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SIMULATION OF THE BUSINESS PROCESSES OF THE DEVELOPING ENTERPRISE TO CREATE COMPLEX PRODUCTS WITH MULTI-LEVEL COMPONENT ARCHITECTURE

The problem of research of business processes related to the organization and management of projects to create the new complex technical products in aerospace, shipbuilding, and other fields of mechanical engineering is stated and solved. The relevance of the study is related to the planning of a set of business processes, taking into account the architectural representation of the complex product being created. The study aims to develop a new method of synthesis of the multilevel complex of business processes to manage the creation of new technology, taking into account the multi-component representation of the complex product architecture. Much attention is paid to the complex product architecture, which is presented as a set of interconnected components. The following component types are outlined: components that can be reused; components that can be adapted to the requirements of the new product; innovative components. The types of components are studied in terms of the building of the set of business processes on their creation, taking into account the main indicators (costs, execution time, risks). Using the positive experience of past developments in the form of ready-to-use business processes helps to minimize the risks, and the new business solutions in their turn ensure the competitiveness of the complex product. The information base of positive past business processes in the form of precedents base is being built. The precedents base is used to find the close analogs of ready-to-use business processes. The set of business processes related to the management of complex product creation is formed. It has a multilevel representation that fully corresponds to the tree-like component architecture of the complex product. The method to synthesize the complexity of business processes that are planned to perform the tasks on the management of projects on creation of complex products for the developing enterprise is constructed. It is based on the "from top to bottom" system design principle. The optimization model to find the minimum costs, time, and risks in the process of business processes creation that takes into account the multilevel structure of the business process is built. The simulation event-based model in the form of a related agent set is used to study the successful execution of planned business processes related to the creation of the complex product. The results of this study should be used in the practice of creating innovative technical products that have a complex multi-level component architecture for the organization and planning of business processes related to development management. Mathematical methods used: systems analysis, precedent theory, lexicographic ordering, component design, integer optimization, simulation modeling.

Keywords: *complex product; business process; business decision; precedent; component architecture; optimization; agent modeling.*

Introduction

To ensure the competitiveness of the developing enterprise it is necessary to diversify its activities, proceed into a new business decisions and forms of organizational management, to form new orders that correspond to the requirements of consumers of complex innovative products [1]. Especially it is actual for high-tech industries (aerospace, shipbuilding, automotive). Efficiency of production organization and projects management of creation of new technique is connected with improvement of business processes to use it for creation of new complex products (CP).

It follows the topic of research is actual, which results are represented in this paper and connected with modeling of CP's multi-level architecture and business processes of its creation in proceeding into a new innovative orders connected with high-tech products [2, 3].

Analysis of publications [4, 5] showed that in existing approaches MRP and ERP influence of external political and economic environment is not fully taken into account; there is no completeness in researches of business processes (structure and dynamic aspects); the experience of past positive business decisions is not fully used; there is no formal presentation of a complex of business processes; accumulation of positive business processes is not considered in new projects management of creation of complex technics with multi-level architecture.

Formulation of the problem

Firstly, an innovation of aerospace products is connected with appearance of new functions and components in complex product's multi-level architecture. So, it is necessary to search new organizational and management decisions for execute works in creation of a new technique.

It follows that CP multi-level architecture is the base for forming of complex of related business processes which are need to be used in future in a project activity management of developing enterprise. Thus, a structural aspect appears related to the organization of business processes, based on the requirements of the multi-level CP architecture. In the further, the set of business processes (BP) is need to be researched in the dynamics to perform the main management tasks for creation a new multi-component CP. It is very important to use the positive solutions of a past experience in project management, minimizing costs, time and risks of a project of creation a new technique

The search for the solution requires the implementation of the following stages because of the complication and complexity of the problem under consideration:

1. Forming of an information base of existing business processes used in the past projects of complex product creation.

2. Synthesis of multi-level complex of a complex product creation business processes.

3. Modeling of execution of complex of business processes related with a new complex product creation.

Research problem solution

It is necessary to form the architecture of a new complex product (CP) on the basis of the componential representation. The set of components corresponds to the hierarchy of detailing of the CP structure and formally represents a tree-like graph, at which upper level the component is the product, at the i-th level each component consists of components (i + 1)-th level, and at the lower N-th level is the elementary components. The component approach allows you to conveniently represent the complex structure of a complex product, which corresponds to the modular, relatively independent, creation of individual components of the CP.

