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Interactive Game Modeling Concept for Personnel Training at the Industrial Enterprises

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Abstract: *The paper proposes* a formalized representation of technological processes and queuing network modelling (QNM) to assess the temporal characteristics that allow implementing the mechanisms of modeling and parameterization of the local environments of the individual processes; in addition, we have developed a Petri net for the compatibility of logical conditions to the technological processes implementation using an event approach; *The theoretical and methodological basis of the study* is the work of Russian and foreign scientists in the field of theory and practice of improving the managing complex, problems in the synthesis of organizational management structures, the application of analytical and empirical methods and models based on queuing and graph theory, as well as methods of simulation and statistical modelling based on the use of modern information technology and computer science. *The practical value of the work* lies is the development of methods for modeling the technological processes included in the simulation system of organizational management structures and others. The developed methods and algorithms have been tested and implemented for practical use in a number of companies and are currently used in the educational process at the Moscow Automobile & Road construction State Technical University (MADI).

Key words: Collaborative learning · Business game · Corporate learning system · Distance learning · Formal models and method · Petri nets · Queuing networks

INTRODUCTION

Organizational and technological level of the modern industrial enterprises is largely determined by the creation and application of effective mechanisms for the formation and implementation of strategic development plans and the effectiveness of the operational management of all production, logistics, organizational and economical processes that aim to achieve high production profitability, development and improvement of production. In this regard, building the organizational structure of the enterprise management is a complex multi-layered problem [1-25]. Principles and methods of the organizational structure development are directly dependent on many factors. The most significant of these are the specifics of particular production, sets of technological processes used, production volumes, capacity utilization, tactical, technical and quality parameters of products, standardization and certification issues, qualification level of technical, administrative and management personnel, management system applied, organizational and legal form, regulatory and legal framework of the enterprise, organization of internal and external documents circulation.

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Building the organizational structure in an industrial environment is a paramount task in relation to other tasks of the industrial process control. Formulation and solution of this task at a high scientific and technical level is a prerequisite for the effective organization of production, high competitiveness of products, growth of financial and economic indicators, continuous dynamic development and improvement of production.

Relevance of the topic is determined by the need to optimize the organizational structure of enterprise management as a "top-level" task to be primarily settled as a basic component of an effective and successful functioning of any industrial enterprise, regardless of the products purpose and production volumes.

Organizational Models Focusing on the Formation of Different Approaches and Principles of Production Processes Management: Control of all the production processes is implemented through the creation of a structural diagram of units with specific production factors and other factors discussed above. In current practice, there are the following approaches to the formation of units:

- Functional model: one unit corresponds to one function;
- Process model: one unit corresponds to one process;
- Contracting party-oriented model: one unit corresponds to one counteragent.

Contracting party-oriented model is useful in a limited number of customers and is used by the following scheme: one unit corresponds to one customer or a group of customers.

The most common are the functional and process models as well as their various modifications. The paper shows that the matrix structure combines the principles of functional and process systems construction.

Direct subordination means an employee or a department is directly subordinated to another subject of industrial relations of a higher level. In this case, the head of the unit gives orders to the subordinated subject in order to execute orders on administrative and functional issues. Direct subordination is the basis of creating a hierarchy of positions and departments.

Functional subordination is the subordination of one entity (an employee or a department) to another entity within the implementation of certain functions. In this case, the head of the unit only gives orders to the subordinated subject within the framework of subordinate entity functions.

To simulate the behavior of staff in decision-making when managing production and technological processes, the thesis proposes to use an interactive simulation.

The analysis of interactive gaming simulation revealed the main options for organizing the business game (Fig. 1) and characterological features of the business game (BG), presented in the form of a functional diagram (Fig. 2) [1-25].

Mathematical models that describe the technological, organizational and other processes in the gaming simulation are subjected to numerical investigation with subsequent quantitative decisions taken based on them. The use of computer technology is not a pre-requisite, however, it contributes to the successful implementation of simulation process, providing several advantages [1, 2, 4, 6-8].

The time factor that is present and accounted for in BG imposes certain conditions on the process and outcome of the game. Changing the time scale makes it possible to cut down processing time, measured in days and years, to minutes and hours, respectively. Due to repeated playback of different situations, the presence of feedback in the simulation system enables the participants of the game to learn and subsequently take more effective decisions on the management of production processes through analyzing the results.

