

UDC 005.411:62:339.14

doi: 10.32620/akt.2021.2.09

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MULTIAGENT MODELING OF PRODUCTION LOGISTICS IN THE CREATION OF HIGH-TECH PRODUCTS

Economic instability and stochastic behavior of the market lead to the need to develop new methods and models to reduce the life cycle of high-tech products. Therefore, the urgent task is a detailed consideration and analysis of each main stage of the life cycle of creating complex technical products. The current study develops a method for optimizing production processes. The subject of research is a production planning and management as the main stage of the life cycle. The method proposed in the publication is based on the component architecture of the created innovative high-tech product, which is obtained because of decomposition at the initial stage of design. Modern production is of distributed nature. While planning production, it is necessary to pay attention to the management and synchronization of material and other types of flows in the logistics chain of distributed production. To form a set of basic and subsidiary operations of distributed production, it is necessary to consider the logistical features, the level of decomposition of the component architecture of the created product, as well as the type of component in the production cycle. Logistics operations are conducted following the requirements for the relevant indicators, namely, the cost of the operation, quality, competitiveness, innovation, the risk of the operation. The main criterion for optimization is the duration of operations. The work uses multi-agent simulation modeling of a sequential logistics chain of production processes, as well as mathematical models and methods: system analysis, optimization using integer programming, multi-criteria optimization, and expert evaluations. The method reduces the duration of the production cycle for the manufacture of individual components of the complex architecture of high-tech products by determining the optimal set of production and ancillary logistics operations for each component, considering the requirements for key production indicators, which minimize production time of high-tech products.

Keywords: *high-tech products; shortening of the life cycle of new equipment; logistic processes of distributed production.*

Introduction

The difficult situation on the market of consumption of high-tech products is associated with the turbulence of the economy, high requirements for competitiveness and innovation of products, leading to the need to shorten the life cycle of complex equipment (aerospace, engineering products, etc.) [1]. Shortening the life cycle of high-tech products requires new appropriate methods and mathematical models at all stages of technology development. The article considers the main stage of the cycle of creating complex equipment associated with production. It is important to carry out the analysis and selection of optimal in time logistic processes for the organization of production with the possibility of shortening the life cycle of complex equipment. In addition, it is necessary to take into account the requirements for competitiveness, cost, and innovation in the production of high-tech products in the limited conditions of operation of domestic enterprises.

1. Statement of the research task

When creating modern high-tech products, much attention is paid to the architecture of the future product. Modern approaches to the construction of architecture use a component approach, which allows you to break the product into appropriate components. Because of decomposition of the created technical product at a design stage its multilevel architecture is formed. The designed complex technical product may contain different types of components (Fig. 1): reusable components, as well as combined components that contain elements of innovation, innovative components that ensure the competitiveness of the created product.

Modern production of high-tech products is based on the distribution of production processes, which in turn requires optimizing the duration and cost of implementing the life cycle of creating a complex product taking into account the logistic processes of movement of materials, raw materials, components [2].

The logistics system of distributed production

provides management of the main flows of the logistics supply chain - production - sales (Fig. 2).

In distributed production, it is necessary to manage: 1 – material, 2 – informational, 3 – transportation and 4 – financial flows [3].

The material flow on its way from the primary source of raw materials materials to the final consumer goes through a number of sections. Material flow management due to the distribution of production requires modern information and communication technologies of production logistics [4]. Logistic operations with information flows are reduced to the creation of distributed information systems and the implementation within this system, actions to collect,

store, process and transmit information related to material flows or analysis of these flows and their management [5].

The reseach focuses on the study of logistics of distributed production. Nowadays, subsidiary logistic operations have a significant impact on the main indicators of production, namely: duration of production, product quality, the risk of successful execution of the order portfolio, sales costs, etc. In addition, the share of subsidiary production operations (transportation, warehousing, control), compared with the main production operations, is constantly growing and can have a significant impact on the duration of the production cycle of high-tech products.

