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METHODS AND MODELS OF RESEARCH OF INVESTMENT ATTRACTIVENESS AND COMPETITIVENESS OF PROJECT-ORIENTED ENTERPRISE IN THE PROCESS OF CREATING INNOVATIVE HIGH-TECH

The subject of the research is the investment attractiveness of enterprises producing competitive products with modern component architecture. **The aim** of the article is to develop complex methods for research of investment attractiveness of projects on creation of new high-tech products with component architecture. **Tasks** to be solved are: to use component method for the analysis of innovativeness of created high-tech products; to study investment attractiveness of an innovation project with the use of expert assessments and the method of planning experiments; to substantiate the composition of a diversification project portfolio for investment taking into account the limited possibilities of the enterprise based on the method of integer optimization; to study the performance of the project portfolio using agent-based imitational modeling. **Methods** used are: system analysis, component design, multi-criteria optimization, expert assessment and agent-based simulation modeling in the form of applied information technology. **The results** have been obtained: the analysis of investment attractiveness of projects on creation of new high-tech products with component architecture is carried out. The architecture of a complex product built with components from previous positive development experience is investigated. A classification of possible components in the architecture of a complex product is created. A set of indicators for assessing the investment attractiveness of an innovative component-based product is formed. The qualitative assessments of experts for the main indicators of the component composition of the product in the form of linguistic variables are proposed. The use of multifactor experiment to assess the investment attractiveness of a project to create a complex product with a component-based architecture is proposed. An optimization model for selecting the rational composition of components in an innovative product is developed. An agent-based simulation model is built to study the performance of work on the preparation of production of innovative products on a component basis. **Conclusions**: The use of a set of developed methods and applied information technology for the creation of high-tech products with component-based architecture allows you to plan a diversification portfolio of projects with investment attractiveness and competitiveness of products.

Keywords: component architecture; innovation components; investment attractiveness; diversification project portfolio; optimization of key project indicators; agent-based simulation model of design work.

Introduction

The interest of investors often depends on the innovativeness and competitiveness of the products that an enterprise can produce. It is relevant for an enterprise to form a new, diversified portfolio of projects in order to attract finances from possible investors. Innovativeness of a product is determined by the novelty of its components. That's why the research of innovativeness of high-tech products, based on the component architecture of the products, is relevant, which allows investors in the process of forming a promising diversification project portfolio by the enterprise to assess the possibility of its financing.

Increased competition between manufacturers of high-tech products, as well as the unstable behavior of sales markets leads to the need for innovative development of enterprises, diversification of their activities, and the formation of a portfolio of future projects that are of interest to investors. The transition to new innovative production technologies that fully meet the requirements of Industry.4.0 depends on the influence of risks of political and economic nature. Consequently, there is a contradiction between the desire of developing enterprises to implement innovations and the lack of scientific justification for the diversification of their production activities to attract investment. There is a difficult scientific and technical problem of a compromise nature associated with the formation of such a diversification project portfolio of the developing enterprise, which, on the one hand, is interesting to investors due to its innovative attractiveness and possible competitiveness in the market of high-tech products consumption, and on the other hand, the increase in terms due to possible risks, as well as unjustified economic costs in the process of creating innovative products.

Therefore, the development of methodological support for scientific justification of investments in innovative development of the enterprise is an urgent task.

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Analysis of recent research and publications

To date, the component approach in the creation of new complex mechanical engineering products exists in practical developments [1–3]. But the works do not pay enough attention to the systematization and formalization of the component approach with the identification of its qualitative characteristics [4, 5]. Explicitly there is no classification of components with components from development experience and new innovative components [6, 7]. Not enough attention has been paid to the evaluation of the component-based performance of a complex product project [8–10]. There is no formal synthesis of the component architecture of complex products based on the use of new and old components [11]. The search for a rational ratio of "new" and "old" components in the composition of a complex product has not been given proper attention [12, 13]. The innovativeness of component-based complex products has not been analyzed [14, 15]. Optimization of the component product structure has not been explicitly performed [16–19]. The investment attractiveness of component-based innovative product projects was practically not considered [20–22]. The process of creating an innovative component-based product has not been modeled [23]. There are practically no publications for expert evaluation of the component architecture of a complex product using linguistic variables [24, 25].