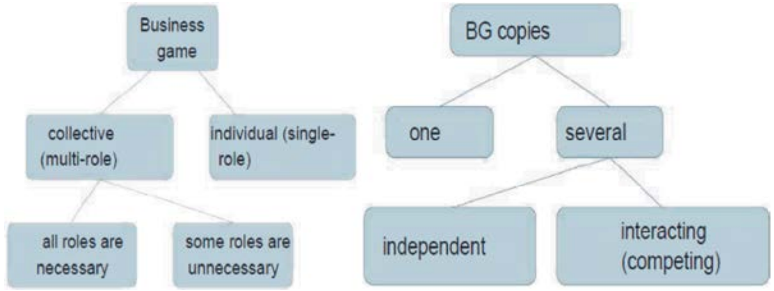


Fig. 1: Types of business games

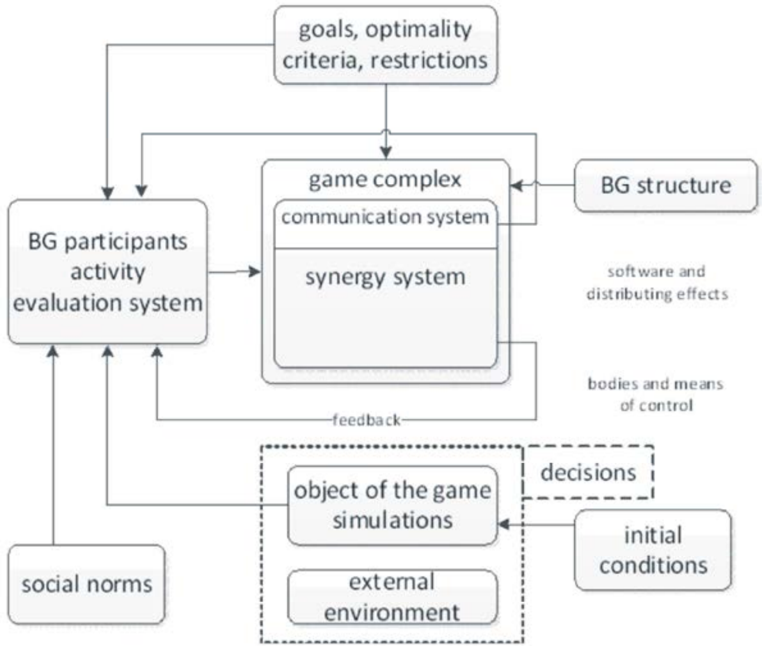


Fig. 2: Business game (BG) functional diagram

The use of BG in the process of personnel training involves the use of didactic methods that are widely used in teaching. Didactic principles of visibility, activity, accessibility, theory and practice connection, science, interest and other principles are successfully used. Each BG implements these principles in appropriate didactics in one way or another.

Analysis of Methods for Simulating Production and Technological Processes in Terms of Temporal Characteristics: In terms of queuing theory, in the general case, the system analysis model can be represented as a closed or open QNM with arbitrary receipt and service of applications in the network nodes, the presence of logical conditions (interlocks) and different disciplines of service [6-8]. This analysis model is given by the following sequence: M=(Q, El, P, L, ω, J, Ω), with Q being a set of nodes; El ={1,∞}-applications sources capacity; P={P^l}-set of stochastic transition matrices for applications in the network; P^l={p^l_{ij}}-probability matrix of l type applications transition from I node to the j node in the network; $l \in L$; L-multiple types of applications; ω: $Q \rightarrow \Theta$; Θ-set of allowable types of QNMs in the network nodes; J: $Q \times L \rightarrow B$, B = {$b_i(l)$, $\sigma_i^2(l)$}-a set defining characteristics of service in the network nodes for l type applications, with $b_i(l)$ and $\sigma_i^2(l)$ being the mean and variance of l type application service time in i node; Ω = {O, 1, 2, 3,...}-detects the presence or absence of logical conditions - interlocks in the network: O-interlock not present; 1-interlock associated with the presence of a limited size buffer; 2-interlock associated with the simultaneous process of an application by several network resources; 3-interlock associated with the presence of a limited number of applications in a certain network segment;...-other interlock types.

Such model can be analyzed using accurate, approximate, simulation or hybrid methods. The choice of analysis method depends on the set of random processes used for the description and analysis of the system, its structure and type, the assumption of independence or dependence of random variables, the distribution function, etc.

It is proposed to use Petri nets in the work to simulate logical conditions of the control mechanisms of technological and production processes. In recent years, the classic networks were substantially expanded to colored, time-related and other hierarchical structures. These extensions contribute to the modeling of complex processes in which data and time are important factors. There are several reasons for using Petri nets in technological processes modeling.

Formal semantics: the process described in terms of a Petri net has a clear and precise definition because semantics of the classical Petri nets is formally defined.

Graphical representation: Petri net is a graphical language that simplifies communication with end users.