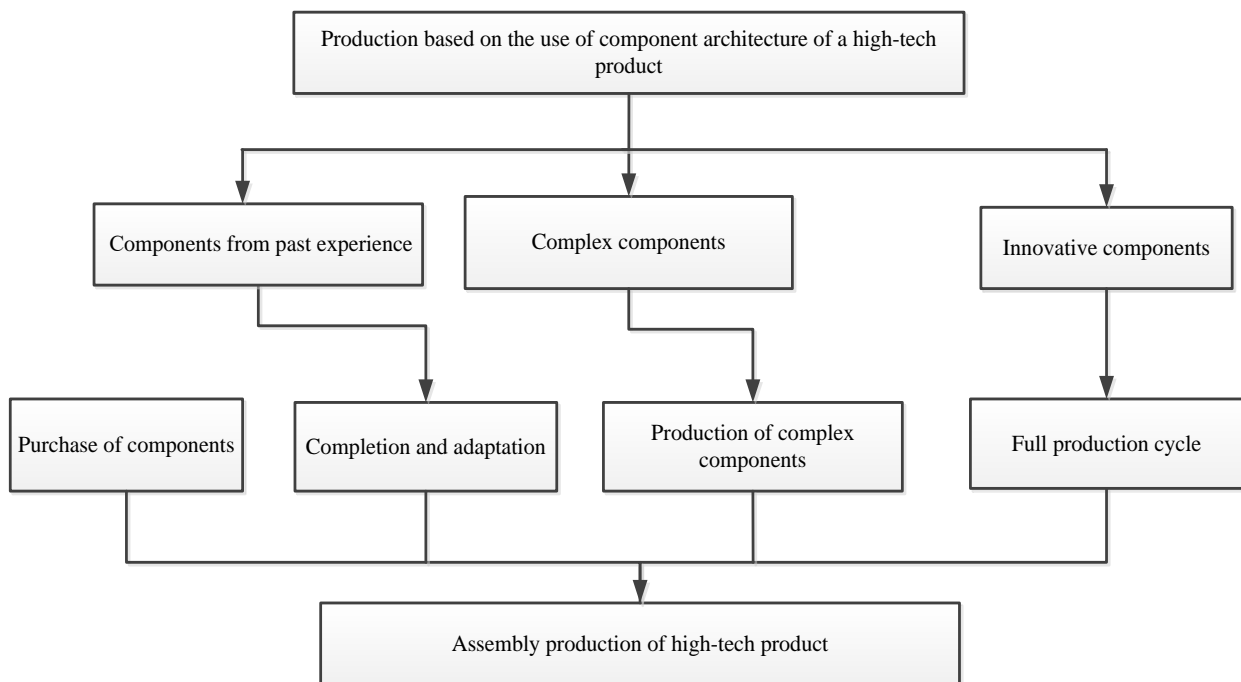


Fig. 1. Production scheme with taking into account the component architecture of a high-tech product

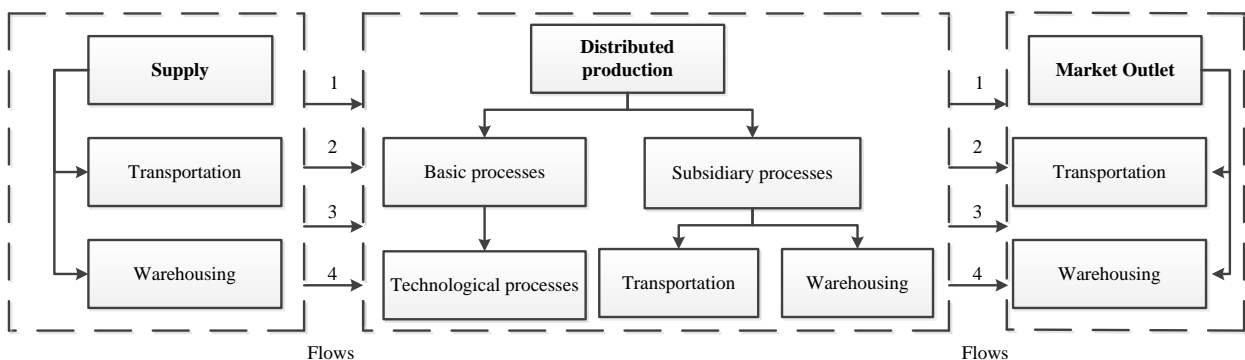


Fig. 2. Logistic system of distributed production

Thus, in conditions of economic instability and stochastic behavior of the market there is a need to shorten the production cycle of technical products in the limited conditions of the enterprise. Thus, the aim of the article is to develop a method of shortening the duration of certain parts of the logistics system by creating a multi-agent simulation model for the analysis of the main and subsidiary production processes.

2. Solving the research problem

Production, as the main stage of the life cycle of creating a high-tech product, can be considered as a process that corresponds to the elements as a sequence of operations (main and subsidiary) during the moving of an unfinished product in the production system of the enterprise.

Considering the territorial distribution of the main components and technological processes of production complexes, it is necessary to select rationally and justify both the main and subsidiary operations of production. To do this, it is necessary to analyze many alternatives of subsidiary operations for timely and high-quality maintenance of the main production process of distributed production.

An important point in the optimization of the production cycle is the choice of possible measures for each stage of production, considering the j -th level of detail of the component architecture of a complex technical product.

For each of the levels of decomposition of the technical product, depending on the type of component (reusable component, innovative component), considering the logistic features of the stage of product creation many possible alternatives for choosing basic and subsidiary operations can be formed.

We introduce a Boolean variable $x_{id_{k_j}}$, which shows the choice of the i -th alternative as the main technological operation and the d -th alternative as a subsidiary operation of the k -th stage of the j -th level of decomposition of the component architecture of the product. With:

$$x_{id_{k_j}} = \begin{cases} 1 - \text{shows the choice of the } i\text{-th} \\ \text{alternative as the main} \\ \text{technological operation and} \\ \text{the } d\text{-th alternative as} \\ \text{a subsidiary operation} \\ \text{of the } k\text{-th stage;} \\ 0 - \text{in another case} \\ \text{(absence of choice).} \end{cases} \quad (1)$$

In its turn:

$k_j = \overline{1, K}$, where k_j is the number of logistic stages of production required for the release of the technical product on the j -th stage of decomposition;

$i_{k_j} = \overline{1, n_{k_j}}$, where n_{k_j} is the number of possible alternatives for the selection of the main operations of the k -th stage of the j -th level of decomposition of the created product;

$d_{k_j} = \overline{1, m_{k_j}}$, where m_{k_j} is the number of alternatives for the selection of subsidiary operations of the k -th stage of the j -th level of decomposition of the architecture of the created product;

$j = \overline{1, L}$, where L is the number of levels of detail of the architecture of the product.

In addition, it is necessary to consider

$$\sum_{i=1}^{n_{k_j}} \sum_{d=1}^{m_{k_j}} x_{id_{k_j}} = 1, \quad (2)$$

which means that you must choose one of the possible alternatives.

Each alternative involves costs and a certain duration, as well as the risk of execution.