The aim of the article

The aim of the article is to develop a set of methods to study the investment attractiveness of projects to create new high-tech products with component architecture.

Problems being solved:

- to use the component method to analyze the innovativeness of created high-tech products;
- to research investment attractiveness of an innovation project using expert assessments and the method of planning experiments;
- justify the composition of the diversification project portfolio for investment, taking into account the limited opportunities of the enterprise based on the method of integer optimization;
- to simulate the implementation of the project portfolio using agent-based information technology.

Materials and methods of the study

The component method is based on the breakdown of the architecture of a high-tech product into components that have a modular structure and the possibility to combine them with each other to create new products. The basic platform simultaneously consists of many basic components and is developed by a separate group of highly qualified designers with the prospect of forming a new family of competitive products. The selection and structuring of basic components with their possible adaptation to the requirements to the technical characteristics of a new product is carried out for a specific project.

In the component representation of a complex high-tech product, as mentioned earlier, the following components can be distinguished:

– simple components used at the lower levels of the product architecture;

– complex components, which are structurally related simple components;

– components of previous experience with positive experience in a number of product generations;

– new components, previously used and which need to be developed, i.e. a full life cycle of creation.

It is important to note that in the creation of new components it is possible to increase the design time, retraining of personnel and new technological equipment. The more new components there will be in the architecture of the new product, the design time as well as the cost of creating the new product will increase significantly. In addition, the risks of creating the product are likely to increase, which affects the possible risks of attracting investors.

To assess the capabilities of the developing enterprise and conducting diversification to perform new innovative projects, we will use component architecture in the representation of a complex product, which can contain both "old", known, components that need to adapt (change) to the technical requirements of the new product, as well as new, innovative components that give investment attractiveness due to the possible competitiveness in the market of high-tech products.

To evaluate the creation of a new product we will apply the following key indicators:

– percentages of new and old components – P(%);

– innovation attractiveness (as a level or qualitative estimates) – Q;

– costs of creating a new product – W;

– terms of creation of a new product – T;

– risks of creating a new product – R.

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To investigate the innovativeness of an individual project we will use the opinion of experts, formalized in the form of a set of estimates and presented by means of a multifactor experiment plan.

A complete factor experiment allows us to evaluate the innovativeness of the product by changing the values of the factors. Individual components of the product in the form of new or "old" components can be used as factors.

Let the singular component as a factor x_j have the value:

x_j =1 if the j-th component is innovative, i.e. it is new;

x_j =0 if the j-th component is taken from the previous experience (in the form of "old") with possible further adaptation to the technical requirements of the new product.

Full factor experiment (FFE) contains a complete enumeration of the values of all factors and three components in the composition of the new product and has the form (fig. 1).

№	$x1$	$x2$	$x3$	P(%)	Q	W	T	R
1	0	0	0					
2	0	0	1					
3	0	1	0					
4	0	1	1					
5	1	0	0					
6	1	0	1					
7	1	1	0					
8	1	1	1					

Fig. 1. Full factor experiment

The combination 010, for example, means that as part of a new product, the first and third components were taken from previous experience, and the second is a new component. As an example, we can consider different models of the AN-178 aircraft family being created, where $x1$ – fuselage; $x2$ – engine; $x3$ – avionics can be considered as the main components. Then 111 means complete innovation of the product containing new components. On the right side of the FFE plan there are "feedbacks" of the research, which are expert evaluations of innovativeness as values – P (%), and also evaluations on investment attractiveness – Q, costs of creation – W, terms of production – T, risks of product creation – R.