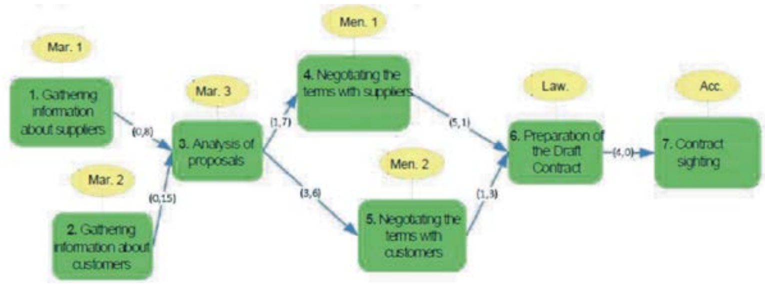


Fig. 3: Technology graph of a business process

Expressiveness: Petri nets support all the entities required for technological process modeling. All kinds of routing that exist in modern process control systems can be simulated.

Analysis: Petri nets are characterized by a variety of analysis techniques. These techniques may be used to verify the properties of Petri nets (safety, invariance, deadlocks, etc.). From this point of view, it is possible to evaluate the effectiveness of alternative processes using standard analysis based on Petri nets.

Independence from the manufacturer: Petri nets provide a mathematical tool for process modeling and analysis independent of specific tools.

Furthermore, the paper will provide an analysis of software technologies for creating simulation tools for manufacturing processes, organizational structures and business games, which revealed feasibility of the following technologies: COM (Component Object Model) for implementation of the endpoints of bilateral BG client and server parts cooperation; ActiveX-for the creation of separately developed and compiled, dynamically linked objects that implement the user interface and the logic of multiple-part game scenarios when combined in the person of one player; TCP/IP Sockets-for two-way data transfer between endpoints for client and server parts of the BG; frame technologies (TFrame, reusable embedded pieces of user interface and logic)-for the implementation of scripts for the specific parts of BG or their automatic models; multithreading-for efficient query processing of BG client parts by the server side; FirebirdSQL (free compact database with transaction support)-for BG data storage, gaming composition, advancing log and the final results of the BG; XML-XML-as a file format for the intermediate storage, import and export of technological processes structure model and the organizational structure description in the form of QNM and simulation process parameters.

Methods of the Formalized Representation of Technological Processes in the Form of QNM: The organizational structure is largely determined by the structure of technological processes flow [6-8, 10, 15, 21]. For this reason, construction of a model structure for technological connections management is of interest. Technology graph over a set of N vertices is a directed graph without loops $T=<N, E_T>$, arcs of which $(u, v)\in E_T$ are mapped to the r- dimensional vectors $l_T(u, v)$ with non-negative components: $l_T:E_T\rightarrow R^r_+$. The graph vertices are the basic operations of the company technological processes or end executors. Relation $(u, v)\in E_T$ in the technology field signifies that there is a r-component flow of raw materials, energy, information and other resources from u-element to the v-element; $l_T(u, v)$ vector components define the intensity of each component of the flow. An example of a process graph with two-component flows is shown in Fig. 3. The numerical values of these components for each arc of the graph process describe the amount of information needed for decision-making.

The graph vertices simultaneously represent operations and workplaces of the technological process. The implementation of technological chain stages is performed by certain performers among whom there is subordination and distinction. Each employee exercises a specific set of technical operations. In this case, the load on each employee is different. As a result, the production cycle generates an appropriate organizational management structure with the necessary number of personnel.

In this paper, it is assumed that each production and manufacturing process may be repeated any number of times. Moreover, individual implementations may be parallel in time, using the same R resources. It is assumed that each implementation is launched by a certain initiator. In particular, the process can be represented by a track with repeating functions (Fig. 4).

