Simulation of manufacturing systems using BPMN visual tools

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Abstract. The paper presents results of the methodology research related to simulation of manufacturing systems in the context of electronic product manufacturing using BPMN visual tools. Modern production of electronic equipment is a complex, distributed, multi-factor system, regarded as a socio-production system, which is a part of a more global socio-economic system. The authors provided the algorithm to synthesize integrated visual models of distributed socio-production systems. There is also a brief overview of main BPMN visual tools. Based on the research findings, the authors provided recommended applications of BPMN tools.

1. Introduction

Modern economic systems are getting more and more sophisticated. They normally have a distributed nature and developed hierarchy of both main and auxiliary components. The development of a common, relevant and comprehensive description of the sophisticated socio-economic system with due consideration to all the aspects of its functioning and at the same time simply interpreted at each of the explored decomposition (inspection) levels is a pressing objective. At each level of simulation, the creation of the model complete, simple in its interpretability and non-redundant is a main challenge that researchers face.

The modern nature of elaborated manufacturing systems in the concept of digital economy Industry 4.0 leads to the problems that arise when the ongoing manufacturing processes, labour inputs of information system making for formal description, storage and processing of knowledge of their objects and processes are assessed. The variety of efficient approaches to formalization of knowledge on them is present in the variety of visual tools and models.

Among levels of visual models, with which knowledge of manufacturing systems is presented, first, there are structure-functional [1, 2] concept-abstract [3], and object models. Research on synthesis methods for a set of valid, reproducible and systemic models and means of a visual description of the processes that occur in complex systems are still relevant.

New approaches to visual simulation would be able to cover almost all the organisation levels in a scope of their operations. The achievement of synchronized parameters and structural composition of interconnected objects at various levels is one of the main objectives in development of integrated systems for visual simulation. One can describe modernity as heterogeneity of the methods used in visual models, with which we obtain and store knowledge of a subject domain, and this leads to the problem of cognition. Complex interpenetration processes between production sequences (conceptual, structure-functional, logical and physical levels of models, etc.) with disappeared boundaries between individual levels and with many attractive solutions at an intersection of levels of visual models generate encapsulation problems.
One may safely apply new tools of visual simulation to elaborated socio-economic systems, which will include tools to present almost all the management levels. These reasons have led us to the purpose of the study – to find algorithms for optimal modeling of production systems using BPMN visual tools. The peculiarities of using the BPMN toolbox will be considered on a simple example of analyzing the production of an electronic product.

2. Review of literature

Visual tools that formalize descriptions of elaborated systems have been in a common use since the 1940s. At the beginning, visual models were usually common for the description of difficult-informalization creative stages in designing in the form of conceptual frameworks based on methods of radiant thinking, multi-screen thinking and graphical decision-making (Lotus Blossom, hierarchical scheme, pyramid, fish skeleton, network diagram, etc.) [1-3]. In order to interpret concept and abstract visual models, methods of synectics, incidental stimulus, focal objects, TIPS, Koller, etc. were used.

In the 1970s, the methodology of IDEF (Integrated definition) structure-functional simulation was developed under ICAM (Integrated Computer-Aided Manufacturing) program aimed at automation in industry and implemented by the U.S. Air Forces (currently standardized in Russia at the level of State Standard) [4].

Along with purely visual methods and models for the description of elaborated manufacturing systems, various hybrid methods are also common that combine a visual calligraph and rigorous mathematical apparatus for processing of related elements. In the work [5], there is a discussion of the used finite automata theory to represent behaviour of objects with an elaborated structure. In the work [6], there is a discussion of specifics in simulation of manufacturing systems based on the theory of queuing system (QS).

In [7], there is a discussion of the ARCHIMATE technology for simulation of an enterprise architecture. In [8], to formalize project procedures, authors provided a model for a search for a solution using predefined performance indicators. This shows that tasks of facility management and automated control over manufacturing processes are not equivalent.

The works [9, 10] explore applications of visual methods and tools at various stages of designing and functioning of elaborated socio-economic systems as objects of digital economy and analysis of modern concepts of Industry 4.0 and Lean Manufacturing. On a separate note, the authors highlight visual tools in use in the development and support to elaborated software systems [11].

BPMN method (Business Process Model and Notation) is a promising approach to manufacturing system simulation. Developed by the Business Process Management Initiative (BPMI), since 2005, it has been supported and developed by the Object Management Group (OMG) [12, 13]. Unlike other methodologies for business simulation with a status of a brand (EPC) or national (IDEF0) standard, BPMN received an international status when the International Organization for Standardization issued ISO/IEC 19510:2013 standard (Information Technology - Object Management Group. Business Process Model and Notation). See specifics of BPMN application in [14-17].

BPMN main purpose is available notation for descriptions of business processes by all the users: from analysts, who create process diagrams, and developers in charge of introduction of business process execution technology, to managers and ordinary users, who manage these business processes and monitor their implementation. Thus, BPMN aims at bridging the gap between business process models and their implementation [12].

