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DEVELOPMENT OF COGNITIVE APPROACH TO THE ORGANIZATION OF BUSINESS PROCESSES IN VIRTUAL MACHINE-BUILDING ENTERPRISES WITHIN INDUSTRY 4.0

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У статті викладено підхід до підвищення ефективності бізнес-процесів на віртуальних машинобудівних підприємствах (ВМБП), що полягає в удосконаленні існуючих методологічних і програмних засобів підтримки життєвого циклу продукції таких підприємств в умовах Індустрії 4.0. В рамках підходу розглядаються концепція створення, розгортання та реалізації бізнес-процесів на ВМБП і принципи, на яких заснована ця концепція, а також методи реалізації базових принципів. Суть підходу полягає в організації повного циклу випуску продукції в рамках ВМБП, при практично повній відсутності на такому підприємстві основних фондів. При цьому, задіються основні фонди субпідрядників, розподілених на території країни і, в ряді випадків, за її межами. Оригінальність підходу полягає в урахуванні специфіки концепції Індустрії 4.0, головною рисою якої є індивідуалізація виробництва й споживання. Застосування обговорюваного підходу на практиці дасть можливість забезпечити: формування маркетингової політики ВМБП шляхом створення багатоагентного веб-орієнтованого середовища; підтримку прийняття рішень по адаптації виробництва на ВМБП до існуючої на даний момент ринкової кон'юнктури; забезпечення альтернативного вибору субпідрядників при організації віртуального виробництва з використанням багатоагентних технологій; інформаційну підтримку рішень про доцільність виробництва продуктів ВМБП на основі технології OLAP; коригування життєвого циклу продукції ВМБП шляхом застосування спеціальних методів і моделей інформаційного забезпечення для організаційного управління ВМБП. Ефективність описаного підходу показана на прикладі аналізу діяльності типового ВМБП. Результати дослідження можуть бути використані для організації, розгортання і підтримки ефективного функціонування віртуальних виробничих підприємств в різних галузях промисловості

Ключові слова: багатоагентне веб-орієнтоване середовище, віртуальні машинобудівні підприємства, Індустрія 4.0, підтримка прийняття рішень

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1. Introduction

The concept of the Fourth Industrial Revolution, better known as "Industry 4.0," was originated in 2011 at the Hanover Fair in Germany, like a way of increasing the competitiveness of the German manufacturing industry through enhanced integration of "cyber-physics systems" (or CPS) into production processes [1]. This concept provides that further industrial development will be linked to the implementation of three revolutionary trends until 2030, namely: a revolution in the design and organization of production processes (technological and organizational reengineering industry, based on the total digitalization of production processes); the transition to new materials (their integration into automated systems of design and production, the combination of the production of materials and the production of components); reasonable environments (their mass implementation is expected in the 2050s and 30s) [2]. According to the forecasts of the world's leading institutions (UNIDO, OECD, World Bank) and international industrial associations and research companies (including MIT, KPMG), by 2030, the above-mentioned trends in industrial production can only be achieved through the introduction of advanced production technologies (APT) on the basis of converging technologies, which are called "breakthroughs", emphasizing their revolutionizing influence on the structure of production.

Thus, APT are associated with non-traditional methods of processing, new tools for control and management of production processes, as well as the use of new materials, automated and intelligent control and management systems for equipment, production processes and systems.

Many countries, including Ukraine, have great potential and competitive technologies in the aerospace industry, the production of new materials with specified properties, industrial biotechnologies, mathematical modelling and regulation of chemical, biochemical and biophysical processes, and intelligent production systems. The "Industry 4.0" movement for these countries is an integration platform for the unification of business associations, communities and market participants in information and communication technologies, industrial control systems, engineering and machine-tool engineering, scientists and educators for the purpose of rapid modernization of the industry, massive and rapid implementation of new technologies 4.0 and accelerated development of high value added production.

For the VMBE, which realize the concept of Industry 4.0 during their activities, the automation of the adoption of rational management decisions is a priority task of increasing the effectiveness of information support systems of life cycle of products (LCP).