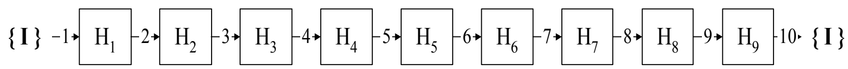


Fig. 4: An example of an abstract business process track

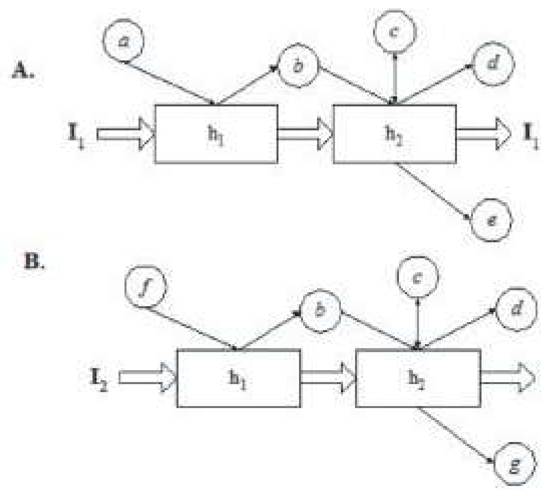


Fig. 5: An example of similar process descriptions

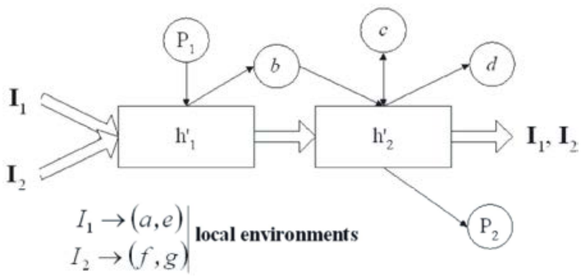


Fig. 6: Unified description of the Z_1 and Z_2 processes

This paper considers the case of assigning processes that are very similar in description, for example Z_1 (track A) and Z_2 (track B) (Fig. 5). Both tracks use equivalent operators h_1 and h_2, but they interact with different input and output parameters. In this paper, we propose a method for combining the description of such processes. To solve the problem, the initiator detection is enhanced with a possibility of including the parameters. An ordered set of parameters represents the local environment of the process [4, 6-8, 22 - 25].

In this case, we can propose the following diagram of folding the descriptions of two processes (Fig. 5) into one general description (Fig. 6).

As can be seen from the figures, $\mathbf{I}_1$-initiator is associated with the local environment (*a*, *e*), whereas $\mathbf{I}_2$-initiator-with the local environment (*f*, *g*). The operator h_1 is modified into the operator h'_1, which is linked to the parameter *b* and the first parameter of the initiator's local environment. The operator h'_2 is connected to the parameters *b*, *c*, *d* and the second parameter of the initiator's local environment. The operators h'_1 and h'_2 shall mean *the union*. The initiators $\mathbf{I}_1$ and $\mathbf{I}_2$ are *simultaneously* present in this diagram.

These arguments can be extended to the case of ***n*** parallel running processes. Processes generated by a track or a structure using the combined elementary operators and the local environment will be *similar*.

Thus, for the model «Execution of customer orders» the process is launched by an input stream P^n_1 (applications received by the organization) and R_1 (supply of goods required for the execution of orders) and ends with an output stream P^n_2 (applications rejected), P^m_5 (request to the warehouse for goods reservation, with m being the number of request), P^j_7 (application to the manufacturer for the supply of products, with j being the number of application submitted to the manufacturer), P^n_{10} (orders delivered to customers) and P^n_{11} (orders collected by the customer).

The implementation of the «Execution of customer orders» (Fig. 7) includes 5 operations (O_1, O_2, O_3, O_4 and O_5), which have input and output objects, converted as a result of their implementation.

This way, the input objects for «receiving and processing requests» operation (O_1) are requests received by the company (P^n_1) and the rejected requests (P^n_2) and requests accepted for execution (P^n_3) are output objects. The logic of converting the input object flow into the output is shown in Table 1.

In order to properly estimate the time and cost of performing an operation, refinement will be launch at the fourth stage. It will identify the sequence of actions performed, during which the objects (i.e. customer orders) that have a certain set of characteristics will be converted into concrete operations and transferred from one activity to another. So, for the operation «receiving and processing requests», an object will be characterized by order identification number ($O_{1.1}$), name of the contracting authority ($O_{1.2}$), bank account of the customer ($O_{1.3}$) and other. When switching to another operation, objects inherit a set of characteristics from the previous operation, gain new ones and lose the ones that are not necessary for the current operation.

It is assumed that the technological process operation flow can be represented in terms of the classical Petri net, which possesses certain properties. Let's