We introduce the following indicators for the analysis of the main and subsidiary production processes of the k -th logistic stage:

$t_{id_{k_j}}$ – the duration of the k -th stage, associated with the selection of the i -th main operation and d -th subsidiary operation for the j -th level of detail of the component architecture of the created product;

$z_{id_{k_j}}$ – the cost of implementing the k -th stage in the case of choosing the i -th main operation and the d -th subsidiary operation of the j -th level of decomposition of the component architecture of the created product;

$p_{id_{k_j}}$ – product quality at the k -th stage in the case of choosing the i -th main operation and d -th subsidiary operation of the j -th level of decomposition of the component architecture of the created product;

$q_{id_{k_j}}$ – competitiveness of products that arise at the k -th stage, which is associated with the choice of the i -th main operation and d -th subsidiary operation for the j -th level of detail of the component architecture of the created product;

$h_{id_{k_j}}$ – innovation of the k -th stage, which is associated with the choice of the i -th main operation and d -th subsidiary operation for the j -th level of detail of the component architecture of the created product;

$r_{id_{k_j}}$ – the risk of performing the k -th stage associated with the choice of the i -th main operation and

d-th subsidiary operation for the j-th level of detail of the component architecture of the created product.

Then the choice of operations and equipment for the main and subsidiary production processes, considering the many possible alternatives at each logistic stage, can be assessed as follows:

$$\begin{aligned} T_j &= \sum_k \sum_i \sum_d x_{id_{kj}} t_{id_{kj}}, \\ Z_j &= \sum_k \sum_i \sum_d x_{id_{kj}} z_{id_{kj}}, \\ P_j &= \sum_k \sum_i \sum_d x_{id_{kj}} p_{id_{kj}}, \\ Q_j &= \sum_k \sum_i \sum_d x_{id_{kj}} q_{id_{kj}}, \\ H_j &= \sum_k \sum_i \sum_d x_{id_{kj}} h_{id_{kj}}, \\ R_j &= \sum_k \sum_i \sum_d x_{id_{kj}} r_{id_{kj}}. \end{aligned} \quad (3)$$

To improve production indicators it is necessary to optimize them.

We minimize the duration of the production cycle by rational choice of technological operations for the implementation of the main and subsidiary production processes at all stages of production:

$$\min T_j = \sum_k \sum_i \sum_d x_{id_{kj}} t_{id_{kj}} \quad (4)$$

under the conditions $Z_j \leq Z'_j$, $P_j \geq P'_j$, $Q_j \geq Q'_j$, $H_j \geq H'_j$, $R_j \leq R'_j$,

where Z'_j – the allowable costs for the implementation of the production of a separate component of the j-th level of detail-architecture of the created product;

P'_j – permissible quality of manufacturing components of the j-th level of detail of the product architecture;

Q'_j – allowable competitiveness;

H'_j – acceptable innovation of the components of the j-th level of detail of the product architecture;

R'_j – the allowable risk of the production cycle for the component of the j-th level of detail of the architecture of the product.

We minimize the cost of realization of the production of components by rational choice of technological operations considering the main and subsidiary production processes at all logistic stages of production:

$$\min Z_j = \sum_k \sum_i \sum_d x_{id_{kj}} z_{id_{kj}} \quad (5)$$

under the conditions $T_j \leq T'_j$, $P_j \geq P'_j$, $Q_j \geq Q'_j$, $H_j \geq H'_j$, $R_j \leq R'_j$,

where T'_j – the allowable duration of the production cycle of the components of the j-th level in terms of its shortening.

It is necessary to obtain the maximum indicator of quality, competitiveness and innovation of the components of the j-th level in terms of shortening of the production cycle:

$$\max P_j = \sum_k \sum_i \sum_d x_{id_{kj}} p_{id_{kj}}, \quad \text{when } T_j \leq T'_j,$$

$Z_j \leq Z'_j$, $Q_j \geq Q'_j$, $H_j \geq H'_j$, $R_j \leq R'_j$;

$$\max Q_j = \sum_k \sum_i \sum_d x_{id_{kj}} q_{id_{kj}}, \quad \text{under the condi-}$$

tions $T_j \leq T'_j$, $Z_j \leq Z'_j$, $P_j \geq P'_j$, $H_j \geq H'_j$, $R_j \leq R'_j$;

$$\max H_j = \sum_k \sum_i \sum_d x_{id_{kj}} h_{id_{kj}}, \quad \text{under the condi-}$$

tions $T_j \leq T'_j$, $Z_j \leq Z'_j$, $P_j \geq P'_j$, $Q_j \geq Q'_j$, $R_j \leq R'_j$.

We minimize risks for successful execution of a production cycle at a choice of technological operations of the main and subsidiary production processes at all stages of production:

$$\min R_j = \sum_k \sum_i \sum_d x_{id_{kj}} r_{id_{kj}} \quad (6)$$

under the conditions $T_j \leq T'_j$, $Z_j \leq Z'_j$, $P_j \geq P'_j$, $Q_j \geq Q'_j$, $H_j \geq H'_j$.