VMBE functioning is based on the concept of virtual production – one that does not have a fixed organizational and territorial structure, in which the process of creating information for software-driven technological equipment and the product itself can be distributed in time and space between many enterprises [3].

Existing methods and decision-making models in automated VMBE management systems do not meet Industry 4.0 requirements, therefore, the need for developing new information technologies for decision-making systems for organizing efficient business processes on the VMBE is uncertain in the conditions of uncertainty about the demand for such enterprises.

Consequently, the imperfection of the methodology of building information support systems for product life cycle phases, including hardware implementation, on VMBE, existing methods for synthesizing the intellectual components of such systems to ensure the rational organization of business processes, resource constraints due to global post-industrialization and the uncertainty of demand for products, the development of advanced technologies, give rise to the need to create new forms of production enterprises and to improve existing on the basis of innovative scientific approaches.

For that reason, the actual scientific task is to create a methodological basis for the information support of the life cycle of VMBE products, in the form of a set of methods and models that allow decisions to be made in conditions of uncertainty of demand.

2. Literature review and problem statement

Currently, virtual enterprises are actively created and developed. The first among such enterprises is the Quasar-Micro Corporation. The author [4] describes that projects of Internet banking systems have been implemented, electronic brokerage services are provided. Among the systems that create the possibility of Internet trading, we can distinguish the systems of Atlanta Capital and Socrates, and for Forex operations, the Forex Service company system. Systems for electronic commerce are being developed, distance education systems, Internet insurance, and others are being developed.

Along with this, it is necessary to note the insufficient efficiency of virtual enterprises (VE) functioning in these corporations due to the lack of a unified methodological approach that provides information support for all stages of the life cycle of such an enterprise.

For most countries with economies in transition, it can be argued that in these countries, there is not such a rapid increase in the number of virtual enterprises as in the West. This is due to several reasons:

– business design by creating a virtual company has a fairly high level of risk, given the practical lack of experience and mentality of domestic companies;

– low level of telecommunication infrastructure;

– lack of an appropriate legislative framework.

The concept of VE is extremely important for both large enterprises and small and medium-sized enterprises. The author [5] showed that the concept of VE is one of the decisive factors for maintaining and increasing the level of income and competitiveness in modern markets. However, the lack of an adequate model for the life cycle of products of VE does not make it possible to solve forecast tasks, namely, evaluating the appropriate production output and planning measures to support the demand for these products.

In practice, the concepts of VE differ from each other both in organizational and functional content, and in the types of information technologies used. Consider practical examples of the concept of VE.

In the activities of virtual enterprises, cooperation in the areas of procurement and production can be distinguished. Industrial cooperation is actively developing within the framework of B2B (Business – to – Business) relations, when large industrial enterprises enter into close cooperation relations with small and medium enterprises that produce certain parts and components for them. There are a lot of examples of cooperation of this type.

General Motors, for example, created an Order To Delivery system, with which end-user orders placed on the Buyer Power website are converted into specific orders for technologists, who in turn through The Supply Power page is converted into orders by suppliers throughout the supply chain. Volkswagen Sachsen in Saxony (Germany) implemented a logistics concept, within the framework of which a cluster of subcontractors was created within a radius of 10 kilometers from the assembly plant, which allowed, firstly, to fully realize the concepts of Just-in-Time and Just-in-Sequence, secondly, to reduce the depth of production to 30 %, thirdly, to significantly improve the basic logistics performance indicators.

SMTS is a Canadian manufacturer of printed circuit boards for personal computers, supplying its products to many consumers, including Dell, IBM, Compraq and others. One of the largest consumers of SMTS products, Dell Computer, has developed a business model for selling computers via the Internet. When consumers place orders on the Dell website, they can choose the configuration of their computers, including various types of monitors, modems, CD-ROMs or RAM and microprocessors. After the consumer places the order and pays for the computer, Dell orders the appropriate components from the suppliers and within several hours performs the final assembly and testing of the finished product. Dell has no inventory. The company does not order any components from its suppliers until the consumer pays for the appropriate computer. This approach provides Dell with an excellent rate of return.