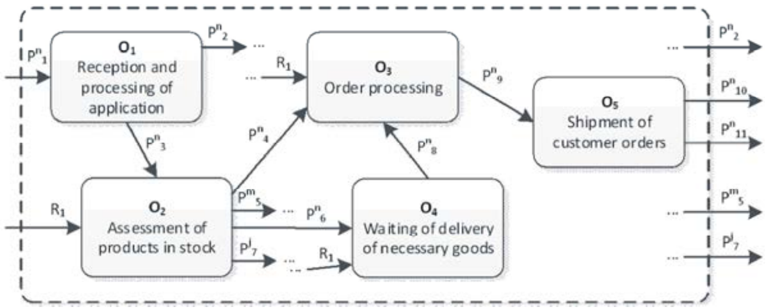


Fig. 7: «Execution of customer orders» process diagram

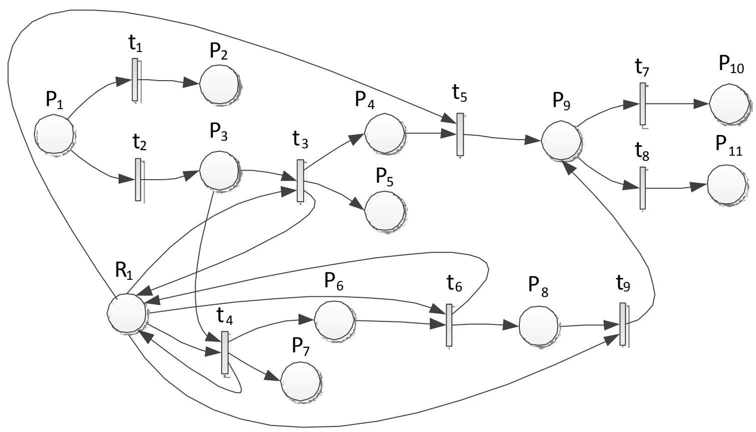


Fig. 8: Petri net for the «Execution of customer orders»

Table 1: Converting the objects flow

Operation	The flow conversion logical formula
O_1	$P_1 \to P_2$ or $P_1 \to P_3$
O_2	$P_3R_1 \to P_4P_5R_1$ or $P_3R_1 \to P_6P_7R_1$
O_3	$P_4R_1 \to P_9$ or $P_8R_1 \to P_9$
O_4	$P_6R_1 \to P_8R_1$
O_5	$P_9 \to P_{10}$ or $P_9 \to P_{11}$

consider the model of a system Σ_0, whose task is to carry the incoming applications. The model implements an event approach, under which the functioning of the system is represented as a sequence of events that take place under appropriate conditions. An incident changes the conditions, allowing new developments occur and so on. In this case, the system Σ_0 can be described as a Petri net

$$\Sigma_0 = \{\theta, P_0, T_0, F_0, M_0(0)\}, \quad (1)$$

with θ being the discrete time, $\theta = 0, 1, 2,...$; $P_0 = \{p_1, \ldots, p_n\}$ - a set of nodes, called positions; $T_0 = \{t_1, \ldots, t_m\}$ - a set of nodes, called transitions; $F_0 = F_0^P \cup F_0^T$ - incidence function; $F_0^P = |f^p_{ij}|$ -$n \times m$ matrix, $F_0^T = |f^t_{ji}|$ -$m \times n$ matrix, f^p_{ij} = 0-arc multiplicity from p_i to t_j, f^t_{ji} = 0-arc multiplicity from t_j to p_i, $i = 1, \ldots, n, j = 1, \ldots, m$.

Petri nets that simulate the Σ_0 system class considered in this paper, have the following features.

- These networks are safe; resource in each of their $m_i(\theta)$ position can be 0 or 1. In this case, $m_i(\theta) = 1$ indicates that there is a condition to perform a specific system function. Accordingly, at $m_i(\theta) = 0$ this condition is not fulfilled.
- Multiplicity of all arcs of the considered network f^p_{ij} and f^t_{ji}, $i = 1, \ldots, n$, $j = 1, \ldots, m$ can only take the values 0 or 1, indicating either no relationship between the nodes, or transfer (or consumption) of a single resource from node to node. Due to such relations, the network security is provided.

Petri nets for modeling the "Implementation of customer orders" has the configuration shown in Fig. 8.

In this case, the network transitions-t_l, l = 1..9-match the set of operations on the process implementation. Positions-P_i, i = 1..11-match the transition conditions. The arrows indicate the arcs connecting the vertices of different types. The objects-requests from various client enterprises (P^j_i, i = 1..11, j = 1..n_i-j-request, entering the i-position), received by the organization and resources (R1), corresponding to the goods in stock, act as markers (chips).

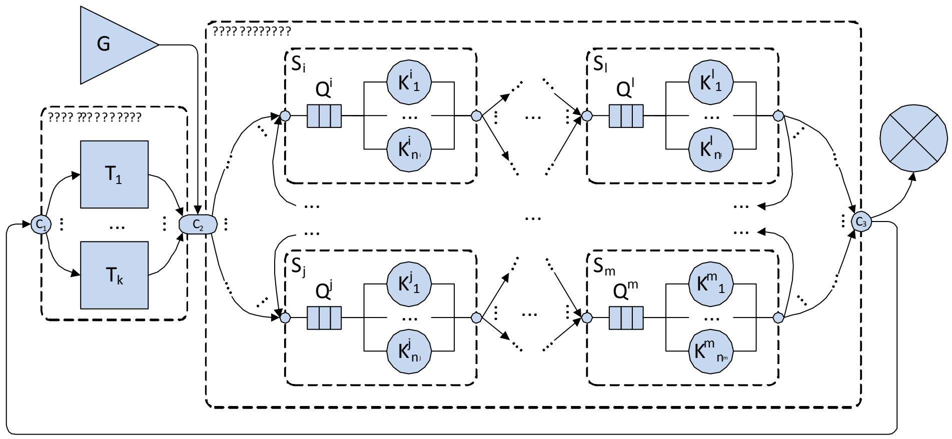


Fig. 9: The general structure of QNM supported by simulation modeling tool environment

