal, emergency and critical situations.

Alongside with the set of the described advantages provided by IM of MP there appears a number of problems associated with its use. Thus, the first and, perhaps, the main distinctive feature of IM of MP is the necessity to effect coordination (conditioning) in the modeling process at the concept, model and algorithm, information and program levels of the models, methods and algorithms used. An emergent effect from IM can only be achieved while carrying out profound and reasonable conditioning of specific models based on the principles of coordination of decomposed models and multiple-model complexes (Trotsky and Gorodetsky 2009).

The second problem is the analysis of fulfillment of manufacturing program that is estimating the possibility of achieving preset MP quality indices considering existing space-temporal, technical, technological and resource constraints. The third problem involves the necessity to use widely modern automation technology for modeling at all stages of IM implementation. Otherwise IM will not be possible because of considerable consumption of time, funds and other resources that are to be allocated when unified automation technology is not available. Also, the third problem involves the stage of basic data input that remains exclusively labor-consuming even if automation technology is available.

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Moreover, while solving problems of structural and functional synthesis of CO of different classes in the framework of IM one may face a new challenge (Sokolov et al. 2006):

- large dimensionality and non-linearity of models describing the structure and variants of functioning of elements and subsystems of complex objects;
- necessity for constructive consideration in the models of uncertainty factors caused by the influence of external environment on a complex object;
- necessity of performing of multi-criteria optimization on a multiple-model complex.

OVERVIEW OF MODERN MEANS OF DESCRIPTION AND AUTOMATION PROCESSES FOR INTEGRATED MODELING OF COMPLEX OBJECTS

To overcome the listed difficulties to the present moment there were developed numerous instruments and automation environments of simulation modeling, such as GPSS, AnyLogic, BPsim, PowerSim, Simplex, Modul Vision, Triad.Net, CERT, ESimL, Simulab, NetStar, Pilgrim, MOST, KOGNITRON, etc. (Trotsky and Gorodetsky 2009). Recently the above mentioned automation environments were supplemented with intellectual information technologies (neural networks, multi-agent systems, fuzzy logic, technologies of evolutionary modeling, etc.). The absence of generally accepted mechanisms of conditioning of the models used both at technical and semantic levels blocks the joint application of diverse set of these instruments in the framework of IM.

Brief mention should be made on the capabilities of modern means of description and automation of the processes of IM of CO. It is known that at the initial stage of application of analytical-simulation modeling (ASM) for CO it is reasonable to make its description with the use of certain specification.

Currently there exists a dozen of the most popular languages for process description.

Petri net model was one of the first formal models designed for specification of process models. Weak expressive power and means for operational semantics of this resulted in the fact that in practice this model is mainly used as a basis for other languages (Laue and Müller 2016).

The group of standards of IDEF (Integrated DEFinition) amounts to 15 separate directions but only IDEF0 (functional modeling), IDEF1 (modeling of information flows) and IDEF3 (documenting of technological processes) came to be widespread.

The most common UML diagrams are focused more on the description of software architecture and support of object-oriented approach than on the description of technological and logistic processes.

The eEPC standard (Extended Event Driven Process Chain) well suits for the description of resource flows and flows of events but is not appropriate for the description of technological and logistic processes that use a great amount of different resources and means. Along with eEPC, BPMN (Business Process Model and Notation) is assigned for the description of the diagrams of business-processes familiar to both technical specialists and business users but it is of more interest in the context of integrated modeling of manufacturing processes. Among the advantages of BPMN the following ones should be mentioned: set of the applied primitives combines the advantages of other notations and allows to represent the models of distributed processes; provides a wide range of capabilities for formal representation of components of complex processes (Trotsky and Gorodetsky 2009).

The processes described in BPMN can be used to carry out both analytical and simulation modeling with application of corresponding software environments. It is referred to the extension of notation - BPSim standard (Business Process Simulation Interchange Standard). Unfortunately, currently there are no programming solutions that fully support this standard (Laue and Müller 2016). The application of IM of business processes assisted by BPsim may possibly increase the relevance of this standard.

COMPLEX OF ANALYTICAL LOGIC-DYNAMIC MODELS OF COMPLEX OBJECTS FUNCTIONING

Referring to analytical modeling one should take into consideration that parameters and structures of a complex object are constantly changing at different stages of its life cycle due to various reasons: objective and subjective, internal and external, etc. Mentioned in article (Sokolov et al. 2006) peculiarity is defined as structure dynamics of complex technical objects (CTO). In the same work it was shown that in order to maintain, increase or restore the level of working efficiency and capacities of the system it is necessary to control their inherent complexity. In particular, it is required to maintain control over their structures.