Such a plan of experiment is multivariant and allows estimating simultaneously the indicators of interest: P (%), Q, W, T, R. As estimates of experts, it is possible to use simultaneously quantitative and qualitative values of indicators. For the quantitative values of indicators, it is possible, based on the results of the study conducted with the participation of experts, to construct a regression dependence and identify significant factors (components) influencing the investment attractiveness. Let us give an illustrated example of using FFE for expert evaluation of possible modifications of AN-178 (fig. 2).

№	$x1$	$x2$	$x3$	P(%)	Q	W	T	R
1	0	0	0	0	1	A	A	A
2	0	0	1	10	2	B	B	A
3	0	1	0	10	3	B	C	C
4	0	1	1	20	5	C	C	C
5	1	0	0	10	4	B	D	C
6	1	0	1	20	6	C	D	C
7	1	1	0	20	7	D	D	D
8	1	1	1	30	10	E	E	E

Fig. 2. Illustrated example
of a multiple recall complete factor experiment

In this example, P (%) corresponds to the percentage ratio of "new" / "old" components, Q – quantitative assessment on a ten-point scale of investment attractiveness; W, T, R – costs, manufacturing time, risks, presented in a qualitative scale:

A – the best value of the indicator;

B – excellent value of the indicator;

C – good value of the indicator;

D – good value of the indicator;

E – satisfactory value of the index.

FFE allows, using the standard calculation technique, to obtain the following regressive dependence with the help of quantitative values of investment attractiveness indicators:

$$Q = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + \\ + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{123}x_1x_2x_3.$$

In the process of calculations for FFE it is necessary to represent zero as the lower value of the factor "–1", and one as the upper value of the factor "+1".

Since we are interested only in the linear part f the regression dependence to estimate the importance of the factors, we obtain:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 = 4,75 + 2x_1 + 1,5x_2 + x_3.$$

Hence, we see that for the proposed illustrated example of assessing the investment attractiveness of the AN-178 aircraft, the factor in the form of the fuselage modification is important, the engine modification is less important, and the avionics is the least important.

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To choose the model of the aircraft of interest to investors it is necessary to take into account the values of all indicators P (%), Q, W, T, R both in quantitative and qualitative forms of representation.

Let us use the lexicographic ordering of qualitative values of indicators. To do this, we must place the values of the indicators as a series, with the most important indicator on the first place, and the least important indicator on the last.

Let the row of importance of the indicators look like this:

Q, W, T, R.

Then estimates of all possible options for modernizing the AN-178 can be presented as a set:

1. 1, A, A, A
2. 2, B, B, A
3. 3, B, C, C
4. 5, C, C, C
5. 4, B, D, C
6. 6, C, D, C
7. 7, D, D, D
8. 10, E, E, E.

Let us order the variants of the aircraft modification lexicographically. We get:

8. 10, E, E, E
7. 7, D, D, D
6. 6, C, D, C
4. 5, C, C, C
5. 4, B, D, C
3. 3, B, C, C
2. 2, B, B, A
1. 1, A, A, A.

The investment attractiveness will be the highest in option 8. But this option has the worst values of all the last characteristics (W, T, R). In order to select a compromise option, we will use the "threshold" value of the indicators, set by the experts in the form of a "word" **5, B, B, B**. Let's place this "word", taking into account lexicographic ordering, in the obtained ordered list of aircraft modification variants. We get:

8. 10, E, E, E
7. 7, D, D, D
6. 6, C, D, C

5, B, B, B

4. 5, C, C, C
5. 4, B, D, C
3. 3, B, C, C
2. 2, B, B, A
1. 1, A, A, A.

From here we see that the compromise option with innovative appeal is placed in the set:

8. 10, E, E, E
7. 7, D, D, D
6. 6, C, D, C.

Given the values of indicators W, T, R, it is reasonable to invest the project of modernization 7.7, D, D, D with good values of indicators W, T, R and good enough investment attractiveness.