At the next stage, multi-criteria optimization is carried out to ensure the optimal choice of the main and subsidiary production processes in terms of shortening the production cycle. To do this, we introduce a comprehensive criterion in the form of the sum of individual indicators:

$$F_j = \alpha_T \hat{T}_j + \alpha_Z \hat{Z}_j + \alpha_P \hat{P}_j + \alpha_Q \hat{Q}_j + \alpha_H \hat{H}_j + \alpha_R \hat{R}_j, \quad (7)$$

where α_T , α_Z , α_P , α_Q , α_H , α_R – weight coefficients T_j , Z_j , P_j , Q_j , H_j , R_j , obtained by expert assessment of their importance. With:

$$0 \leq \alpha_T \leq 1, \quad 0 \leq \alpha_Z \leq 1, \quad 0 \leq \alpha_P \leq 1, \quad 0 \leq \alpha_Q \leq 1,$$

$$0 \leq \alpha_H \leq 1, \quad 0 \leq \alpha_R \leq 1,$$

$$\alpha_T + \alpha_Z + \alpha_P + \alpha_Q + \alpha_H + \alpha_R = 1.$$

Indicators of the production process $\widehat{T}_j, \widehat{Z}_j, \widehat{P}_j, \widehat{Q}_j, \widehat{H}_j, \widehat{R}_j$ are normalized (translated into a dimensionless scale $0 \div 1$):

$$\begin{aligned} \widehat{T}_j &= \frac{T_j - T_j^*}{T_j' - T_j^*}, \widehat{Z}_j = \frac{Z_j - Z_j^*}{Z_j' - Z_j^*}, \widehat{P}_j = \frac{P_j^* - P_j}{P_j^* - P_j'}, \\ \widehat{Q}_j &= \frac{Q_j^* - Q_j}{Q_j^* - Q_j'}, \widehat{H}_j = \frac{H_j^* - H_j}{H_j^* - H_j'}, \widehat{R}_j = \frac{R_j - R_j^*}{R_j' - R_j^*}, \end{aligned} \quad (8)$$

where in turn $T_j^*, Z_j^*, P_j^*, Q_j^*, H_j^*, R_j^*$ – the extreme values of indicators $T_j, Z_j, P_j, Q_j, H_j, R_j$, obtained by local optimization at the previous stage.

It is necessary to minimize the complex criterion taking into account the requirements for reducing the production cycle:

$$\begin{aligned} &\min F_j, \\ F_j &= \alpha_T \widehat{T}_j + \alpha_Z \widehat{Z}_j + \alpha_P \widehat{P}_j + \alpha_Q \widehat{Q}_j + \alpha_H \widehat{H}_j + \alpha_R \widehat{R}_j = \\ &= \alpha_T \frac{T_j - T_j^*}{T_j' - T_j^*} + \alpha_Z \frac{Z_j - Z_j^*}{Z_j' - Z_j^*} + \alpha_P \frac{P_j^* - P_j}{P_j^* - P_j'} + \\ &+ \alpha_Q \frac{Q_j^* - Q_j}{Q_j^* - Q_j'} + \alpha_H \frac{H_j^* - H_j}{H_j^* - H_j'} + \alpha_R \frac{R_j - R_j^*}{R_j' - R_j^*}, \end{aligned}$$

with the restrictions $T_j \leq T_j', Z_j \leq Z_j', P_j \geq P_j', H_j \geq H_j', R_j \leq R_j'$.

Consider a sequential scheme of organization of the main process of production of a complex component product, when the main technological operations are performed one after another, creating a sequential logistics chain (Fig. 3).

To perform basic technological operations, subsidiary operations must be used, which form a set of alternatives, from which it is necessary to choose rational options for organizing the process of production of a component product. Suppose that for each i -th main operation a set of alternatives in the form of d -th subsidiary operations is possible.

With the help of experts, by preliminary analysis of many ancillary logistic operations in the manufacture of components of a complex product, you can determine:

$t_{id_{kj}}$ – the duration of the d -th subsidiary operation to ensure the execution of the i -th main operation of the k -th stage of the j -th level of decomposition of the component architecture of the created product;

$Z_{id_{kj}}$ – the cost of implementing the d -th subsidiary operation to ensure the implementation of the i -th

main operation of the k -th stage of the j -th level of decomposition of the component architecture of the created product;

$P_{id_{kj}}$ – product quality of the i -th main operation,

which is associated with the choice of the d -th subsidiary operation of the k -th stage of the j -th level of decomposition of the component architecture of the created product;

$q_{id_{kj}}$ – competitiveness of products of the i -th main operation, which is associated with the choice of the d -th subsidiary operation of the k -th stage of the j -th level of the decomposition of the component architecture of the created product;

$h_{id_{kj}}$ – product innovation of the i -th main operation, which is associated with the choice of the d -th subsidiary operation of the k -th stage of the j -th level of decomposition of the component architecture of the created product;

$r_{id_{kj}}$ – the risk of performing the i -th main operation, which is associated with the choice of the d -th subsidiary operation.

It is necessary to choose a rational composition of subsidiary operations in the manufacture of product components, which ensures the implementation of the according indicators:

T_{kj} – the total time of subsidiary operations of the k -th stage of the j -th level of decomposition of the created product;

Z_{kj} – the total cost of organizing and performing subsidiary operations to ensure the work of the main production of the k -th stage of the j -th level of decomposition of the component architecture of the created product;

P_{kj} – product quality, which depends on the rational choice of the set of subsidiary operations of the k -th stage of the j -th level of decomposition of the component architecture of the created product;

Q_{kj} – competitiveness of high-tech product, which depends on the rational choice of many subsidiary operations of the k -th stage of the j -th level of decomposition of the created product;

H_{kj} – innovativeness of a high-tech product, which depends on the rational choice of the set of subsidiary operations of the k -th stage of the j -th level of decomposition of the component architecture of the created product;

R_{kj} – the risk of the main production of the k -th stage of the j -th level of decomposition of the component architecture of the created product.