Each component in hardware and software serves as a "brick", from which by combining them and the requirements of the functional completeness of the tasks performed, a multi-component CP architecture is formed.

During creating a multi-level architecture of a new CP, the developers use the following possible components types:

– components of reuse (CR), which were taken from the past positive development experience;

– adapted components (AC), which were taken from the past experience and upgraded to correspond to the technical requirements for a new CP;

– innovative components (IC), which did not exist before and need to be created from scratch.

There is a brief description of the separate types of components.

CRs, which are used in a new CP, ensure the minimization of costs, time and risks of CP. However, there is no innovation, which may has influence to the competitiveness of a new CP.

ACs, which are used in a new CP, require the implementation of processes, related to modernization for corresponding to the technical requirements of a CP. This lead to the additional cost increases in the creation time and risks.

Used ICs require the set of a new works. ICs provide innovation and competitiveness of a new product. However, the costs, time and risks of creating a new CP increase sharply.

Using the multi-component CP architecture, the whole set of business processes, which are needed to manage the project of creating a new CP, can be represented as a multi-level complex of business processes.

The multi-component CP architecture generates a multi-level structure of the business process complex, which consists of BP CR, BP AC and BP IC. In fig. 1 the CP multi-component architecture is represented, which is completely corresponds to multi-level structure of BP complex.

To find the best existing solutions for business processes to create a new CP will be used a precedent approach. The precedent is a ready past business solution which will be able to use for business processes organization for creating a new CP. The precedent has a set of attributes in the form of organizational and managerial events and characteristics (costs, time risks), which will be used for realization of works to create a new product.

In order to form a multi-level structure of the BP complex, it is necessary to form a multi-level base of precedents, which must fully correspond to the multi-component architecture of the new CP and contain positive past experience in the form of precedents. The multilevel base of precedents is the basis for selecting the best BPs from a past experience. In this case, for each j-th BP of the i-th level of the precedents base, it is necessary to find an analogue in the set of formed BP CPV of the i-th level. The search for a close analogue can be done in different ways using different metrics (quantitative and qualitative assessments). For example, to find the best BP CR from a set of analogues the method of lexicographic ordering was used.

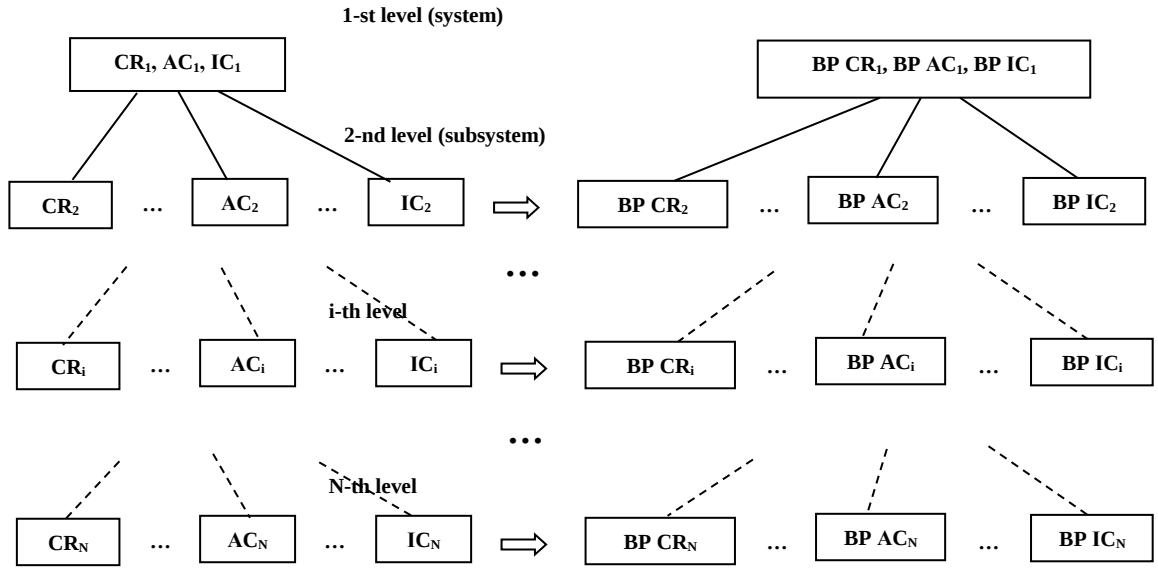

Fig. 1. Multi-level structure of complex product and complex of business processes for its creation