To form a diversification portfolio of projects of a developing enterprise, it is necessary to take into account the possible large dimensionality of the problem, which is associated with both the number of components in the architecture of innovative products, and the number of projects in the portfolio itself. Therefore, to solve this problem we will use the methods of integer (Boolean) programming. Let us introduce the variables x_{kj}, where:

$$x_{kj} = \begin{cases} 1, \text{ if the } k\text{-th } \textit{product} \text{ will use} \\ \text{the } j\text{-th innovative component;} \\ 0, \text{ if the } k\text{-th } \textit{product} \text{ will use} \\ \text{the } j\text{-th component from a previuos experiment.} \end{cases}$$

Then w_{kj} – the cost of creating the j-th innovative component in the k-th product;

w'_{kj} – costs of adapting the j-th component, taken from previous experience, to the technical requirements of the k-th product;

t_{kj} – time of creation of the j-th innovative component for the k-th product;

t'_{kj} – time of adaptation of the j-th component, taken from previous experience, to the technical requirements of the k-th product;

r_{kj} – risks associated with the creation of the j-th innovation component of the k-th product;

r'_{kj} – risks of adaptation of the j-th component, taken from previous experience, to the technical requirements of the k-th product.

In this case, the cost of implementing a diversified project portfolio containing N projects (products) has two components:

$$W = \sum_{k=1}^{N}\sum_{j=1}^{n_k}\left(1-x_{kj}\right)w'_{kj} + \sum_{k=1}^{N}\sum_{j=1}^{n_k}x_{kj}\cdot w_{kj},$$

where $\left(1-x_{kj}\right)w'_{kj}$ – costs associated with the use (adaptation) of the j-th component, which was taken from previous experience, to the technical requirements of the k-th product;

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$x_{kj} \cdot w_{kj}$ – costs associated with the creation of an innovative component in the k-th product.

For the timing of the project portfolio, we obtain:

$$T = \sum_{k=1}^{N}\sum_{j=1}^{n_k}\left(1-x_{kj}\right)t_{kj}^{'} + \sum_{k=1}^{N}\sum_{j=1}^{n_k}x_{kj}\cdot t_{kj}.$$

For the risks of implementing a diversified portfolio of projects, we will have:

$$R = \sum_{k=1}^{N}\sum_{j=1}^{n_k}\left(1-x_{kj}\right)r_{kj}^{'} + \sum_{k=1}^{N}\sum_{j=1}^{n_k}x_{kj}\cdot r_{kj}.$$

The main criterion related to the investment attractiveness of a diversification portfolio of N projects (products) will be as follows:

$$Q = \sum_{k=1}^{N}\sum_{j=1}^{n_k}\left(1-x_{kj}\right)q_{kj}^{'} + \sum_{k=1}^{N}\sum_{j=1}^{n_k}x_{kj}\cdot q_{kj},$$

where $q_{kj}^{'}$ – investment attractiveness of the k-th project, which uses the j-th component taken from the previous experiment;

q_{kj} – investment attractiveness of the k-th project, which uses the j-th innovative component.

It is necessary to maximize the investment attractiveness of a diversified portfolio of projects:

$$\max Q, Q = \sum_{k=1}^{N}\sum_{j=1}^{n_k}\left(1-x_{kj}\right)q_{kj}^{'} + \sum_{k=1}^{N}\sum_{j=1}^{n_k}x_{kj}\cdot q_{kj}.$$