Customer requests (P^1_1, P^2_1, …, P^n_1) received by the organization match the network input position (P_1). Output position (P_{10} and P_{11}) are complete orders delivered (P^n_{10}) or received by the customer on the spot (P^n_{11}).

Thus, the system describes the topology of process models and rules of control transfer between the stages. At the physical level, these limitations corresponds to the study of the system without considering the resource flow in the system.

The Presentation of Technological Processes as QNM Models with Descriptive Elements in the Form of Petri Nets: A graphical editor that allows to structure parallel-sequential processes (Fig. 9) using visual means has been developed; serving nodes represent the multichannel queuing systems (servers) and the arcs are marked with transition probabilities between them [8].

Server block may have any structure and consist of an arbitrary number of nodes. The terminal block can also consist of an arbitrary number of nodes connected in parallel. Points C_1, C_2, C_3 in the QNM diagram are fixed nodes of the diagram, intended to be connected to a single generator network, terminal block, server block and a circuit network by snapping to them with arrows of the corresponding blocks. Each server S_i in the diagram editor is represented as a single unit. Placement sequence of blocks in the diagram and their connection is arbitrary.

The transition probabilities along the arcs between the network nodes are bound by the following restrictions: $\Sigma P(C_2, \bullet)=1$, $\Sigma P(S\ , \bullet)=1$, the transition probabilities for all other arcs equal to 1.

The multitude $\boldsymbol{X}$ of all parameter nodes in the system can be represented as:

$$X = P^{(g)} \bigcup_{i=1..M^{(t)}} P^{(t)}{}_i \cup \bigcup_{i=1..M^{(s)}} P^{(s)}{}_i, \quad (2)$$

where $P^{(g)}$ is the multitude of generator parameters; $P^{(t)}{}_i$-the multitude of i-terminal parameters; $M^{(t)}$-the number of parameters in the QNM; $P^{(s)}{}_i$-the multitude of i-server parameters; $M^{(s)}$-the number of servers in the QNM.

The multitude $\boldsymbol{Y}$ of all system characteristics is represented as:

$$Y = H^{(sys)} \bigcup_{i=1..M^{(s)}} H^{(s)}{}_i, \quad (3)$$

where $H^{(sys)}$ is the multitude of system characteristics; $H^{(s)}{}_i$-the multitude of i-server characteristics; $M^{(s)}$-the number of servers in the QNM.

The following set of parameters is formed for the construction of functional relationships

$$Y^{(v)}=f(X^{(v)}, X^{(c)}, c^1{}_{start}, t^1{}_{end}, c^{cm}{}_{start}, t^{cm}{}_{start}), \quad (4)$$

$X^{(v)}=\{x^{(v)}{}_j\}$-the multitude of system nodes' variable parameters,

$j=1..K^{(v)}$, with $K^{(v)}$ being the number of system nodes' variable parameters,

$X^{(v)} \subseteq \boldsymbol{X}$, with $\boldsymbol{X}$ being-the multitude of all parameter nodes in the system.

$X^{(c)}=\{x^{(c)}{}_j\}$-the multitude of system nodes' invariable parameters,

$j=1..K^{(c)}$, with $K^{(c)}$ being the number of system nodes' invariable parameters,