Suppose at the i-th level of the multilevel base of precedents there is the following set of analogues for the j-th BP of a new CP project:

$$\begin{array}{l}1.\ \text{B, A, C,}\\ 2.\ \text{B, B, A,}\\ 3.\ \text{A, A, C,}\\ 4.\ \text{C, B, B,}\\ 5.\ \text{B, C, A,}\end{array} \qquad (1)$$

where A, B, C are qualitative values of BP CR characteristics:

A – the best value of proximity,

B – a good value of proximity,

C – a satisfactory value of proximity.

Suppose at the first place in the tuple of qualitative assessments are costs, as a significant factor, at the second – terms, at the third – risks.

In this case, the CP developers identified "thresholds" for the selection of BP analogues from the precedents base in the form of a tuple of characteristics $\boxed{\text{B, B, B}}$. Arranging the set (1) in the lexicographic sense, will receive:

$$\begin{array}{l}3.\ \text{A, A, C,}\\ 1.\ \text{B, A, C,}\\ 2.\ \text{B, B, A,}\\ 5.\ \text{B, C, A,}\\ 4.\ \text{C, B, B.}\end{array} \qquad (2)$$

Place the given tuple $\boxed{\text{B, B, B}}$ of developers' requirements to select analogues to the ordered list (2). Will be received:

$$\begin{array}{l}3.\ \text{A, A, C,}\\ 1.\ \text{B, A, C,}\\ 2.\ \text{B, B, A,}\\ \boxed{\text{B, B, B}}\\ 5.\ \text{B, C, A,}\\ 4.\ \text{C, B, B.}\end{array} \qquad (3)$$

Obviously, the best close solution for choosing the j-th BP CR will be higher than $\boxed{\text{B, B, B}}$ in the sublist:

$$\begin{array}{l}3.\ \text{A, A, C,}\\ 1.\ \text{B, A, C,}\\ 2.\ \text{B, B, A.}\end{array} \qquad (4)$$

Depending on the limited capabilities of the developing enterprise, the appropriate analogue will be selected at the i-th level of the multi-level precedents base, for example, in the form of B, B, A.

To search of the close analogue it is possible to use method of integer (Boolean) programming because of a large amount of analogues at the i-th level of multi-level BP CR precedents base for j-th component of a new CP.

A Boolean variable x_{ije} is introduced:

$$x_{ije} = \begin{cases} 1, & \text{if for the j-th component of the i-th level} \\ & \text{the e-th analogue was chosen from precedents base,} \\ 0, & \text{in other case.} \end{cases}$$

A distance z_{ije} is introduced, which means proximity of BP characteristics for the j-th components to the e-th analogue in multi-level precedents base at the i-

th level in considering CP architecture. It is necessary to find the minimum distance for the j-th component to search for analogues at the i-th level of the multilevel base of precedents, by selecting a close j-th component of the BP for a new CP from the set of BP analogues. m_j:

$$\min z_{ij}, z_{ij} = \sum_{e=1}^{m_j} z_{ije} x_{ije}, \quad (5)$$

taking into account costs related with possible adaptation (modernization) of a business process for the selected analogue. It is necessary to take into account such limits:

$$W_{ij} \le W_{ij}^{'}, W_{ij} = \sum_{e=1}^{m_j} w_{ije} x_{ije},$$
$$T_{ij} \le T_{ij}^{'}, T_{ij} = \sum_{e=1}^{m_j} t_{ije} x_{ije}, \quad (6)$$
$$R_{ij} \le R_{ij}^{'}, R_{ij} = \sum_{e=1}^{m_j} r_{ije} x_{ije},$$

where $W_{ij}^{'}$ – acceptable costs W_{ij} connected with using and possibility of adaptation of the e-th BP analogue for the j-th CP component, which creates at the i-th level of the multi-level precedents base;

$T_{ij}^{'}$ – acceptable terms T of BP adaptation, which connected with a choice of the e-th BP analogue БП for the j-th CP component of the i-th level of the multi-level precedents base;

$R_{ij}^{'}$ – acceptable risk R connected with possible adaptation during a choice of the e-th BP analogue БП for the j-th CP component of the i-th level of the multi-level precedents base;

t_{ije} – time of the e-th BP analogue adaptation, which was selected for the j-th CP component of the i-th level of multi-level precedents base;

r_{ije} – adaptation risks of the e-th BP analogue selected for the j-th CP component of the i-th level of multilevel precedents base.