At the same time, it is necessary to meet the constraints on costs, timing of the project portfolio and risks:

$$W \le W, W = \sum_{k=1}^{N}\sum_{j=1}^{n_k}\left(1-x_{kj}\right)w_{kj}^{'} + \sum_{k=1}^{N}\sum_{j=1}^{n_k}x_{kj}\cdot w_{kj},$$

$$T \le T, T = \sum_{k=1}^{N}\sum_{j=1}^{n_k}\left(1-x_{kj}\right)t_{kj}^{'} + \sum_{k=1}^{N}\sum_{j=1}^{n_k}x_{kj}\cdot t_{kj},$$

$$R \le R, R = \sum_{k=1}^{N}\sum_{j=1}^{n_k}\left(1-x_{kj}\right)r_{kj}^{'} + \sum_{k=1}^{N}\sum_{j=1}^{n_k}x_{kj}\cdot r_{kj},$$

where W – acceptable costs associated with the implementation of a diversified portfolio of projects;

T – acceptable terms of implementation of the diversification portfolio of projects;

R – acceptable risks associated with the implementation of a diversified portfolio of projects.

To model the diversification portfolio of projects, an applied information technology of agent-based simulation modeling was developed. The modeling will allow to take into account the time of the project portfolio implementation, as well as the impact of risks on the timing and implementation of projects. Fig. 3 shows a block diagram of the agent model for the implementation of a diversification portfolio of projects of a developing enterprise.

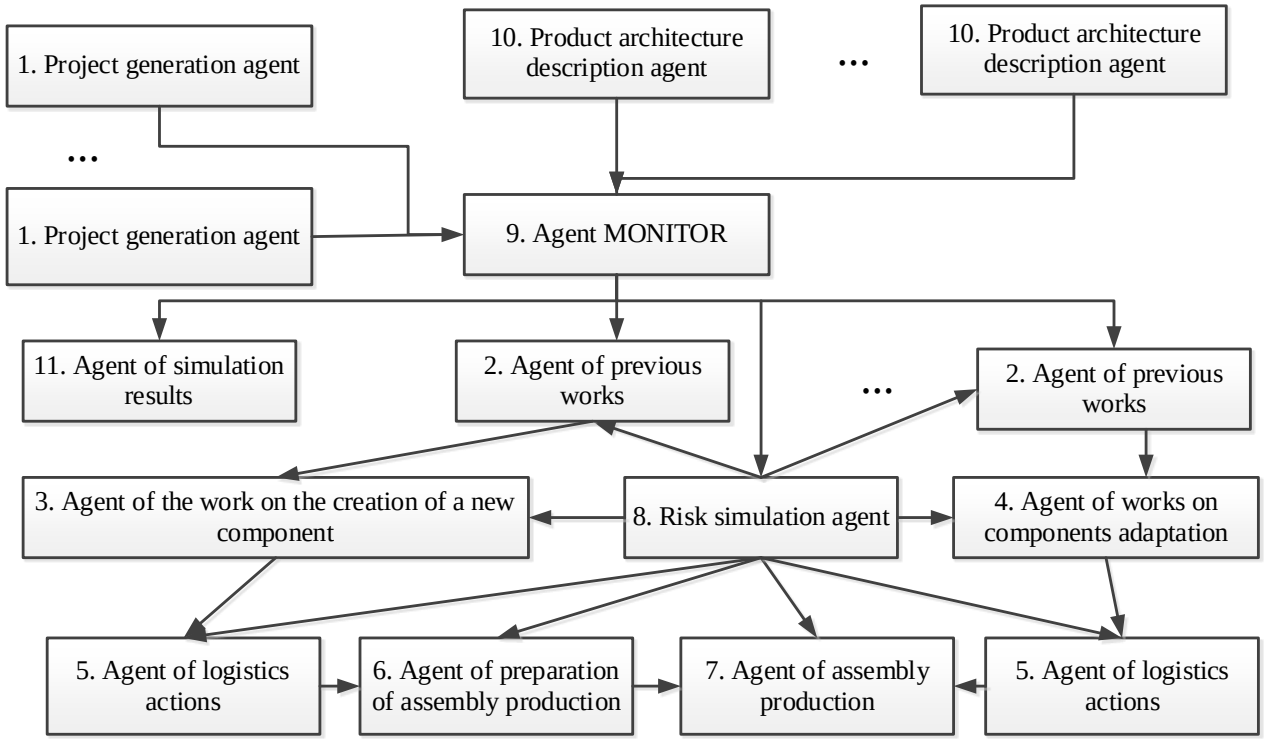

Fig. 3. Block diagram of agent-based simulation of the diversification portfolio of enterprise projects

