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Simulation Design of Manufacturing Processes and Production Systems

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***Abstract* –The paper addresses up-to-date approaches to model design of manufacturing processes and production systems. In view of high complexity and labor intensity of designing manufacturing processes and production systems, it is quite expedient to use computer facilities. It is most appropriate to predict the results of designing manufacturing processes and production systems by means of simulation modeling. The stages of creating manufacturing process models, computer modeling and simulation modeling are described. The presentation of ongoing events with a full retention of their logical structures and time sequence takes place in simulation modeling of production systems or manufacturing processes. Simulation modeling makes it possible to determine the most accurate characteristics of manufacturing processes (technical performance, the time of processing and assembling, the use or load factors etc.). Some examples of practical application of models in design are given. It is revealed that model design is an optimal if not the only possible way for improving the structure of production systems and technological processes as well as for their control.**

Keywords - modeling, simulation, design, manufacturing process, production system

I. Introduction

Optimization or reorganization of production and manufacturing processes is necessitated by many factors and is caused by the instability of production systems. At the same time any manufacturing system is characterizes by complex relations between elements of technological, transport and warehouse subsystems. To reveal and analyze these relations is a difficult engineering task.

Therefore it is quite difficult to evaluate in advance a potential profit or loss due to project implementation. Decision making is traditionally based on previous experience and intuition. However, such approaches are very risky and do not conform to up-to-date technologies of making managerial decisions. The most effective way of analyzing production processes is simulation modeling. The essence of simulation modeling lies in the fact that a process is simulated by means of arithmetic and logical operations in a sequence corresponding to the process under modeling.

Simulation modeling will make it possible to:

1. Specify and model a lot of scenarios of implementing a production program in time using various resources and risk impacts (equipment failures, deviation from delivery schedules, work schedules, human factor and others).
2. Calculate optimal values of a production system's parameters in terms of the specified production plan.
3. Take into account random factor effects on the realization of a production program.
4. Calculate stock volumes of materials and components necessary to realize a production program with due regard for risks.
5. Model delivery chains and consider their effect on the realization of a production program.
6. Determine a feasibility of realizing a production program on the given equipment in the given premises.
7. Determine critical operations according to the existing technologies.
8. Identify bottlenecks and propose ways of their elimination.
9. Determine the time period necessary to fulfill a production program using the available manufacturing capacities.
10. Determine an optimal arrangement of equipment and confirm the necessity of using the proposed equipment in terms of the feasibility of fulfilling the program. Determine or optimize the production volume.
11. Test manufacturing processes in terms of their feasibility and preliminary rating before their actual introduction.
12. Model assembly lines.
13. Schedule component (material) delivery.
14. Optimize material flows. Reduce the stock volumes and determine optimal amounts of buffer stocks. Determine or optimize transport resources.

Problems of production optimization or reorganization by modeling have been studied in Russia [1-6] and other countries [7-9] for a long time.

According to the data of the American National Institute of Standards and Technology, only the use through design makes it possible to:

1. Improve considerably the quality of the output.

2. Accelerate the output entry to the market by 20-90%.
3. Reduce the time of the product development by 30-70%.
4. Decrease the time of introducing changes by 65-90%.
5. Reduce costs of preparing products for manufacture by 5-50%.
6. Accelerate the recoupment of expenses by 20-85%.

Present-day production comprises technological systems having a complicated structural and functional organization. A specific technological process (or a combination of objects) which can be described by a system of transitions, conditions and relations is used as a control object in such systems. All production processes are divided into stages (steps). At each stage a complex of certain actions with transformation of material flows and conversion of energy is carried out. The sequence of these stages can be described as process flow diagrams where every element corresponds to a specific manufacturing process. The interrelations of the elements of the process flow diagram are presented by both material and energy flows in the system. The operation algorithm intended for the implementation of the target function characterizes the system itself.

A system approach to a manufacturing process is characterized by a complex dynamic system which includes various units of "equipment, control and management facilities, auxiliary and transportation systems, machining tools or environments" [1] which are in a continuous motion, interaction and change; production objects and operators (people, robots or manipulators) carrying out the processes or controlling them. An analysis of complex manufacturing processes implies a decomposition of a production system into subsystems and sub-subsystems of various depths. As a result of the decomposition of a system into subsystems, a hierarchy of a production system structure can be built which will allow studying it at different levels of its specification.