The technology of synthesis based on system design conception “from up-to-down” is proposed to forming of multi-level business processes complex for creation a new CP.

The main stages of multi-level BP complex synthesis can be represented in such a way:

The first stage. For a new CP the search for the BP complex in the form of an existing analogue at the system level is carried out. In the absence of an analogue, we move on to the next stage associated with the search for analogues of BP for subsystems.

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The I-th stage. At the i-th level of the multilevel CP architecture, a search is carried out in the precedents base of the e-th analogue of the BP for the j-th CP component of the i-th level. If it is necessary, the found analogue of BP adapts to the management tasks of creating the j-th component. In case of the absence of an analogue of the BP for the j-th component, the formation of a new BP which corresponds to the objectives of management to create a new innovative component (IC).

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The N-th stage. At the N-th level of the CP architecture the search for analogs of the BP for the j-th components of the lowest level of representation of the multilevel architecture of the new CP is carried out.

The proposed method of synthesis requires taking into account the main indicators - costs, time and risks associated with the organization of a multi-level complex of BP to manage the creation of a new CP.

As instance, the task of minimizing the costs W associated with the formation of a multi-level set of business processes for management tasks to create a new CP is given.

It is necessary to minimize the costs W:

$$W = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \sum_{e=1}^{m_j} w_{ije} x_{ije} + \sum_{i=1}^{N} \sum_{j=1}^{p_i} q_{ij}, \quad (7)$$

under constraints:

$$Z \le Z', Z = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \sum_{e=1}^{m_j} z_{ije} x_{ije}, \quad (8)$$

$$T \le T', T = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \sum_{e=1}^{m_j} t_{ije} x_{ije} + \sum_{i=1}^{N} \sum_{j=1}^{p_i} t_{ij}^{'}, \quad (9)$$

$$R \le R', R = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \sum_{e=1}^{m_j} r_{ije} x_{ije} + \sum_{i=1}^{N} \sum_{j=1}^{p_i} r_{ij}^{'}, \quad (10)$$

where Z', T', R' – the acceptable is distance between the BP analogues, time and risks connected with forming of the multi-level BP complex for management tasks to create a new CP;

q_{ij} – costs connected with forming a new BP for management tasks to create a new j-th component for i-th level of CP multi-level architecture;

n_i – the number of possible BP analogues for the j-th component of the i-th level of precedents base;

p_i – the number of a new BP which are need to be formed for the i-th level of multi-level BP complex detail for a new CP creation;

t'_{ij} – time spent on the forming of a new BP in the creation of the j-th component of the i-th level of the multi-level architecture of a new CP;

r'_{ij} – risks connected with forming a new BP to the j-th component creation of the i-th level of the multi-level architecture of a new CP.

The previous tasks were connected with forming and further planning of business processes for complex product creation with accounting of component representation of complex product architecture and active using of positive experience of past developments in a form of precedents. Designed business processes complex includes different BP types: BP CR, BP AC and BP IC. Synthesis of CP architecture for BP complex forming was carried out by system ideology "from up-to-down". For modeling of planned BP executions its initialization will carry out in "from down-to -up", starting with execution of BP from the lowest N-th level, and connect with using of BP CR, it adaptation and using as BP AC and creation new BP ICs at the low level of complex product representation. Transfer to the next (n-1)-th level and in further to the (i-1)-th one carries out only after a total execution all of BPs of the i-th level. That's why the synchronization is necessary in BP realization at the i-th level to transfer to the (i-1)-th one. The event-based simulation is a convenient method for modeling dynamic processes connected with realization of business processes and its synchronization. The model of imitation for BP realization research is designed based on agent representation using by JADE platform. This model consists of the following agents:

1. Agent "initialization". This agent is used for the start BP to a CP creation at the lowest architecture level.

2. Agent "delay of time". The delay is simulated in the implementation time depending on a BP type (BP CR, BP AC, BP IC).

3. Agent "synchronizer". This agent is used to transition from the executed BPs of i-th level to the BPs of the (i-1)-th one. The transition is carry out only in case of totally implementation of all BPs of the i-th level which are included in the j-th BP of the (i-1)-th level.