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In order to simulate the implementation of a diversified portfolio of enterprise projects, it is necessary to use the following types of agents:

1. Agent for generating the start of project execution.
2. Agent of preliminary work related to the preparation of the production of a product component ("new" or "old").
3. Agent of the execution of work on the creation of a new component.
4. Agent of works on adaptation of the component, which was taken from the previous experience, to the technical requirements of the new product.
5. Agent related to the logistics of moving the component that has been produced to the assembly production.
6. Agent for the preparation of the assembly production of a new high-tech product.
7. Agent of the assembly work on the manufactured new product.
8. Agent of simulating the risks of performing work to create a new product.
9. MONITOR agent to manage the process of simulation event modeling.
10. Agent for describing the component architecture of a new product.
11. Agent of simulation results.

Conclusion

The analysis of publications and results on this topic was carried out and the lack of a systematic and formal presentation of component synthesis for the creation of innovative engineering products was revealed. A classification of the component composition of a technical product based on the following components is proposed: components from previous positive development experience, new innovative components and combined components. The investment attractiveness of a project to create a complex product with a component architecture and using the method of the theory of experiment planning and expert assessments of designers is investigated. Both quantitative and qualitative assessments are used to determine the investment attractiveness of a diversification project to create a new complex product on a component basis. To solve the optimization problem of large dimensionality, with the choice of a rational composition of components of innovative products, integer (Boolean) programming is used. In solving a multi-criteria problem, cost, time and project risks are used to create a complex product on a component basis. An agent-based simulation model has been developed to study the implementation of a project to create a complex engineering product with a component architecture. The complex of methods is used with the help of applied information technology, which allows planning the innovative activity of the enterprise to ensure investment attractiveness.

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МЕТОДИ ТА МОДЕЛІ ДОСЛІДЖЕННЯ ІНВЕСТИЦІЙНОЇ ПРИВАБЛИВОСТІ ТА КОНКУРЕНТОСПРОМОЖНОСТІ ПРОЕКТНО-ОРІЄНТОВАНОГО ПІДПРИЄМСТВА ПРИ СТВОРЕННІ ІННОВАЦІЙНИХ ВИСОКОТЕХНОЛОГІЧНИХ ВИРОБІВ

Предметом дослідження є інвестиційна привабливість підприємств, що створюють конкурентоспроможні вироби із сучасною компонентною архітектурою. **Мета** статті – розроблення методу дослідження інвестиційної привабливості проєктів зі створення нових високотехнологічних виробів із компонентною архітектурою. Вирішувані **завдання**: використання компонентного методу для аналізу інноваційності створюваних високотехнологічних виробів; дослідження інвестиційної привабливості інноваційного проєкту з використанням експертних оцінок і методу планування експериментів; обґрунтування складу диверсифікаційного портфелю проєктів для інвестування з урахуванням обмежених можливостей підприємства на основі методу цілочисельної оптимізації; дослідження виконання портфелю проєктів з використанням агентного імітаційного моделювання. **Методи**, що застосовуються: системний аналіз, компонентне проєктування, багатокритеріальна оптимізація, експертне оцінювання та агентне імітаційне моделювання у вигляді прикладної інформаційної технології. Отримані **результати**: проведено аналіз інвестиційної привабливості проєктів зі створення нових високотехнологічних виробів із компонентною архітектурою. Досліджено архітектуру складного виробу, яка побудована за допомогою компонент із минулого позитивного досвіду розробок. Створено класифікацію можливих компонент в архітектурі складного виробу. Сформовано множину показників для оцінювання інвестиційної привабливості інноваційного виробу на компонентній основі. Запропоновано якісні оцінки