The profit margins of Dell, as well as the other companies mentioned above, would be greater if multi-agent technology and ontological engineering were used as the basis for supporting the VE product life cycle when creating the corresponding information systems.

VE are widely used in the textile and light industries. Consider the structure of the PUMA concern, which manufactures sports and textile products. The modern structure of the concern arose in stages based on the operational interactions of the participants of the logistics center, i. e. it was not planned centrally. The company's management focuses on three core competencies: development, design and marketing. Production and almost all logistics operations are carried out by other participants – partners of the LC. Major manufacturers are located in Asia. Transport operations are carried out by the English company P&O. A number of subsidiaries are responsible for the marketing of products. With the exception of Indonesia, where factories have large capacities and also fulfill orders for competitors, in other factories PUMA's share is 2/3 of the total output. PUMA provides these partners with market forecasts and compensates for potential losses in the event of significant non-compliance. On the basis of information technologies (IT), a system of on-line interactions with cooperation partners has been created, which allows for operational monitoring of drugs at all stages. Concerns such as Adidas, Reebok and Benetton have a similar structure.

For many years, the European Union has been operating the international subcontracting exchange, which publishes information on the technological capabilities of enterprises in different countries in the form of a directory. During exhibitions of subcontracting, these directories are especially actively used by companies that want to place orders for components and components as shown in [6].

Virtual enterprises in the field of procurement were called E-Procurement (electronic procurement portals). The paper [7] discussed automotive giants such as Daimler Chrysler, Ford, and General Motors that have developed this scheme, developing Covisint's single digital market space for future purchases of raw materials for automobiles and some components.

Covisint Identity Management provides control and accounting capabilities that provide technical support for incoming information. Covisint Connect Server is a server that provides secure and reliable data exchange between business partners. It allows you to interact using a communication style that is convenient for partners and exchange documents using a format that is convenient for everyone, which significantly reduces the cost of exchanging information. Covisint Communicate Server provides information sharing and sharing infrastructure for partners, customers, suppliers. Its installation is much cheaper than creating and maintaining a portal within the enterprise. This allows you to reduce the cost of creating a portal by 80 % and operation costs by 50 %.

The goal of these actions is to develop a complete on-line network that would unite buyers who order a car and suppliers. The buyer orders a new car, informing the manufacturer about the details (seats, trim, design). Further, all component suppliers receive information about the needs arising from the buyer. Within two weeks after placing the order, the buyer can receive the car. Direct communication with all suppliers of components does not yet exist. For example, BMW buys exclusively standardized parts online. BMW, like Volkswagen, operates only in e-commerce.

The main problem that impedes the creation and support of an online telecommunication network on BMW and other enterprises is maintaining a high level of security in the web space. The solution to this problem is very difficult and is beyond the scope of this study.

The authors [8] discuss that environmental challenges within Industry 4.0, i. e. the challenges posed by globalization, technological and institutional changes will inevitably affect the conditions of development and the structure of markets and business conditions (Fig. 1). The most significant factors are the growth of uncertainty and a change in the nature and forms of competition, which, in turn, causes the emergence of a new paradigm for decision-making and implementation.

In [9], the author shows that in Ukraine, last years, small industrial enterprises of the region sold products worth 917 million UAH, or 10 % of the total volume of products sold by all small enterprises.

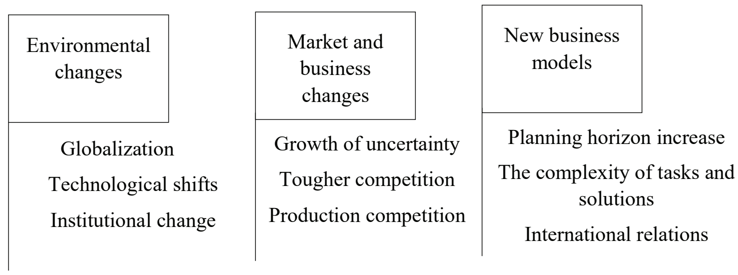

Fig. 1. The role and influence of the external environment on the activities of a virtual enterprise in the framework of Industry 4.0

By the type of activity, a third of the products were sold by machine-building enterprises, 24 % – food industry, 12 % – light industry.