Support to BPMN and its further development by OMG has left its mark. UML promotion is a key activity for OMG, intended for simulation of object-oriented systems. In this connection, in the framework of BPMN, in simulation (diagram development), along with concepts and terms from the structural approach (action, control flow, data object, etc.), such concepts as message, message exchange and message flow are in use that are typical for the object-oriented approach. [12]

3. Materials and methods
According to the purpose, in BPMN graphic notation, elements (symbols) are grouped as follows: FlowObjects, Data, Swimlanes, ConnectionObjects, Artifacts. Basic elements of the BPMN visual language see in [12]. There are such basic elements as:

1. Symbols of flow objects
   - (Event) refers to the event, fact (situation, set of conditions or circumstances) that triggers or influences the further development of one or more processes. The event triggers actions or is their results. Unlike the function, the execution of which takes a certain period of time, the event refers to a specific point in time.
   - (Activity) refers to the action or set of actions performed by an executor in a process. Along with a name of the action, at the top and bottom of the symbol, there might be names of participants.
   - (Gateway) refers to the go-out, logical operator, used to denote merging and/or branching of the flow of events and actions.
   - (Conversation) refers to exchange of messages, description of an action that describes the information exchange between participants (pools) of interaction.

2. Symbols of data
   - (DataObjects) refers to the object of data, inventories or the information used or obtained as a result of actions.
   - (DataStores) refers to the database or its fragment that contains the information for performing of actions.
   - (Message) refers to the message that shows a fact of the information transfer between process participants.

3. Symbols of responsibility area
   - (Pool, Participant) refers to the pool, participant, structural unit, entrusted with implementation of an action (company, organization, department, service).
   - (Lane) refers to the path, position of an actor or role of a subject, entrusted with execution of an action, integral part of an organizational unit.

4. Symbols of connecting elements (lines)
   - (SequenceFlow) refers to the flow of actions; the control flow predefines a sequence (before-after) of events and actions that occur.
   - (MessageFlow) refers to the flow of messages, shows the exchange of information between participants of a process, and normally connects actions and/or pools of two participants in a process.
   - (Association) refers to the connection and shows relationship between data (artifacts) and flow objects, link to the messages exchange.
   - (ConversationLink) refers to the message exchange between interaction participants.

5. Artefact symbols (special-purpose characters)
   - (Group) is the cluster used for grouping of graphic elements that belong to the same category.
   - (TextAnnotation) - comment, text abstract, note (additional information) related to a displayed item.
   - The symbols of flow objects, data object and control flow have additional semantic dividing to display specifics of the events that take place, action execution, features of flow merging/branching, etc. [12]. Specifics is shown with an additional graphic image (icon, marker) placed inside the main symbol. Besides, event symbols might have various outlines and background colours.
   - All the diverse processes and ways of interaction between participants in BPMN are divided by type (sub-model). Each type has its own semantics and a set of displayed elements.

4. Results
Practical formalizing of documented description of social and production processes at various organizations has revealed a high need in simple and affordable software easy to learn, with which it is possible for the user in a quick and accurate way to simulate various aspects of production, build both decomposition and process (operating) models.
The authors will review specifics of BPMN toolkit application with a simple example of the production analysis of an electronic product (EP) (with the example of assembly of an electronic cell of TDA2030 amplifier of an element of a sensor system). Its assembly circuit is presented in figure 1.

**Figure 1.** Radio product assembly scheme (with the example of assembly of electronic cell of TDA2030 amplifier) (1 - fixing of printed circuit board, 2 - forming of component outputs, 3 - installing output on printed circuit board, 4 - visual control of brazed joints, 5 - board turnover, 6 - soldering with soldering iron, 7 - visual control of brazed joints, 8 - functional check).

The production analysis might have either the AS-IS form (audit), or TO-BE form. In both cases, deciding on a working object (group of objects) and organizational structure is a starting point. The assembly scheme is one of the main design and technological documents that describes the working object (in our case, standard sample, electronic product). Within the general framework of visual simulation, the assembly scheme is a model of an object at the concept-abstract level (single-screen models). It might be presented in a more generalized form as the MINDMAP model [3], which at the conceptual level discloses a production pattern, its properties and overall cause-and-effect relationship (figure 2).

**Figure 2.** Concept-abstract model of manufacturing process

Within the traditional structural-functional approach, based on the concept-abstract model and device assembly scheme, a structural-functional manufacturing model is developed [9] with due consideration to institutional structure data. Then, based on them, information and object models of the system (EP life cycle information support) [1, 2, 10, 11] are built.

The development of the business process model in BPMN methodology is based on the following algorithm:

1. Scheduling of the beginning and end of the process. In this case, a printed circuit board is a starting point, while a welded functioning electronic cell is a final one. Upon the decision-making about the starting and end points, it will be required to describe a linear sequence of actions.
2. Making a description of the linear sequence of actions with decision making about persons in charge.

3. Operations of persons in charge are decomposed to an atomic-scale level.

4. Model auditing (adequacy check).

Each stage is described with its own diagram in BPMN notation. The detailed approach to development of simulation diagrams for the business process with an example of diagrams for production of the electronic unit of TDA2030 amplifier, based on the assembly scheme is presented below.