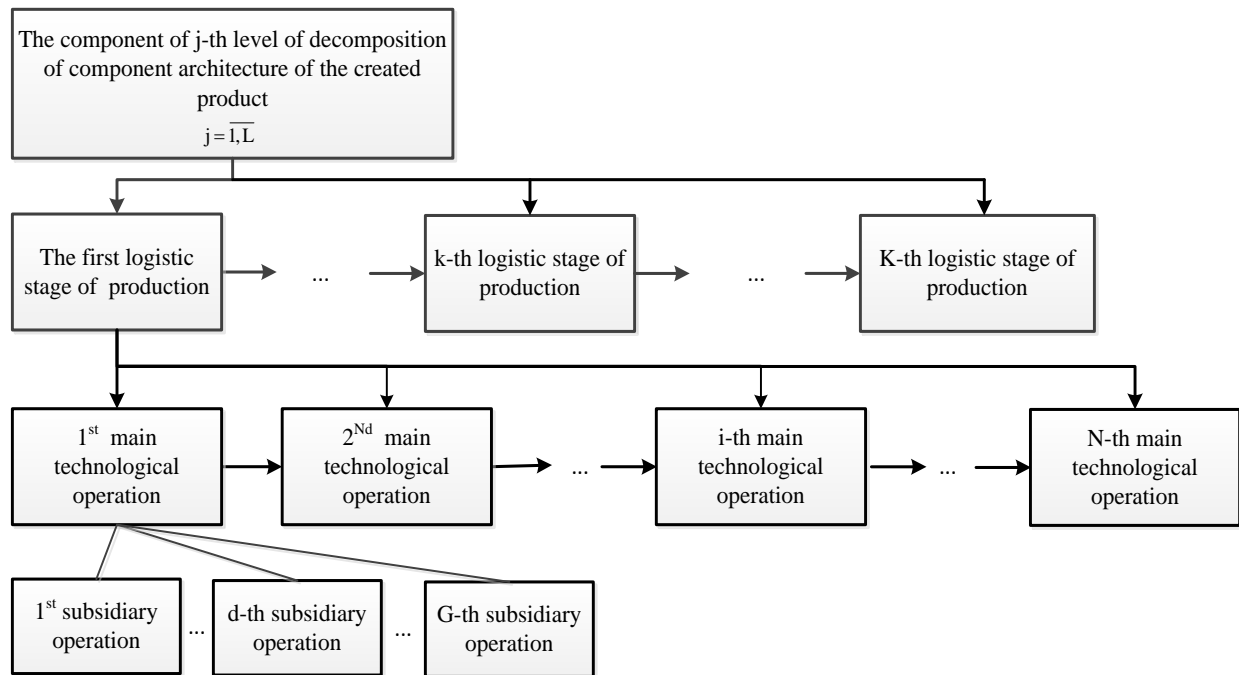


Fig. 3. The structure of the sequential logistic chain of the production cycle of component product

To solve the problem of optimization for the rational choice of many subsidiary operations in the manufacture of product components, you can use the method of integer linear programming.

We introduce a Boolean variable $x_{id_{kj}} \in \{0;1\}$, which $x_{id_{kj}} = 1$ means that to perform the i -th main technological operation selected d -and subsidiary (support) operation of the k -th stage of the j -th level of detail of the component architecture of the created product, $i_{k_j} = \overline{1, n_{k_j}}$ $d_{k_j} = \overline{1, m_{k_j}}$; $x_{id_{kj}} = 0$ – otherwise. The obvious condition is:

$$\sum_d x_{id_{kj}} = 1 \text{ для усіх } i_{k_j} = \overline{1, n_{k_j}}.$$

Considering the introduced Boolean variables $x_{id_{kj}}$ formulates the main indicators of production:

1. $T_{k_j} = \sum_{i=1}^{n_{k_j}} \sum_{d=1}^{m_{k_j}} x_{id_{kj}} t_{id_{kj}}$ – the total time of

execution of subsidiary operations of the k -th stage of the j -th level of decomposition of the component architecture of the created product.

2. $Z_{k_j} = \sum_{i=1}^{n_{k_j}} \sum_{d=1}^{m_{k_j}} x_{id_{kj}} z_{id_{kj}}$ – total costs for the

organization and implementation of subsidiary operations of the k -th stage of the j -th level of

decomposition of the component architecture of the created product.

3. $P_{k_j} = \sum_{i=1}^{n_{k_j}} \sum_{d=1}^{m_{k_j}} x_{id_{kj}} p_{id_{kj}}$ – product quality, which

depends on the rational choice of the set of subsidiary operations of the k -th stage of the j -th level of decomposition of the component architecture of the created product.

4. $Q_{k_j} = \sum_{i=1}^{n_{k_j}} \sum_{d=1}^{m_{k_j}} x_{id_{kj}} q_{id_{kj}}$ – competitiveness of a

high-tech product, which depends on the rational choice of the set of subsidiary operations of the k -th stage of the j -th level of decomposition of the component architecture of the created product.

5. $H_{k_j} = \sum_{i=1}^{n_{k_j}} \sum_{d=1}^{m_{k_j}} x_{id_{kj}} h_{id_{kj}}$ – innovativeness of a

high-tech product, which depends on the rational choice of the set of subsidiary operations of the k -th stage of the j -th level of decomposition of the component architecture of the created product.

6. $R_{k_j} = \sum_{i=1}^{n_{k_j}} \sum_{d=1}^{m_{k_j}} x_{id_{kj}} r_{id_{kj}}$ – the risk of successful

production of the k -th stage of j -th level of decomposition of the component architecture of the created product.