Taking into account above mentioned, it is offered to choose a dynamic alternative system-related graph with controllable structure as a basic mathematic structure, with the help of which it is possible to describe multiple-model structure dynamics of CO. Analysis of the possible options for creation of analytical models of control over CO structure dynamics showed that during the process of their creation, it is worthwhile to focus on the class of logic-dynamic models (LDM).

A significant theoretical and practical experience is accumulated in this area, and the results are provided in a number of works (Potriasaev 2006, Potriasaev et al. 2008).

Within the framework of the developed multiple-model complex, the following basic content of LDM is suggested: logic-dynamic models of control over operations, flows, resources, operation parameters, and structures.

Formally, the designed generalized model of enterprise structure dynamics control (SDC) represents finitedimensional non-stationary non-linear differential dynamic system with variable area of acceptable control actions with partially fixed boundary conditions at the initial and finite timepoints. For the purpose of this article, the objective of the enterprise SDC may be formulated as the task of searching optimal controls over this specified generalized dynamic model.

On the basis of above mentioned particular dynamic models a generalized LDM of enterprise functioning processes was formed:

$$M = \left\{ \begin{array}{l} \vec{u}(t) \mid \dot{\vec{x}} = \vec{f}(\vec{x}, \vec{u}, t); \\ \vec{h}_0(\vec{x}(t_0)) \le \vec{O}; \vec{h}_1(\vec{x}(t_f)) \le \vec{O}; \\ \vec{q}^{(1)}(\vec{x}, \vec{u}) = \vec{O}; \vec{q}^{(2)}(\vec{x}, \vec{u}) \le \vec{O}; \end{array} \right\} \quad (1)$$

where $\vec{x} = \left\| \vec{x}^{(o)T} \vec{x}^{(r)T} \vec{x}^{(s)T} \right\|^T$; $\vec{u} = \left\| \vec{u}^{(o)T} \vec{u}^{(r)T} \vec{u}^{(s)T} \right\|^T$ – generalized vectors of status and control over the enterprise manufacturing processes (index o refers to the model of the basic control over operations, r – to the model of control over resources, s – to the model of control over flows); $\vec{h}_0, \vec{h}_1$ are common vector-functions that set boundary conditions for vector $\vec{x}$ at the timepoints $t = t_0$ and $t = t_f$; $\vec{q}^{(1)}, \vec{q}^{(2)}$ are vector functions that set basic space-temporal, technical and technological constraints imposed on the process of the enterprise functioning.

Also, vector quality index of planning quality metrics with such components as vectors of particular indices of quality of programmed control over operations, resources and structures is offered:

$$\vec{J}_{gen} = \left\| \vec{J}^{(o)T} \vec{J}^{(r)T} \vec{J}^{(s)T} \right\|^T. \quad (2)$$

Problem and formal description of above mentioned task as well as the methods of its solution are specified in works (Sokolov 1992, Potriasaev et al. 2008).

For brevity sake a simplified variant of such formalization is given in this article. In this case the main technological and technical constraints defining the priority of serial-parallel business operation execution within the framework of the proposed complex of models (1) can be represented in the following way:

$$\Delta = \left\{ \mathbf{u} \mid \dot{x}_i = \sum_{j=1}^{m} u_{ij}; \sum_{i=1}^{n} u_{ij}(t) \le 1; \sum_{j=1}^{m} u_{ij} \le 1; u_{ij}(t) \in \{0,1\}; \right.$$

$$t \in (t_0, t_f] = T; \ x_i(t_0) = 0; x_i(t_f) = a_i;$$

$$\sum_{j=1}^{m} u_{ij} \left[\sum_{\alpha \in \Gamma_{1i}^-} (a_\alpha - x_\alpha(t)) + \prod_{\beta \in \Gamma_{i2}^-} (a_\beta - x_\beta(t)) \right] = 0;$$

$$\left. i = 1, \ldots, n; \ j = 1, \ldots, m \right\}, \quad (3)$$

where $x_i(t)$ is a variable characterizing operation completion status at the timepoint t; a_i is the set value of specified operation completion; $u_{ij}(t)$ is a control action taking on value 1, if operation D_i is completed using enterprise resource B_j, 0 – otherwise; $\alpha \in \Gamma_{1i}^-$, $\beta \in \Gamma_{2i}^-$ is a set of numbers of operations, directly precedent and technologically connected with operation D_i with the help of logical operations "AND", "OR" (alternative "OR"), T is time interval during which enterprise functioning is examined; t_0, t_f are the initial and finite timepoints. It is necessary to emphasize that the very recording of these constraints allows to refer the designed model (1) to the class of logic-dynamic models.