In view of a high complexity and labor intensity of the processes of designing manufacturing processes, it is quite expedient to use computer facilities.

II. PROBLEM STATEMENT

It is most appropriate to predict the results of designing manufacturing processes given the information-computer technologies by using simulation modeling.

The introduction of simulation modeling into the Boeing company practice ensured its economy in:

1. Changing the shop layouts (in area) by 40%.
2. Design of equipment by 50%.
3. Planned time of assembly by 25%.
4. Workers' errors/updating by 50%.
5. Planning errors by 50%.
6. Training technician by 15%.

The purpose of simulation modeling of manufacturing processes is "design calculation of performance and main indicators of economic efficiency taking into account various versions of the structure and the degree of risk" [2] as well as disturbing influences of external and internal environments. To achieve the goal, it is necessary to cope with the following objectives of model design:

- predicting the main characteristics of production systems and manufacturing processes;
- obtaining statistical indicators and other characteristics of technical and economic efficiency;
- using the obtained results of model design to choose an optimal version of a production system or a manufacturing process;
- studying possible versions of the structure of manufacturing process operations by using model design tools.

Using model design tools, it is possible, for example, to describe the work of a production section, an assembly line, an industrial enterprise shop or an enterprise as a whole. Model design of production systems or manufacturing processes will make it possible to "reproduce a parallel, sequential or parallel-sequential scheme of functioning taking into account stochastic events and their influence on the process" [2]. Model design will also allow a detailed analysis of the designed versions of "the operation structure and the influence of various parameters on the performance, the load ratio and other economic indicators necessary to make managerial decisions with due regard for unexpected risks" [2].

In scientific information sources on modeling "problems of modeling costs based on the Petri nets to reveal inconsistencies and duplication of operations constituting processes as well as an optimal sequence of their execution and as a result to reduce a total amount of costs. The use of Petri nets makes it possible to determine an optimal sequence of operations of the process under modeling as well as the time and costs of its execution [3].

III. THEORY

Modeling of a process of a specific structure is carried out at the stage of choosing an optimal operation. A production system can contain one, two or more operation positions. Operation can also be executed simultaneously at all positions. A model is treated as a process of functioning of complex production and economic systems.

Real complex production-economic systems and manufacturing processes "function under conditions of many random disturbing factors resulting in the disruption of normal operation" [1]. Disturbing factors include impacts of the environment and a number of deviations occurring inside the system during the execution of the target plan.

The presentation of ongoing events with a full retention of their logical structures and time sequence takes place in simulation modeling of production systems or manufacturing processes. Simulation modeling makes it possible to determine the most accurate characteristics of manufacturing processes (technical performance, the time of processing and assembling, the use or load factors, etc.).

An operation structure that clearly defines the order of execution, namely, what transitions at what position and in what sequence are realized (Table 1) forms the basis of simulation modeling.

A production process is a discrete and stochastic process by its nature. Its discreteness is characterized by the fact that elementary acts (transitions, readjustments, measures on performance restoration and others) are not implemented immediately but are characterized by certain duration (delay), with the next act being performed only after a full completion of the previous one.

TABLE I. GRAPHIC STRUCTURE OF SYSTEMS AND TECHNOLOGIES IN MODELING

	Name	Nota-tion	Presentation	Remarks
T	Event		Finite set of transitions: T=(T1,T2,...Ti), where i is a number of transitions	Assembly, processing, loading, unloading .
P	Condition		Finite set of positions: P=(P1,P2,...Pj), where j is a number of positions	Units, operators, accumulators, equipment
A	Relations		Finite set of relations: A=(A1,A2,... Ak) where k is a number of relations	Sequence of implementing a manufacturing process
M	Tags (tokens)	•	Tag (token) in the condition means its execution	Marking of a set positions
I	Input function	P(A)→T	Finite set of inputs: I(j,k)	How many times the position P(j) is an input of the transition T(k)
O	Output function	T→P(A)	Finite set of outputs: O(j,k)	How many times the position P(j) is an output of the transition T(k)
Z	Actuation of transitions		T(k)→P(j)*M(i)→A	Transition is allowed when there are places for tags and if the number of tags is larger or equal to the number of relations

In the operation of a production system or during manufacturing processes “a great number of elements (tools, equipment) which can break down at random moments of time and require replacement or repair take part” [1]. This results in various failures of a standard operation of the manufacturing process of the production system under modeling. “Values evaluating failures and determining the time for recovery operations are of a random character” [1]. Besides, random values also include the length of the tool life cycle until they fail, cycles of undisturbed operation of separate subsystems between successive failures and the duration of the performance restoration.