The diagram of private (in-house) processes describes the process performed by one participant without other interaction participants shown in the diagram. A degree of detailing (abstraction) regarding a process participant might be arbitrary (organization, team, employee). It is allowed using a pool in the diagram with paths inside, but flows of actions and messages shall not go beyond the pool. Figure 3 shows the diagram of private (in-house) processes in notation of BPMN methodology for TDA2030 amplifier production.

**Figure 3.** Diagram of private (in-house) processes in TDA2030 amplifier manufacturing

The diagram has the beginning and end of a process, indicated with symbols as circles of a corresponding colour. Between the beginning and the end of the process, there is a sequence of operations, presented in a general form, ensuring manufacturing of TDA2030 amplifier.

**Figure 4.** Diagram of disclosed (open) processes in TDA2030 amplifier manufacturing
The diagram of disclosed (open) processes is used to display interactions between a private process and another process or participants, displayed as folded pools. Figure 4 shows the diagram of disclosed (open) processes in BPMN methodology notation in manufacturing of TDA2030 amplifier.

The diagram presented above more precisely describes the manufacturing process in comparison with the diagram of private (in-house) processes.

The diagram of process interaction is used to display a composition and execution sequence of two or more processes as pools, indicating interactions between their components with message flows. In figure 5, there is the interaction diagram for processes in notation of BPMN methodology in TDA2030 amplifier manufacturing.

![Diagram of processes interaction in TDA2030 manufacturing](image)

Figure 5. Diagram of processes interaction in TDA2030 manufacturing

The diagram shows decomposition of actions of each production participant. The description of the manufacturing model is given in the AS-IS form. Note that along with certain persons in charge of each operation, there is a parallel logical gateway equivalent to logical I. This means that the next stage in production will not be started until the previous one is completed.

5. Conclusion
The paper presents the system analysis method with the example of electronic product manufacturing using the BPMN toolkit. The authors see modern production as a complex, distributed, multi-factor system, part of the global socio-economic system. The authors provide the concept of model to build integrated visual models of distributed socio-production systems using BPMN visual tools. Based on
research findings, they also provide recommended applications of BPMN tools. Specifics of model building, main types of diagrams in BPMN notation are showcased in the context of TA2030 amplifier manufacture.

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References
[1] Koznov D 2008 Basics of Visual Modeling (Moscow: Internet University of Information Technologies)
[2] Il'in V 2006 Modeling of Business Processes. Practical Developer Experience (Moscow: Williams)
[3] Rezhikova E and Vlasov A 2011 Prospects for use of concept cards to build HTR knowledge base HTR. Application of Methodical Tools ed S Yakovenko et al pp 140–45
[4] Russia State Standard 2001 P 50.1.028-2001 Information technology to support the life cycle of products. Methodology of functional modelling (Moscow: IPK Izdatel'stvo standartov)
[5] Koznov D 1999 Finite state machine – basis for visual representations of objects’ behavior Object-oriented visual modeling ed A N Terekhov (Saint Petersburg) pp 101–22
[6] Mezentsev K 2011 Modeling of Systems in AnyLogic 6.4.1 Part 2 ed A B Nikolaev (Moscow: MADI)
[7] Kocheshkov A and Karpunin A 2017 ARCHIMATE technology – new standard for enterprise architecture modeling Inform. technology in design and production [in Russian – Informacionnye tehnologii v proektirovani i proizvodstve] 4(168) 3–9
[8] Prudnikov V 2018 Statement of procedure for implementation of prognostic evaluations of design solutions to design and technological problems Inform. technology in design and production [in Russian – Informacionnye tehnologii v proektirovani i proizvodstve] 1 43–9
[9] Vlasov A 2013 System analysis of the technological processes of the complex technical systems with visual models Res. J. of Int. Studies 10–2(17) 17–26
[10] Scheer A 1999 Business Processes Basic Concepts Theory Methods (Moscow: Vest’-MetaTekhnologiya)
[11] Demin A, Karpunin A and Ganev Yu 2014 Verification and validation methods for complex software systems Software products and systems 4 229–33
[12] Becmology 2019 Introduction to Description of Business Processes (Moscow: Becmology) Available at: http://becmology.ru/blog/business/bp01.htm
[13] Abdikeev N, Danko T, Ildemenov S and Kiselev A 2005 Reengineering of Business Processes (Moscow: Eksmo)
[14] Conforti R, La Rosa M, Dumas M and García-Barañuelos L 2016 BPMN MINER: automated discovery of BPMN process models with hierarchical structure Information Systems 56 284–303
[15] Conforti R, La Rosa M, Dumas M and García-Barañuelos L 2014 Beyond tasks and gateways: discovering BPMN models with sub-processes, boundary events and activity markers Lecture Notes in Computer Sci. 8659 101–17
[16] Wang Y, Wen L, Sun B, Wang J and Yan Z 2015 Discovering BPMN models with sub-processes and multi-instance markers Lecture Notes in Computer Sci. 9415 185–201
[17] De Giacomo G, Dumas M, Maggi F and Montali M 2015 Declarative process modeling in BPMN Lecture Notes in Computer Sci. 9097 84–100