The most distinctive feature of the offered multiple-model complex is unification of control and flow modeling at the constructive level. Thus, for example, the model of programmed control over operations M_o affects on the model of programmed control over resources M_r with the use of control $\vec{u}^{(o)T}$. In its turn, programmed control $\vec{u}^{(o)T}$ has an impact on the model of flows control M_s through corresponding constraints. In its turn, the flow model M_s via boundary conditions determines initial timepoints when to start operation execution.

Due to the use of listed properties of the offered logic-dynamic model with its capabilities, the above-mentioned problems inherent to IM of complex object functioning can generally be solved at the constructive level.

The originality and the main advantages of the developed complex of analytical LDM complemented with the corresponding complex of dynamic simulation models consist of below mentioned points. Firstly, unlike earlier offered approaches to formal description of the considered class of logic-dynamic models of complex object control (Zimin and Ivanilov 1971), all basic space-temporal, technical and technological constraints having absolutely non-linear character are taken into account not while setting differential equations describing the dynamics of the relevant processes but while forming an area of acceptable control actions values. In addition offered dynamic interpretation of the complex of carried out operations allows to substantially reduce the dimensionality of the current tasks of optimization defined by the number of independent ways in the generalized graph of fulfilled works that form existing front of operations ready for execution. Secondly, constructive recording of nonstationarity of complex objects functioning (in this particular case manufacturing enterprise, for example, a shipbuilding yard) is carried out in the designed model on the basis of introduction of multi-dimensional dynamic matrix functions, such as "contact potential" and "potential of availability" (Potriasaev 2006). Thirdly, consideration of factors of uncertainty in the framework of the considered class of LDM describing ctructure dynamic control of control objects makes provision for adaptation of parameters and models structures, algorithms of structural dynamics control of CO with relation to previous, current and possible future conditions of control objects on the basis of multi-variant scenario prognosis and complex preemptive analytical-and-simulation modeling.

It is necessary to emphasize once again that with the application of the unified language the use of the offered variant of formalization of logic-dynamic control models of CO allows to describe both the processes of application planning of CO and the processes of plan completion, the processes of multi-variant prognosis of implementation of different scenarios of proactive control of CO.

Finally, in the framework of the offered formalization there were developed several approaches to the solution of the problem of multi-criteria optimization of SDC of CO based both on orthogonal projection of target set on the extensible set of attainability of dynamic model (1) (Sokolov et al. 2006) and on methodology of creation and use of integral index of quality and efficiency of CO functioning based on combined use of mathematic tools of fuzzy logic and experimental design theory (Adler et al. 1976).

CORRELATION OF THE ELEMENTS OF ANALYTICAL MODEL AND CONCEPTS OF BPMN

The considered complex of analytical logic-dynamic models relies on the corresponding conceptual model that includes the following basic notions: “operation”, “resource”, “objective”/”task”, “flow”, “structure”. Their detailed description was given earlier in work (Sokolov et al. 2015). Using the concepts listed above, one can set different classes of relations that in their turn are defined by those space-temporal, technical, technological, material, informational, and energy constraints, etc. being typical for specific subject area.

Detailed consideration of BPMN 2.0.2 and particularly the specific section “BPMN Process Execution Conformance” allows to make a conclusion about the possibility of using this notation with the purpose of formation of the set of basic data for the analytical model described above (see Table 1).

Table 1: Correlation of Elements of Analytical Model (AM) and BPMN

Concept of AM	Concept of BPMN	Data Available in BPMN	Extensible data for AM
Operation	Task	Identifier, name, resources used	Target volume of operation, interruption feasibility
Resource	Resource	Identifier, name, supply, cost of single use, cost of use per minute	Performance
Goal	–	–	Status variable values at finite timepoint
Flow	Sequence Flows / Message Flows	Identifier, name, input source, output source	Maximum Flow Rate
Structure	Pool	Identifier, name, resource scope, scheduled availability	Total output
Operation	Task	Identifier, name, resources used	Target volume of operation, interruption feasibility
Resource	Resource	Identifier, name, supply, cost of single use, cost of use per minute	Performance

As follows from Table 1, in the basis of BPMN there are not enough declared attributes to carry out analytical modeling. At the same time, BPMN originally has been created as an extensible language that allows to freely supplement the model description with necessary attributes without losing backward compatibility with its runtime environment.

Recorded in BPMN complex process with all necessary additional attributes can be executed in the earlier-developed environment of analytical modeling based on dynamic interpretation of the processes of carrying out the operations and distributing the resources of complex objects.

Thus, when using the model of complex process described in the extensible BPMN it is possible to simultaneously perform simulation and analytical modeling that allows to speak about conditioning of the model at the conceptual, model-algorithmic, informational and program levels.