IV. EXPERIMENT RESULTS

The application software package “Simulator” can be used in various industries of the national economy, in trade, in goods production or rendering services. It allows modeling of economic processes when they are implemented on systems (S) of a specific structure, i.e. separate modules, departments, production sections, assembly-lines and shops [2]. Production systems or manufacturing processes can consist of any number of “input loading units, output unloading units and any number of successively positioned modules connected with each other by accumulators of a preset capacity. A module can consist of one or several units of equipment and workplaces of operators (robots, manipulators or people). An operator can serve any numbers of production units” [2]. A mathematical presentation of a simulation model in the software package fully corresponds to its graphic presentation whose symbolic notation is given in Table 1

Based on the simulation modeling theory the application software package “Simulator” was developed. It is “a model of successive events **(T)** when the necessary conditions **(P)** are fulfilled in compliance with the established relations (**A**)” [2]. The validity of the simulation design logic was proved based on the results of the software package analysis using the Petri nets. It was shown that simulation modeling made it possible to optimize the event content and to eliminate doubling relations between events and states. Model design of production and economic systems and manufacturing processes is presented by the Petri net comprising four basic parameters (Table I):

$$\mathbf{C = (P,T,I,O).}$$

For model design to form a net structure these parameters as initial data should be presented in the following sequence: the number of positions (**P**), the number of transitions **(T)**, all inputs **(I)** and outputs (**O**) in all transitions. (Table II). The “Simulator” demonstrates the net formed based on the initial data and requests its approval. After this the user sets the operating mode. All other conditions being equal, the order of transition firing is realized for the highest priority whose value must always be an integer and more than 0. The transition that has the highest priority value (Pr) is executed in the first place. Using the model, it is possible to choose the best version by changing priority values.

Possible system failures and organizational peculiarities of production are taken into account in the software package by using a random number generator. The duration of operation of devices and operators before a failure and the recovery time are described by random numbers (mathematical expectation (AO [1]) and mean square deviation (ZO [1]) of delays of positions and transitions.

TABLE II. MENU OF THE APPLICATION SOFTWARE PACKAGE “SIMULATOR”

	Simulator
1	The Petri net structure input
2	Transition priorities input
3	Delay arrow input
4	Position delays input
5	Transition delay input
6	Position marking input
7	Modeling time input
8	General entry input
9	Printing of results
10	Operating mode continuation
11	Operating mode
12	End

Capacities of accumulators and other positions can be restricted by delay arrows whose beginning emerge from the position and rest upon the transition whose execution is delayed with the indication of the restriction value. When delay arrows are entered, the position and the restriction value (a maximal number of tags in the position) are indicated. If this value is higher, the execution of this transition is delayed and another possible transition is performed. The position and restriction are separated by a comma when entered. If there is no restriction in the transition, 0 is entered.

Every position is marked by tags (tokens). Marking is a function transferring a set of positions into a set of integer nonnegative numbers. The state of an economic system at any moment of time is characterized by its marking. All possible markings of a system are described by the formula P = (C, M). The entry of the marking is an indication of the number of tags (goods, semi-finished products, prepared foods, equipment, robots, etc.) in the net positions. Marking is an integer positive number: 0, 1, 2, 3, etc. After that the operation time in the system and the number of kinds of parallel operation are entered. It is possible to detect deadlock conditions occurring because of the improper organization of the system and processes [4]. When simulation is completed correctly, a summary table appears.

V. Results and Discussion

A graphic model of modules (Fig.1), mathematical models as graphs presented by a binary relation matrix (Table III) and a set of two-component sequences are generated at the first stage of model design:

$$M_1 = \begin{pmatrix} \langle P_1, T_1\rangle, \langle P_2, T_1\rangle, \langle P_3, T_1\rangle, \langle T_1, P_4\rangle, \\ \langle P_4, T_2\rangle, \langle T_2, P_2\rangle, \langle T_2, P_3\rangle, \langle T_2, P_5\rangle \end{pmatrix}.$$

Based on the graphic model (Fig.1), a table for entering initial data (Table III) is built. Initial data are processed using the application package “Simulator” [2].