Thus for each of indicators of manufacture certain restrictions are imposed:

$T_{k_j} \leq T'_{k_j}$, T'_{k_j} – the allowable duration of the subsidiary operations of the k-th stage of the j-th level of decomposition of the component architecture of the created product;

$Z_{k_j} \leq Z'_{k_j}$, Z'_{k_j} – allowable total costs for the organization and implementation of subsidiary operations to ensure the operation of the main production of the k-th stage of the j-th level of decomposition of the component architecture of the created product;

$P_{k_j} \geq P'_{k_j}$, P'_{k_j} – the allowable quality of the product, which depends on the rational choice of the set of additional operations of the k-th stage of the j-th level of decomposition of the component architecture of the created product;

$Q_{k_j} \geq Q'_{k_j}$, Q'_{k_j} – the allowable value of the competitiveness of a high-tech product, which depends on the rational choice of the set of additional operations of the k-th stage of the j-th level of decomposition of the component architecture of the created product;

$H_{k_j} \geq H'_{k_j}$, H'_{k_j} – the allowable value of innovation of a high-tech product, which depends on the rational choice of the set of subsidiary operations of the k-th stage of the j-th level of decomposition of the component architecture of the created product;

$R_{k_j} \leq R'_{k_j}$, R'_{k_j} – the allowable risk of the main production operations of the k-th stage of the j-th level of decomposition of the component architecture of the created product.

The rational choice of subsidiary production operations will allow, depending on the indicator we are interested in (T_{k_j} , Z_{k_j} , P_{k_j} , Q_{k_j} , H_{k_j} , R_{k_j}) to optimize the production cycle in terms of acceptable values of the main indicators T'_{k_j} , Z'_{k_j} , P'_{k_j} , Q'_{k_j} , H'_{k_j} , R'_{k_j} .

To shorten the implementation time of the production cycle, it is necessary to find $\min T_{k_j}$ minimize the duration of subsidiary operations of the k-th stage of the j-th level of decomposition of the component architecture of the created product:

$$\min T_{k_j} = \sum_{i=1}^{n_{k_j}} \sum_{d=1}^{m_{k_j}} x_{id_{k_j}} t_{id_{k_j}}, \quad (8)$$

under the appropriate conditions $Z_{k_j} \leq Z'_{k_j}$, $P_{k_j} \geq P'_{k_j}$, $Q_{k_j} \leq Q'_{k_j}$, $H_{k_j} \leq H'_{k_j}$, $R_{k_j} \geq R'_{k_j}$.

Intra-production logistics is an element of the logistics chain. Skillful connection with the external logistics accompanying production is necessary. Supply and sales logistic plans are secondary to basic planning. The calculation of ancillary plans for supply and marketing should take into account the characteristics of a complex product produced by the enterprise, and depends on the characteristics of suppliers, transport operations, the characteristics of external warehousing, the requirements and planned tasks of the customer, and also from the infrastructure of the transport network.

Therefore, for simulation of logistic production processes it is necessary to use a multiagent model [6]. We introduce the following agents (Fig. 4):

1. Agent "MONITOR". Performs time management in multi-agent simulation and event management.
2. LC detail level setting agent. Agent for determining the j-th level of detail of the component architecture of the created product.
3. Agent for determining the k-th stage of product creation.
4. Agent for determining the main technological operation.
5. Duration Determination Agent (t).
6. Innovation Definition Agent (h).
7. Risk Determination Agent (r).
8. Competitiveness Determination Agent (q).
9. Cost Estimation Agent (z).
10. Quality Determination Agent (p).
11. The agent of the choice of the d-th subsidiary operation.
12. Results Agent for LC Management Decision Making.

When conducting multi-agent modeling of material flow and other types of production flows, it is necessary to approach the choice of interconnected technological processes at different stages of material movement from a systemic standpoint [4]. Material flows within production include flows between shops, between individual enterprises of distributed production, between sites and machines (flows are the movement of raw materials, components, parts, assemblies). Most often, the movement of material flow is carried out in batches, which are reflected in the agent model.

When modeling the production process, it is necessary to determine how the material flow loads the main production units, where the occurrence of queues associated with the violation of capacity; how many units of material flow enters and leaves the shop; the intensity of the input and output flow. If the flows interact with each other, it is determined which flows inhibit the production units, and which accelerate. It is important to find out the difference between the planned

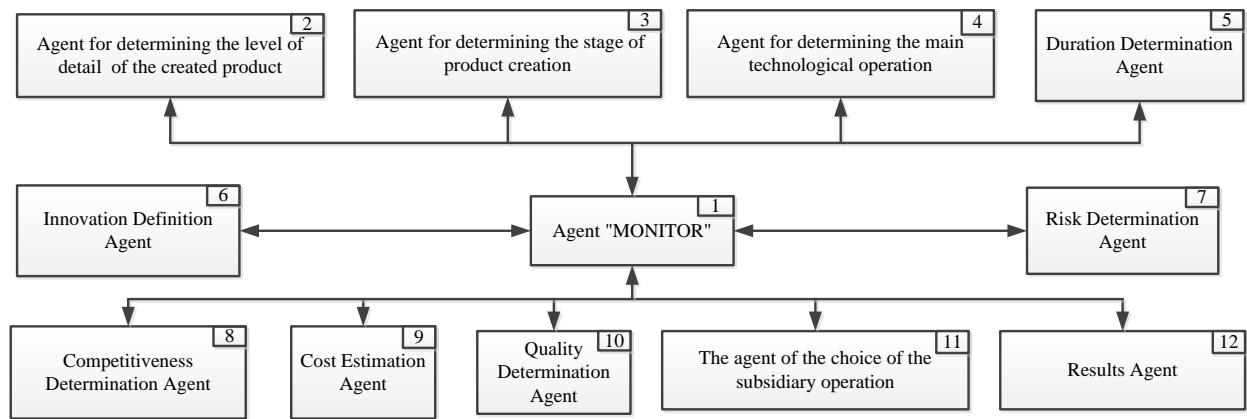


Fig. 4. Block diagram of a multi-agent simulation model

and actual modeling result. In the process of modeling is:

1. Ensuring the receipt of products exactly on time and in a given quantity.
2. Deviations from the terms of delivery of materials and components are minimized.
3. The deviation of the "plan-fact" of production activity is minimized:

$$\min \Delta = \Pi_{(\text{plan})} - \Phi_{(\text{fact})} .$$

4. Different kinds of equipment failures are analyzed.
5. The staff of the enterprise is optimized, which ensures the implementation of basic and ancillary logistics operations.

Conclusions

This article analyzes the production in the form of the main stage of the life cycle of creating a high-tech product. Production implements a logistics chain, which carries out the implementation of many technological operations. A study of the sequential logistic chain of the main processes of the production stage during the movement of the unfinished product in the production system. In order to obtain optimal timing of successive production processes, a rational choice of operations is carried out, both the main and subsidiary processes. It is important to take into account certain limitations that affect the choice of specific production processes. Restrictions relate to indicators: duration of operations, innovation, competitiveness, and quality of the created product and the risk of operations at a certain stage, taking into account the level of detail of the created product.

To solve this problem, the method of integer linear programming, multicriteria optimization and multi-agent simulation model are proposed.

References (GOST 7.1:2006)

1. Оптимізація життєвого циклу створення нової техніки в умовах конкуренції та стохастичної поведінки ринку збуту високотехнологічної продукції [Текст] / О. Є. Федорович, О. С. Уруський, Л. М. Лутай, К. О. Западня // *Авіаційно-космічна техніка і технологія*. – 2020. – № 6 (166). – С. 80-85. DOI: 10.32620/akt.2020.6.09.
2. Xiao, Shufeng (Simon). *International new product development performance, entrepreneurial capability, and network in high-tech ventures [Text]* / Shufeng (Simon) Xiao, Yong Kyu Lew, Byung Il Park // *Journal of Business Research*. – 2021. – Vol. 124. – P. 38 -46. DOI: 10.1016/j.jbusres.2020.11.048.
3. Федорович, О. Е. *Исследование логистики управления производством высокотехнологической продукции виртуального предприятия [Текст]* / О. Е. Федорович, О. В. Сломчинский, В. А. Пуйденко // *Авіаційно-космічна техніка і технологія*. – 2018. – № 4 (148). – С. 107-115. DOI: 10.32620/akt.2018.4.13.
4. Glatt, Moritz. *Physical modeling of material flows in cyber-physical production systems [Text]* / Moritz Glatt, Jan C. Aurich // *Procedia Manufacturing*. – 2019. – Vol. 28. – P. 10-17. DOI: 10.1016/j.promfg.2018.12.003.
5. Smith, Matthew. *International production and trade in a high-tech industry: A multilevel network analysis [Text]* / Matthew Smith, Sara Gorgoni, Bruce Cronin // *Social Networks*. – 2019. – Vol. 59. – P. 50-60. DOI: 10.1016/j.socnet.2019.05.003.
6. *Decentralized Multi-Agent Production Control through Economic Model Bidding for Matrix Production Systems [Text]* / Maya Marvin Carl, Kiefera Lars, Kuhnlea Andreas, Strickera Nicole, Lanza Gisela // *Procedia CIRP*. – 2021. – Vol. 96. – P. 3-8. DOI: 10.1016/j.procir.2021.01.043.

References (BSI)

1. Fedorovych, O. Ye., Urus'kyi, O. S., Lutay, L. M., Zapadnya, K. O. Optymizatsiya zhyttyevoho tsykladu stvorenniya novoyi tekhniki v umovakh konkurentsii ta stokhastichnoyi povedinky rynku zbutu vysokotekhnologichnoyi produktsiyi [Optimization of the life cycle of creating new equipment in conditions of competition and stochastic behavior of the market of high-tech products]. *Aviacijno-kosmicna tehnika i tehnologia – Aerospace technic and technology*, 2020, no. 6 (166), pp. 80-85. DOI: 10.32620/akt.2020.6.09.
2. Xiao, Shufeng (Simon), Lew, Yong Kyu., Park, Byung Il. International new product development performance, entrepreneurial capability, and network in high-tech ventures. *Journal of Business Research*, 2021, vol. 124, pp. 38-46. DOI: 10.1016/j.jbusres.2020.11.048.
3. Fedorovich, O. Ye., Slomchinskii, O. V., Puidenko, V. A. Issledovanie logistiki upravleniya proizvodstvom vysokotekhnologicheskoi produktsii virtu-
al'nogo predpriyatiya [Investigation of logistics to manage high-tech technology production of virtual enterprise]. *Aviacijno-kosmicna tehnika i tehnologia – Aerospace technic and technology*, 2018, no. 4 (148), pp. 107-115. DOI: 10.32620/akt.2018.4.13.
4. Glatt, Moritz., Aurich, Jan C. Physical modeling of material flows in cyber-physical production systems. *Procedia Manufacturing*, 2019, vol. 28, pp. 10-17. DOI: 10.1016/j.promfg.2018.12.003.
5. Smith, Matthew., Gorgoni, Sara., Cronin, Bruce. International production and trade in a high-tech industry: A multilevel network analysis. *Social Networks*, 2019, vol. 59, pp. 50-60. DOI: 10.1016/j.socnet.2019.05.003.
6. Marvin, Carl Maya., Lars, Kiefera., Andreas, Kuhnlea., Nicole, Strickera., Gisela, Lanza. Decentralized Multi-Agent Production Control through Economic Model Bidding for Matrix Production Systems. *Procedia CIRP*, 2021, vol. 96, pp. 3-8. DOI: 10.1016/j.procir.2021.01.043.