Сучасний стан наукових досліджень та технологій в промисловості. 2022. № 3 (21)
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експертів для основних показників компонентного складу виробу у формі лінгвістичних змінних. Запропоновано використання багатофакторного експерименту для оцінювання інвестиційної привабливості проєкту зі створення складного виробу з компонентною архітектурою. Розроблено оптимізаційну модель щодо вибору раціонального складу компонент в інноваційному виробі. Побудовано агентну імітаційну модель для дослідження виконання робіт із підготовки виробництва інноваційних виробів на компонентній основі. **Висновки**: використання запропонованого методу, що містить комплекс розроблених моделей та прикладну інформаційну технологію, для створення високотехнологічних виробів із компонентною архітектурою дозволяє планувати диверсифікаційний портфель проєктів з інвестиційною привабливістю та конкурентоспроможністю виробів.

Ключові слова: компонентна архітектура виробу; інноваційні компоненти; інвестиційна привабливість; диверсифікаційний портфель проєктів; оптимізація основних показників проєкту; агентна імітаційна модель проєктних робіт.

МЕТОДЫ И МОДЕЛИ ИССЛЕДОВАНИЯ ИНВЕСТИЦИОННОЙ ПРИВЛЕКАТЕЛЬНОСТИ И КОНКУРЕНТОСПОСОБНОСТИ ПРОЕКТНО-ОРИЕНТИРОВАННОГО ПРЕДПРИЯТИЯ ПРИ СОЗДАНИИ ИННОВАЦИОННЫХ ВЫСОКОТЕХНОЛОГИЧЕСКИХ ИЗДЕЛИЙ

Предметом исследования является инвестиционная привлекательность предприятий, создающих конкурентоспособные изделия с современной компонентной архитектурой. **Цель** статьи – разработка метода исследования инвестиционной привлекательности проектов по созданию новых высокотехнологичных изделий с компонентной архитектурой. Решаемые **задачи**: использование компонентного метода для анализа инновационности создаваемых высокотехнологичных изделий; проведение исследования инвестиционной привлекательности инновационного проекта с использованием экспертных оценок и метода планирования экспериментов; обоснование состава диверсификационного портфеля проектов для инвестирования с учетом ограниченных возможностей предприятия на основе метода целочисленной оптимизации; исследование выполнения портфеля проектов с использованием агентного имитационного моделирования. Использованные **методы**: системный анализ, компонентное проектирование, многокритериальная оптимизация, экспертные оценки и агентное имитационное моделирование в виде прикладной информационной технологии. Полученные **результаты**: проведен анализ инвестиционной привлекательности проектов по созданию новых высокотехнологичных изделий с компонентной архитектурой. Исследована архитектура сложного изделия, которая построена с помощью компонентов из прошлого положительного опыта разработок. Создана классификация возможных компонентов в архитектуре сложного изделия. Сформировано множество показателей для оценки инвестиционной привлекательности инновационного изделия на компонентной основе. Предложены качественные оценки экспертов для основных показателей компонентного состава изделия в виде значений лингвистических переменных. Предложено использование многофакторного эксперимента по оценке инвестиционной привлекательности проекта по созданию сложного изделия с компонентной архитектурой. Разработана оптимизационная модель по выбору оптимального состава компонент в инновационном изделии. Построена имитационная агентная модель для исследования выполнения работ по подготовке производства инновационных изделий на компонентной основе. **Выводы**: использование предложенного метода, включающего в себя комплекс разработанных моделей и прикладную информационную технологию, для создания высокотехнологичных изделий с компонентной архитектурой позволяет планировать диверсификационный портфель проектов с инвестиционной привлекательностью и конкурентоспособностью изделий.

Ключевые слова: компонентная архитектура изделия; инновационные компоненты; инвестиционная привлекательность; диверсификационный портфель проектов; оптимизация основных показателей проекта; агентная имитационная модель проектных работ.

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