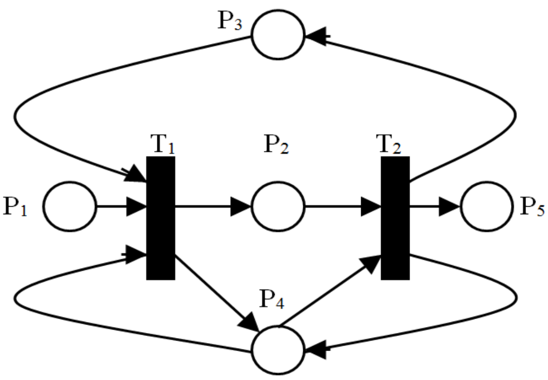

Fig. 1. Graphic model of modules

TABLE III. Binary Relation Matrix

G=

	T_1	T_2	P_1	P_2	P_3	P_4	P_5
T_1	0	0	0	1	0	1	0
T_2	0	0	0	0	1	1	1
P_1	1	0	0	0	0	0	0
P_2	0	1	0	0	0	0	0
P_3	1	0	0	0	0	0	0
P_4	1	1	0	0	0	0	0
P_5	0	0	0	0	0	0	0

To analyze model design qualitatively, it is necessary to calculate a simulation model at least in five points. The calculation results are presented in a summary table in whose basis a graph is built (Fig. 2).

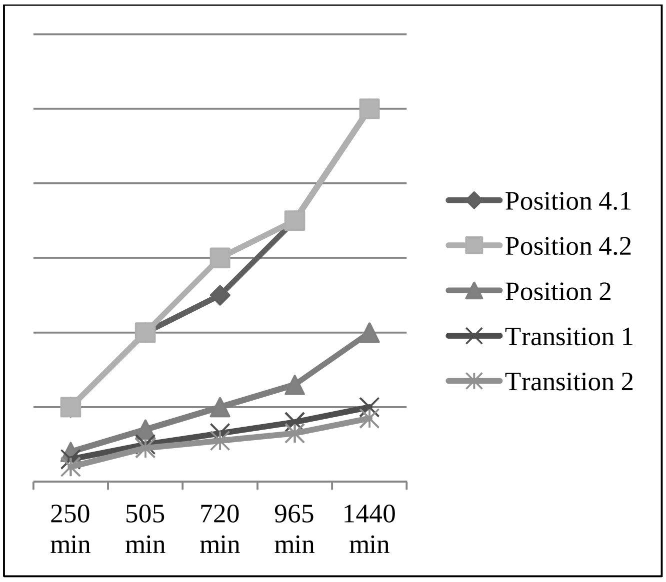

Fig. 2. Efficiency of equipment and operations loading

While analyzing the calculation results the optimization of the module structure is performed based on the initial data and managerial decisions are made to update the production system or manufacturing processes, that is to reduce or increase the number of equipment units or operators as well as to change their technical and economic indicators, namely, to increase or to decrease performance indicators (the duration of delays in operation positions and in transitions), to change accumulator capacities (delay arrows), etc.

In addition to simulation modeling of production systems it is imperative to create a system of production operative control which takes into account not only the output program, the production system parameters and the manufacturing process structure, but also such an important characteristic of the production system as flexibility (adaptability).

The operating control system (OCS) makes it possible to control the production process automatically by conveying shift/daily targets to every worker and appropriate support services. Besides, the system makes it possible to respond quickly to failures in the manufacturing system operation (irrespective of the human factor) including searching for alternative ways of solving the problem. .

A simulation model of the production system complete with OCS allows predicting the output program for certain time periods.

VI. Summary and Conclusions

After the module having been modernized, the calculation of an optimal version and the evaluation of its efficiency are made compared to the basic version expressed in the customer’s requirements specification.

After that, first, the operation of all sections consisting of one, two or more modules, then the operation of systems comprising one, two or more sections, and, finally, the operation of the entire organization consisting of one, two or more systems are optimized.