Moreover, application of ASM allows to analyze more profoundly the models of complex processes described in the extensible BPMN, i.e. the application of the categories of control theory to the analysis of actual manufacturing tasks.

The advantage of extension of BPMN application area consists in considerable reductionof labor intensity of basic data input while conducting analytical modeling of actual manufacturing systems. For example, this refers to dozen thousands of variables and thousands of constraints when considering mathematical models for manufacturing processes in shipbuilding industry. While speaking on specified advantages, it is necessary to mention, firstly, that BPMN is focused on the simplification of data input and their visualization due to availability of graphic representation and limited number of concepts. Secondly, many enterprises already have manufacturing processes described in this notation; and consequently preparation of basic data for analytical modeling is limited to introduction of some additional concept attributes. Thirdly, the area of automatic creation of diagrams described in the form of a text form is being developed (Deeptimahanti and Sanyal 2009). For example, a number of works informing on successful implementation of the method of creation of BPMN on the basis of sequence of actions description in the form of text are known (Fabian et al. 2011, Henrik at al. 2012). In addition, there appears a possibility to apply modern technologies of modeling automation at all stages of complex modeling implementation.

SAMPLE OF PRACTICAL IMPLEMENTATION OF SHIPBUILDING ENTERPRISE INTEGRATED MODELING

The proposed in this article approach was used while carrying out the research work devoted to the investigation and selection of methods and algorithms of solving tasks of integrated and simulation modeling as well as multi-criteria analysis of the manufacturing systems in shipbuilding industry. BPMN was used to perform IM of MP including technological and auxiliary manufacturing processes. In Figure 1 one can find an extract of specified processes description.

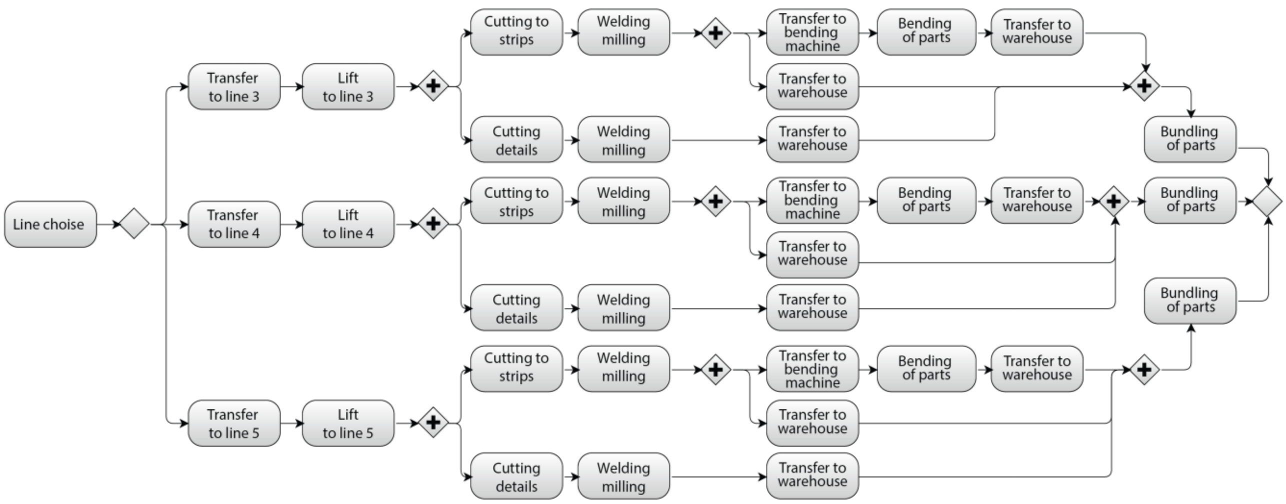

Figure 1: Fragment of Manufacturing Process in BPMN

Agreed use of simulation and analytical logic-dynamic model on the basis of BPMN application allowed to extend the set of calculated indices of shipbuilding enterprise functioning and to make computation, multi-criteria evaluation and analysis of structure dynamics of a shipbuilding enterprise under different variants of input effect.

It is important to emphasize once again that designed special software of IM of CO using BPMN represents unified modern automation tool for modeling built on service-oriented architecture and web-technologies.

CONCLUSION

Finally, it may be concluded that considering the problems of IM of MP of an enterprise in overall context of SDC allows, firstly, to directly connect those common goals for achieving of which the functioning of the enterprise is oriented with the goals that are executed in the course of manufacturing processes control. Secondly, to reasonably define and choose relevant sequence of the problems to be solved and operations to be executed; in other words, to synthesize technology of control over enterprise manufacturing processes. And, thirdly, to consciously find compromise solutions while distributing limited resources of an enterprise.

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