At the same time, small enterprises occupy leading positions in certain areas as described in [10], in particular, in pulp and paper production and publishing, they provided more than half of the volume of sales. Their significant contribution to the sale of textile products, clothing – 28 %, as well as to the sale of leather and products from it – 23 %.

The paper [11] considered virtual enterprises, and what they most intensively created in high-tech industries (electronics, telecommunications, pharmaceuticals), where production processes are easily standardized. According to the website of global statistics of the Internet, the number of active Internet users amounted to about 2 million people, and the number of registered resources, i. e. sites in the Internet zone – about 80 thousand, of which 24 thousand account for business entities. For example, the total number of business entities in Ukraine is about 2 million, the enterprises represented on the Internet form only 1.2 % of their total number. According to the Association of Advertisers, about 15–20 % of enterprises regularly place advertisements on television, radio, in print and other media.

In the framework of Industry 4.0, virtual organizations are becoming the most important tool for economic and foreign economic activity, being a leverage for increasing the competitiveness of domestic enterprises by entering foreign markets. Acceleration of the development of a small virtual business, as an important component in the industry, can be achieved through its balanced and targeted state support, the formation of which should take into account the great demand from potential recipients and the severely limited resources that can be used to form it.

Based on this, virtual entrepreneurship is a priority in supporting small businesses. The essence of this priority area is to establish direct contacts between producers, consumers, potential partners and investors with the help of IT; providing information support to those organizations that contribute to the development of electronic business at the regional level, regardless of ownership and departmental affiliation. Virtual business is the catalyst that leads to the creation of completely new models of market relations, completely new associations of partners and, as a result, to a completely new economy that can bring to the level of highly developed countries, increasing competitiveness within Industry 4.0.

Along with purely technical tasks, the development of an approach to creating and supporting the functioning of VMBE also involves the creation of methodological tools for assessing the economic efficiency of enterprises, which, in the first place, is fundamentally important for small businesses.

Based on the above, it can be argued that today there is a problem caused by the contradiction between the formation and development of a new form of enterprise organization, such as VMBE, and the capabilities of existing means of information support for the product life cycle, focused on traditional production organization schemes.

3. The aim and objectives of the study

The aim of the study is to elaborate an approach to improving the efficiency of VMBE functioning by improving the information support of the main stages of the product life cycle of such enterprises.

To achieve this aim, the following objectives are accomplished:

– create a method for flexible transformation of production within VMBE according to market conditions;

– create a method for providing an alternative choice of subcontractors in the organization of virtual production;

– create a method of provision of the informational support for steady demand for VMBE products based on a product life cycle model.

4. Materials and methods for research of the possibilities of increasing the efficiency of VMBE functioning

4. 1. Method for flexible transformation of production within VMBE according to market conditions

Within the framework of the analysis of the problem of increasing the efficiency of VMBE functioning, the key advantage of virtual enterprises over traditional ones is highlighted, which is the ability to select and use the best resources of subcontractors when organizing virtual production. The characteristic features of the VMBE are: flexible change in the product range, "no warehouse", actual lack of fixed assets, minimum number of employees, priority of horizontal ties, relative autonomy and narrow specialization of VMBE staff, high status of information and personnel integration, compliance with the principle of the system use of resources, the availability of a flexible and adaptive organizational structure, the temporal nature of the organization and production of products, which is impossible without the unification of partners on a single again, minimal starting capital, work in conditions of uncertainty of sales.

As a result of the analysis of possible risks that arise during the whole life cycle of products in a traditional enterprise and comparison with those that occur in the activities of a virtual enterprise, the risk management method in a virtual enterprise is formed and focuses on the fact that, unlike the traditional manufacturing enterprises, VMBE are much less exposed because almost all production-related risks relate to the activities of manufacturing subcontractors. This makes VMBE more stable and flexible in terms of economic instability. VMBEs have a more flexible management system and are less dependent on such risk factors of classical manufacturing enterprises as: work on the warehouse, narrow specialization, anchoring to fixed assets. At the same time, one of the main issues with the functioning of VMBE is the risk of illiquidity, since virtual enterprises operate in a "no warehouse" mode. Thus, the relationship between the causes of the risk of illiquidity and the factors of production in terms of the life cycle of products is established. The typical organizational structure of the virtual VMBE is shown in Fig. 2.