In conclusion, the operation of all modules, sections, systems and the organization as a whole is analyzed and recommendations on the efficient operation of the modernized version are made.

It has been found that model design is an optimal, if not the only possible, way to update the structure of production systems and manufacturing processes as well as to control these structures [5]. The design technology proposed makes it possible to reduce risks, to decrease time expenditures, to improve quality, to intensify control of the technological and technical compliance, to reduce the degree of the influence of uncertainty, multiple factors, inconsistency, distribution, multiple criteria, time diversity and many other factors, which in the long run facilitates obtaining target results with great accuracy and efficiency..

To implement the program of making and optimizing technological decisions it is necessary to introduce a system of operations control supported by a system of simulation modeling of manufacturing processes.

According to preliminary estimates the application of a complex approach to designing a shop production system will make it possible to increase the performance of the shop production system by more than 30%.

There are also other approaches to practical application of Petri nets related to the development of efficient algorithms for designing manufacturing processes and production systems. In [10, 11] it is shown that under some life-time conditions the limitation of the net can be determined compositionally, that is as a consequence of its component life time limitation,.

Simulation design of manufacturing processes and production systems allows:

1. Technological audit of industrial enterprise upgrading projects.

2. Statement of goals and objectives of industrial enterprise technical upgrading projects.

3. Design of production systems and logistics of industrial enterprises.

Simulation design of manufacturing processes and production systems makes it possible to:

1. Reduce risks in determining the amount of technological equipment necessary to carry out the production program.

2. Increase the efficiency of investments in technical upgrading.

3. Reduce errors in developing technological layouts.

4. Improve the quality of design production and technological decisions.

5. Increase the efficiency of a production system based on the following indicators of performance:

5.1. Production cycle of output manufacturing

5.2. Ratio of production system element loading.

5.3. Nonproductive time losses.

References

[1] M. K. Chernyakov, M. M. Chernyakova, K. C. Akberov, and B. V. Malozemov, Modeling of systems: study guide, Novosibirsk: NSTU, 2017.

[2] M. K. Chernyakov, V. M. Chernyakov. Software Package "Simulator". https://refdb.ru/look/1968832.html. (in Russian).

[3] N. A. Poleshchuk, Modelirovaniezatrat v ekonomicheskikhsistemakh s pomoshch'yusetei Petri [Cost Modelling in Economic Systems Using Petri Nets]. Available at: http://www.marketing-mba.ru/article/v4_11/Paliashchuk.pdf

[4] V. V. Sinoviev, A. N. Starodubov, M. U. Dorofeev, and V. V. Okolnishnikov, "Simulation Application for Evaluating of Efficiency of Mining Systems Automatization," WSEAS Transactions on Systems, Vol. 14, pp. 261267, 2015.

[5] V.Konyukh, V. and Davidenko, "Petri Nets as a Tool for Mine Simulation," Mineral Resources Engineering, Vol. 8, № 4, pp. 361-371, 1999.

[6] Yu.E. Obzherin, E.G. Boyko, Semi-Markov Models. Control of Restorable Systems with Latent Failures. USA, Elsevier, Academic Press, 2015, 214 p.

[7] A.I. Peschansky, Semi-Markov Models of One-Server Loss Queues with Recurrent Input. Germany: LAP LAMPERT Academic Publishing, 2013, 138 p.

[8] J. Mqqte, I. Bhkcni, "Alpha/Sim Simulation Software Tutorial," Proc. Of the 1999 Winter Simulation Conference. USA: Phoenix, pp. 621–625.

[9] V. Jqnkh, V. Ccxkfenkq, "Petri Nets as a Tool for Mine Simulation," Mineral Resources Engineering, Vol. 8, № 4, pp. 361–371, 1999.

[10] L.V. Dvoryansky, I.A. Lomazova, Compositionality of some behavioral L.V.properties for free-choice nested Petri nets., Proc. Second Workshop "Program Semantics, Specification and Verification: Theory and Application". Yaroslavl, 2011. pp. 27–36.

[11] L.V. Dvoryansky, and I.A. Lomazova, "On Compositionality of Boundedness and Liveness for Nested Petri Nets," Fundamental Informaticae, Vol. 120(3-4), pp. 277–295, 2012.