$X^{(c)}=\boldsymbol{X}/X^{(v)}$, $K^{(v)}+K^{(c)}=|\boldsymbol{X}|$

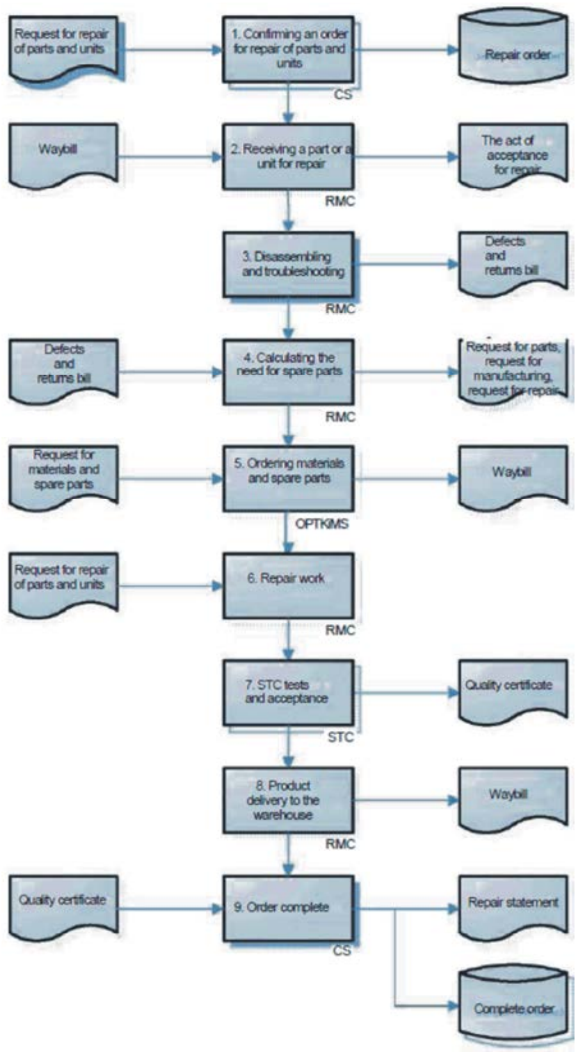


Fig. 10: Process description

$Y^{(v)}=\{y^{(v)}_j\}$-the multitude of dimensional vectors N, one per each output (the one for which to the relation of variable parameters and system nodes is built) system or node characteristic.

$Y^{(v)}\subseteq \boldsymbol{Y}$, with $\boldsymbol{Y}$ being the multitude of all system and node characteristics.

$$|\{I\}|=|x^{(v)}_j|=|y^{(v)}_j|=N$$

$\langle c^1_{end}, t^1_{end}\rangle$-value of the number of processed applications and modeling time for stop condition of one model run;

$\langle c^{cT}_{start}, t^{cT}_{start}\rangle$- value of the number of applications processed and simulation time for the condition to start collecting statistics during each model run.

Thus, there has been developed a simulation model in the form of a nine-phase QNM (Fig. 11) for the registration process, accounting and control of components repair order execution (Fig. 10). FIFO is used as a service discipline [6-12].

For the uniform intensity distribution of applications received and the implementation of the operations λ~R(1.5, 5), μ_1~R(0.2, 0.5), μ_2~R(0.3, 0.5), μ_3~R(1, 3), μ_4~R(0.3, 0.6), μ_5~R(0.4, 0.5), μ_6~R(1, 5), μ_7~R(0.5, 1), μ_8~R(0.5, 0.6) and μ_9~R(0.1, 0.2), sample path diagram of the process and the autocorrelation function of its implementation time are shown in Fig. 12

Analysis of the process time autocorrelation function showed that it has overextended nature, i.e. the process is rather slow.