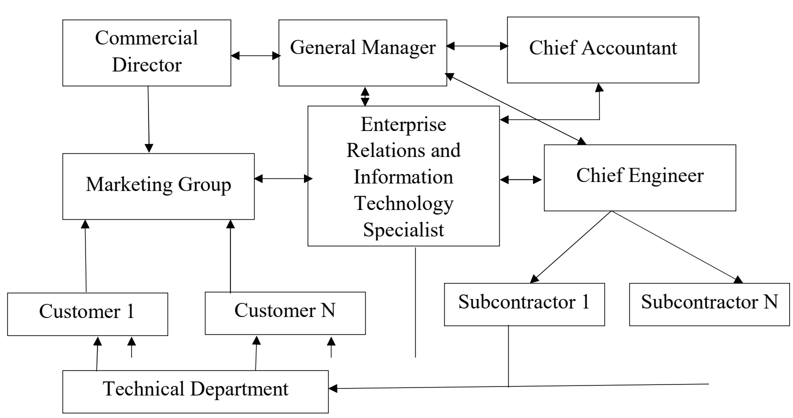

Fig. 2. Organizational structure of VMBE

As the conceptual basis for creating models, methods, algorithms and software life cycle products (LCP) for VMBE, the following principles of information support for LCPs on the VMBE were announced in the course of the study:

– the principle of universality, which can be implemented by flexible reshuffling of production in accordance with market conditions and ensuring usability of the user interface;

– the principle of diversification, which can be implemented through the provision of a variety when choosing subcontractors for the organization of virtual production;

– the principle of integrity, which is able to ensure the sustainability of demand for VMBE products.

The above principles can be fully realized only in the context of a special integrated information system (IIS), which will ensure the coordination of decision-making by various VMBE participants. The central points in creating the concept of IIS are the construction of "decision-making" and "assessment of the economic efficiency of implementation".

When developing the concept of IIS, it is necessary to consider the strategic aspects of VMBE activity, to determine if there is a fundamental possibility of creating a system, to formulate goals, to define the principles of constructing a methodology, as well as to identify strategic risks of the project and how to minimize them. Within the framework of the concept of VMBE, the functional model shown in Fig. 3, which reflects all business processes, from the receipt of external information through web-resources (ordering) to the production of components and assembly of finished products.

Improving time and economic performance without creating a relevant market demand for VMBE products means insensitive investment, as well as the lack of opportunities to meet available demand leads to losses for the enterprise. Thus, for the further development of the concept of VMBE IIS, a functional model of information support for LCP on VMBE was created (Fig. 4).

The above functional model contains objects: a management system for providing information support, an information support object, a functional performer, a holder of "Know-How".