4. Agent "risk". Possible BPs violations are imitated which are lead to the time increase of BP realization.

5. Agent "BP complex". The multi-level structure of BP complex to creation a new CP is formed for the further research using of this agent.

6. Agent "monitor". Using of this agent time changes and new events are planned to start and end of the BP realization.

7. Agent "results". The result obtaining is carried out in a form of time realization of a BP complex connected with a new CP creation. "Narrow places" are researched in a BP complex in a form of BP delaying realization of other BPs.

In fig. 2 the structure scheme of agent-based modeling of multi-level business processes complex to creation a new complex product is represented.

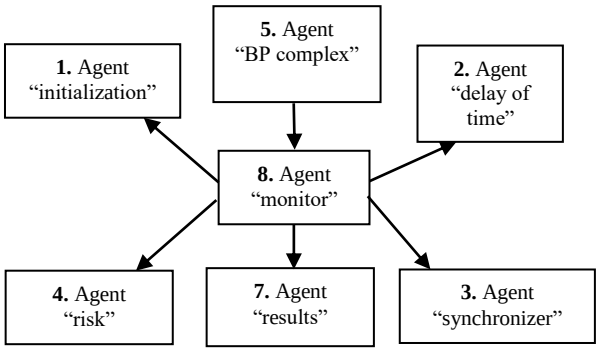

Fig. 2. The structure scheme of agent-based modeling of multi-level business processes complex

Conclusion

The research was carried out which connected with forming of multi-level business processes complex which need for a new complex product creation. The tree-like architecture of a complex product was formed in a component representation. Three main components are separated in the complex product architecture:

- components of reuse,
- adapted and modernize components,
- innovative components.

Creation peculiarities of each type of components leaded to the necessity of forming different types of business processes. The structure of multi-level business processes complex was developed, which totally corresponds to the multi-level architecture of a complex product. The precedents base, which corresponds to the multi-level structure of business processes to creation a complex product, was formed to use an experience of past developments. The set of analogues was separated for the each component of a complex product in precedents base. The search for the best solution for business processes is carried out either in quantitative or qualitative assessments of analogue proximity to the designing component. The synthesis of the multi-level business processes complex was carried out using of system ideology "from up-to-down". The optimization model based on an integer (Boolean) programming was developed for the minimization of costs, time and risks connected with using of business processes for management tasks of a complex product creation. The event-based simulation model using of agent-based representation

was developed for the validation of the formed business processes multi-level complex for a creation of a new complex product. The timing of business processes to create a new complex product, taking into account the possible risks, are determined by the path of movement "from down-to-up" during modeling, which is associated with the use of business processes and its synchronization for transmission from lower to upper level.

Proposed approach in the beginning stage allows you to form a multi-level complex of business processes for organization and management of creation of a new complex product.

The scientific novelty of the study is related to the development of a method of forming complex business processes to create a new complex product based on the structure of the product component and the use of positive experience of past developments in the form of precedents.

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МОДЕЛИРОВАНИЕ БИЗНЕС-ПРОЦЕССОВ РАЗВИВАЮЩЕГОСЯ ПРЕДПРИЯТИЯ ДЛЯ СОЗДАНИЯ СЛОЖНЫХ ИЗДЕЛИЙ С МНОГОУРОВНЕВОЙ КОМПОНЕНТНЫЙ АРХИТЕКТУРОЙ

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Ставится и решается задача исследования бизнес-процессов, связанных с организацией и управлением проектами по созданию новых сложных технических изделий в аэрокосмической, судостроительной и