Поступила в редакцію 12.02.2021, рассмотрена на редколлегии 16.04.2021

МУЛЬТИАГЕНТНЕ МОДЕЛЮВАННЯ ВИРОБНИЧОЇ ЛОГІСТИКИ ПРИ СТВОРЕННІ ВИСОКОТЕХНОЛОГІЧНОЇ ПРОДУКЦІЇ

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Економічна нестабільність та стохастична поведінка ринку призводить до необхідності розроблення нових методів і моделей для скорочення тривалості життєвого циклу створення високотехнологічної продукції. Тому актуальним завданням є детальний розгляд і аналіз кожного із основних етапів життєвого циклу створення складних технічних виробів. Метою дослідження є розроблення методу оптимізації процесів виробництва. Предметом дослідження є планування та управління виробництвом, як основним етапом життєвого циклу. В основі методу, запропонованого у публікації, лежить компонентна архітектура створюваного інноваційного високотехнологічного виробу, що отримана у результаті декомпозиції на початковому етапі проектування. Сучасне виробництво має розподілений характер. При плануванні виробництва необхідно приділяти увагу управлінню та синхронізації матеріального та інших видів потоків в логістичному ланцюзі розподіленого виробництва. Для формування множини основних і допоміжних операцій розподіленого виробництва необхідно враховувати логістичні особливості, рівень декомпозиції компонентної архітектури створюваного виробу, а також вид компонента, що знаходиться в виробничому циклі. Логістика операцій здійснюється згідно з виконанням вимог до відповідних показників, а саме витрати на реалізацію операції, якість, конкурентоспроможність, інноваційність, ризик виконання операції. При цьому головним критерієм оптимізації виступає тривалість виконання операції. В роботі використовується мультиагентне імітаційне моделювання послідовного логістичного ланцюга процесів виробництва, а також математичні моделі та методи: системний аналіз, оптимізація за допомогою цілочисельного програмування, багатокритеріальна оптимізація, експертні оцінки. Метод дозволяє скоротити тривалість виробничого циклу для виготовлення окремих компонент складної архітектури високотехнологічного виробу шляхом визначення оптимальної множини виробничих та допоміжних логістичних операцій для кожного компонента з урахуванням вимог до основних показників виробництва, що дозволяє мінімізувати термін часу виготовлення високотехнологічної продукції.

Ключові слова: високотехнологічна продукція; скорочення життєвого циклу нової техніки; логістичні процеси розподіленого виробництва.

МУЛЬТИАГЕНТНОЕ МОДЕЛИРОВАНИЕ ПРОИЗВОДСТВЕННОЙ ЛОГИСТИКИ ПРИ СОЗДАНИИ ВЫСОКОТЕХНОЛОГИЧНОЙ ПРОДУКЦИИ

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Экономическая нестабильность и стохастическая поведение рынка приводит к необходимости разработки новых методов и моделей для сокращения продолжительности жизненного цикла создания высокотехнологичной продукции. Поэтому актуальной задачей является детальное рассмотрение и анализ каждого из основных этапов жизненного цикла создания сложных технических изделий. Целью исследования является разработка метода оптимизации процессов производства. Предметом исследования является планирования и управления производством, как основным этапом жизненного цикла. В основе метода, предложенного в публикации, лежит компонентная архитектура создаваемого инновационного высокотехнологичного изделия, полученная в результате декомпозиции на начальном этапе проектирования. Современное производство имеет распределенный характер. При планировании производства необходимо уделять внимание управлению и синхронизации материального и других видов потоков в логистической цепи распределенного производства. Для формирования множества основных и вспомогательных операций распределенного производства необходимо учитывать логистические особенности, уровень декомпозиции компонентной архитектуры создаваемого изделия, а также вид компонента, находящегося в производственном цикле. Логистика операций осуществляется в соответствии с выполнением требований к соответствующим показателям, а именно расходы на реализацию операции, качество, конкурентоспособность, инновационность, риск выполнения операции. При этом главным критерием оптимизации выступает продолжительность выполнения операций. В работе используется мультиагентное имитационное моделирование последовательной логистической цепи процессов производства, а также математические модели и методы: системный анализ, оптимизация с помощью целочисленного программирования, многокритериальная оптимизация, экспертные оценки, агентное моделирование. Метод позволяет сократить длительность производственного цикла для изготовления отдельных компонент сложной архитектуры высокотехнологичного изделия путем определения оптимального множества производственных и вспомогательных логистических операций для каждого компонента с учетом требований к основным показателям производства, что позволяет минимизировать срок времени изготовления высокотехнологичной продукции.

Ключевые слова: высокотехнологичная продукция; сокращение жизненного цикла новой техники; логистические процессы распределенного производства.

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