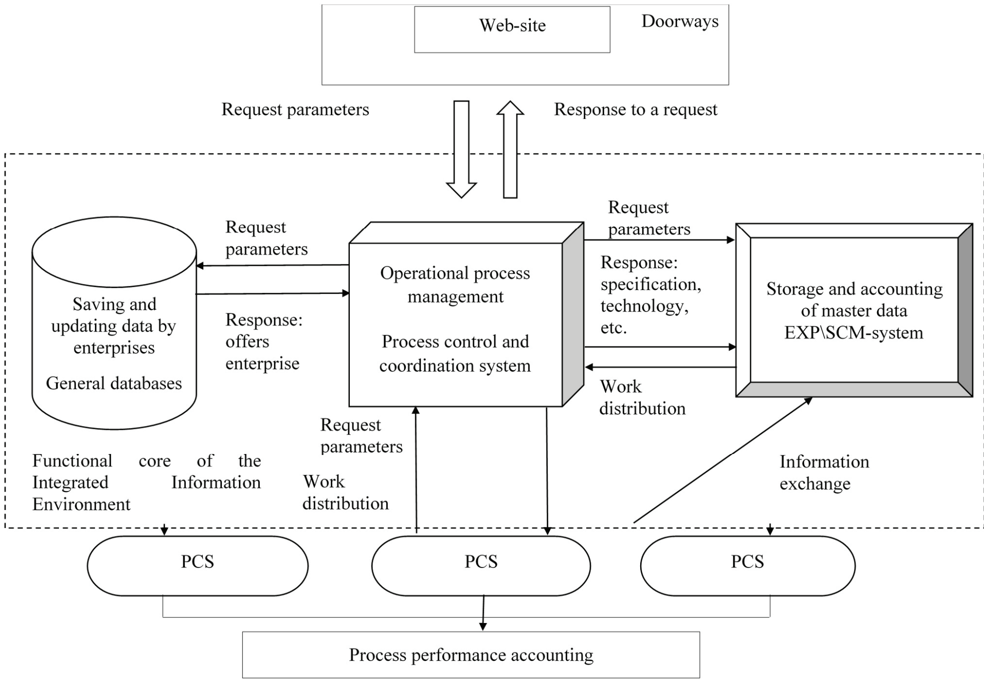

Fig. 3. Process model of information support of the LCP stages on VMBE

During the study, a generalized structure of the VMBE management system as a complex organizational and technical object was developed, which can be constructed in three layers: selection, adaptation and self-organization. For these layers, respectively, are the choice of the mode of action M, the specification of the set of uncertainties U (which exist in the layer of choice) and the choice of structure and strategy of the lower layers that maximally bring the whole system to a common goal. This general goal is usually difficult to formalize, but it is possible to isolate constraints (in the form of structures and strategies) for the lower layers in which the goals are formed more specifically (Fig. 5).

In Fig. 5, the following designations are given: W_1 – set of variables (signals); $W_1^{(I)}$ – input variable information flows; $W_1^{(0)}$ – output quantities; W_2 – a set of variables (signals) that represent feedback information from the selection layer; U – a set of signals that specify the uncertainty from Ω; Ω – set of uncertainties; M – a set of decisions that are realized on the object of decision-making; S_1, S_2, S_3 – functions of each level; C_1, C_2 – signals (parameters) that form the structure and strategy of action of the lower layers of decision-making. The described structure of the processes of formation and decision-making on the functioning of VMBE was the basis for the model of the VMBE products life cycle.

$$A=<S,\overline{X,Y},R,T>, \quad (1)$$

wherein

$$S=\sum_{i=1}^{7} S_i,\ \overline{X}_i=\{x_j\},\ \overline{X}_i=\{x_j\},\ \overline{Y}_i=\{y_k\},$$

$$j=\overline{1,7},\ k=\overline{1,7}, R\supset\{R_{l_1}\}\cup\{R_{n_2}\},$$

$$l=\overline{1,7},\ n=\overline{1,7},\ \{R_{l_1}\}\cap\{R_{n_2}\}=\varnothing;$$

$$T=\{\tau_1,\ldots,\tau_7\},$$

$$\forall\tau_i\in T\left|\tau_i=\left[t_i^f,t_i^k\right]\right.,\forall\tau_i\in T\left|t_{i+1}^{(f)}\right.\ i=\overline{1,7},$$

$$S_{\tau_i}: R_{\tau_i}\to\overline{X_{\tau_i}}, \quad (2)$$

where $S_1,\ldots,S_7$ – stages of product life cycle; $\overline{X_i}$ – input data at the appropriate stage of the product life cycle; $\overline{Y_i}$ – output data of the relevant stages of the product life cycle, $t_i^{(f)}$, $t_i^{(k)}$ – moments of the beginning and end of each stage of the product life cycle respectively; R_{l_1} – data converter type “operation – element” for the l-th stage of the LCP; R_{n_2} – data element type “element-element” for the n-th stage of the LCP; – time intervals of the duration of LCP each stage.

Graphic representation of LCP states is shown in Fig. 6.