других отраслях машиностроения. Актуальность исследования связана с планированием множества бизнес-процессов с учетом архитектурного представления сложного создаваемого изделия. Целью исследования является формирование нового метода синтеза многоуровневого комплекса бизнес-процессов для управления созданием новой техники с учетом многокомпонентного представления архитектуры сложного изделия. Большое внимание уделено архитектуре сложного изделия, которая представлена в виде множества связанных между собой компонентов. Выделяются типы компонентов: повторного использования; компоненты, которые адаптируются к требованиям нового изделия; инновационные компоненты. Типы компонент исследуются с точки зрения формирования множества бизнес-процессов по их созданию, с учетом основных показателей (затраты, время выполнения, риски). Использование положительного опыта прошлых разработок в виде готовых для использования бизнес-процессов, позволяют минимизировать риски, а новые бизнес-решения обеспечивают конкурентоспособность сложного изделия. Строится информационная база положительных прошлых бизнес-процессов в виде базы прецедентов. База прецедентов используется для поиска близких аналогов готовых для использования бизнес-процессов. Формируется комплекс бизнес-процессов, связанных с управлением создания сложного изделия, которое имеет многоуровневое представление полностью соответствует древовидной компонентной архитектуре сложного изделия. Построен метод синтеза комплекса бизнес-процессов, которые планируются для выполнения задач управления проектами создания сложных изделий развивающегося предприятия, который основан на системном принципе проектирования «сверху-вниз». Построена оптимизационная модель для поиска минимальных затрат, времени и рисков при формировании бизнес-процессов, которая учитывает многоуровневую структуру комплекса бизнес-процессов. Для исследования успешного выполнения запланированных бизнес-процессов, связанных с созданием сложного изделия, используется имитационная событийная модель в виде множества связанных агентов. Результаты проведенного исследования целесообразно использовать в практике создания инновационных технических изделий со сложной многоуровневой компонентной архитектурой для организации и планирования бизнес-процессов, связанных с управлением разработкой. Использованы математические методы: системный анализ, теория прецедентов, лексикографическое упорядочивание, компонентное проектирование, целочисленная оптимизация, имитационное моделирование.

Ключевые слова: сложное изделие; бизнес-процесс; бизнес-решения; прецедент; компонентная архитектура; оптимизация; агентное моделирование.

МОДЕЛЮВАННЯ БІЗНЕС-ПРОЦЕСІВ ПІДПРИЄМСТВА, ЩО РОЗВИВАЄТЬСЯ, ДЛЯ СТВОРЕННЯ СКЛАДНИХ ВИРОБІВ З БАГАТВОРІВНЕВОЮ КОМПОНЕНТНОЮ АРХІТЕКТУРОЮ

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Ставиться та вирішується задача дослідження бізнес-процесів, пов’язаних з організацією та управлінням проектами зі створення нових складних технічних виробів у аерокосмічній, суднобудівельній та інших галузях машинобудування. Актуальність дослідження пов’язана з плануванням множини бізнес-процесів з урахуванням архітектурного представлення складного виробу, який створюється. Метою дослідження є формування нового методу синтезу багаторівневого комплексу бізнес-процесів для управління створенням нової техніки з урахуванням багатокомпонентного представлення архітектури складного виробу. Велику увагу приділено архітектурі складного виробу, яка представлена у вигляді множини пов’язаних між собою компонент. Відокремлюються типи компонент: повторного використання; компоненти, які адаптуються до вимог нового виробу; інноваційні компоненти. Типи компонент досліджуються з точки зору формування множини бізнес-процесів щодо їх створення, з урахуванням основних показників (витрати, час виконання, ризики). Використання позитивного досвіду минулих розробок у вигляді готових для використання бізнес-процесів, дозволяють мінімізувати ризики, а нові бізнес-рішення забезпечують конкурентоспроможність складного виробу. Будується інформаційна база позитивних минулих бізнес-процесів у вигляді бази прецедентів. База прецедентів використовується для пошуку близьких аналогів готових для використання бізнес-процесів. Формується комплекс бізнес-процесів, пов’язаних у управлінням створення складного виробу, який має багаторівневе представлення, яке повністю відповідає деревовидній компонентній архітектурі складного виробу. Побудовано метод синтезу комплексу бізнес-процесів, які плануються для виконання завдань управління проектами створення складних виробів підприємства, що розвивається, заснований на системному принципі проектування «згори-вниз». Побудована оптимізаційна модель для пошуку мінімальних витрат, часу та ризиків при формуванні бізнес-процесів, яка враховує багаторівневу структуру комплек-

су бізнес-процесів. Для дослідження успішного виконання запланованих бізнес-процесів, пов'язаних зі створенням складного виробу, використовується імітаційна подійна модель у вигляді множини пов'язаних агентів. Результати проведеного дослідження доцільно використовувати у практиці створення інноваційних технічних виробів зі складною багаторівневою компонентною архітектурою для організації та планування бізнес-процесів, пов'язаних з управлінням розробкою. Використані математичні методи: системний аналіз, теорія прецедентів, лексикографічне впорядкування, компонентне проектування, цілочисельна оптимізація, імітаційне моделювання.

Ключові слова: складний виріб; бізнес-процес; бізнес-рішення; прецедент; компонентна архітектура; оптимізація; агентне моделювання.

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