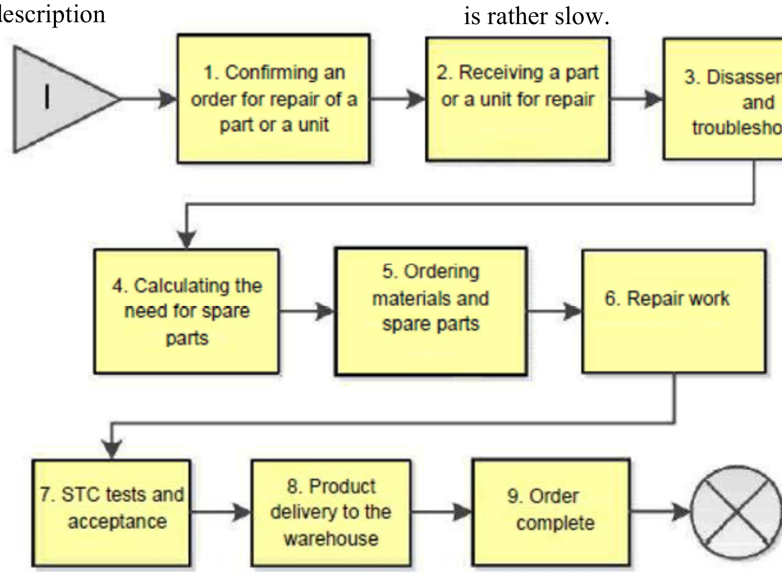
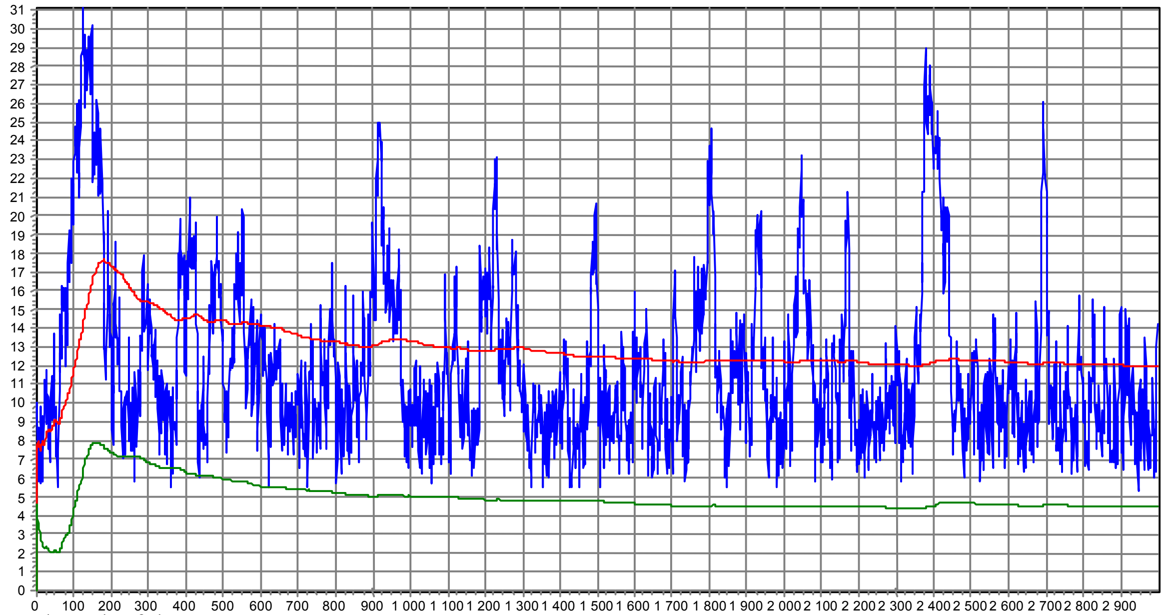
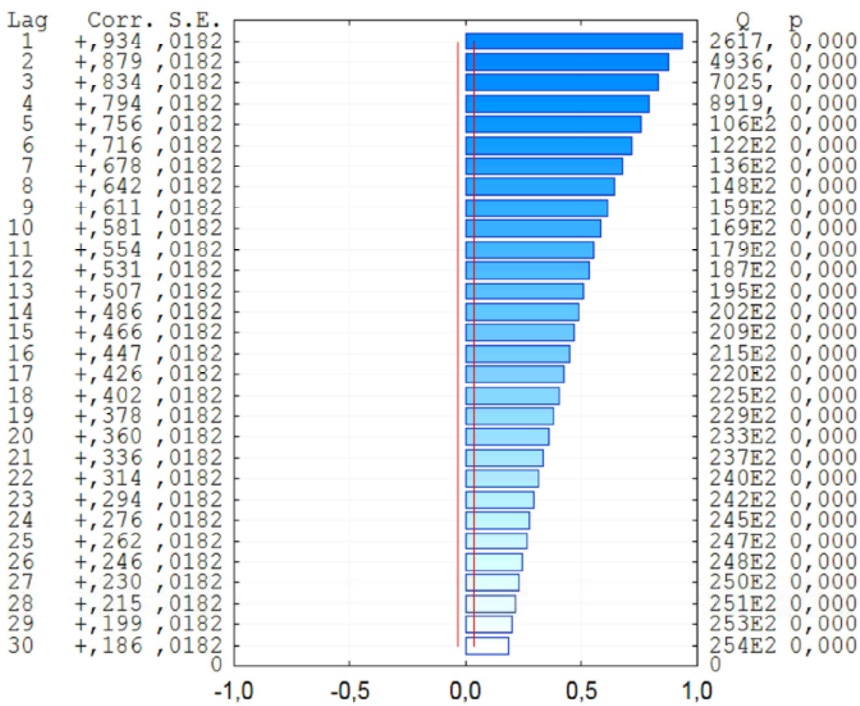


Fig. 11: Nine-phase QNM model for order execution



a) sample path of the process



b) autocorrelation function

Fig. 12: Characteristics of repair order execution

CONCLUSION

Thus, we have carried out a systematic analysis of the methods and models used to describe production and technological processes in industrial enterprises and associations, organizational structures, process control and business games aimed at assessing the personnel qualifications in terms of the effectiveness of decision-making.

There has been developed a formalized process-oriented description of the parallel to serial execution of process flow diagrams' individual stages in the common space of resources (such as technological lines, personnel, energy resources, etc.), which allows to implement the mechanisms of modeling and parameterization of local environments of the individual processes.

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