An important property of hierarchical systems is the reduction of information that goes up the hierarchy: for the levels above, most influential factors from the lower strata carry the same information, so the multi-level description of the VMBE architecture needs to be supplemented by a functional hierarchy of decision-making under uncertainty (Fig. 7).

The hierarchical structure of the LCP on the VMBE reflects two aspects of vertical decomposition (layers, levels), as well as the ambiguity of the processes of implementing the knowledge of oriented support for decision-making on VMBE management, both within the VMBE IIS and in each of its typical blocks. Thus, the problem of decision-making can be divided into layers by the complexity of the decisions, and the decisions in these layers are localized, that is, there is a distribution in the structure of the service of the enterprise and in decisions taken by this service. Due to the fact that the complexity of decision-making processes at different levels of the implementation of technological preparation of production does not allow the use of analytical models, the only effective means is the organization of information support for the adoption of technological solutions based on ontological engineering.

In the course of research, the possibility of creating a unified knowledge space in the form of a set of dynamic expert systems functioning in the hyper-media environment and the model of the information system in the form of information-analytical portal (IAP) (Fig. 8), which will ensure the effectiveness of marketing as a defining LCP stage on VMBE.

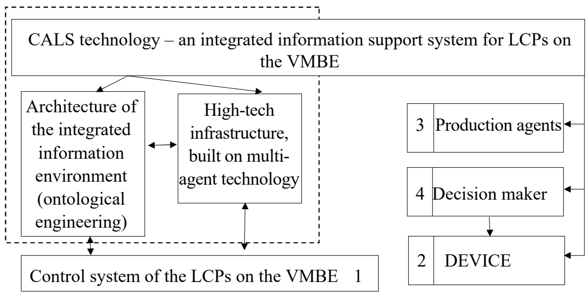

Fig. 4. The concept of information support for LCP on the VMBE

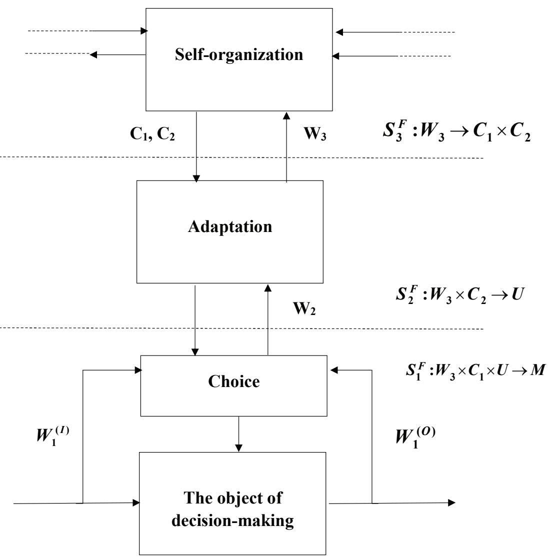

Fig. 5. Hierarchy of layers of decision-making in the control system of a VMBE

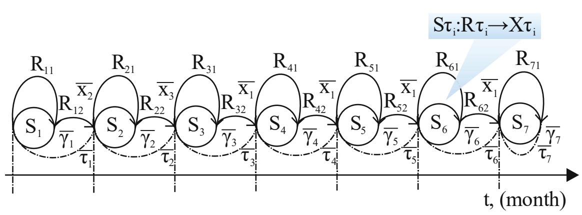

Fig. 6. Process model of LCP on VMBE

The model presented in Fig. 8 represents the process of creating orders from potential customers, which will then be transferred to production as soon as the necessary conditions of expediency (profitability) of the production of the *i*-th type of products are fulfilled, that is, the orders form the product line that will be produced on VMBE. Thus, on the basis of the model of the information and analytical portal, the method of decision-making support for the transformation of production into VMBE is implemented, in accordance with the market situation, which consists in organizing computer support for decision-making by the top management of the VMBE regarding the formation of the enterprise's production program, based on the existing demand for various categories of products included in the product range, which is issued on VMBE.

We introduce the following notation:

$$\overline{X_1} = \left\{x_1^1,...,x_n^1\right\}, \tag{3}$$

$$\left\{x_{1(i)}^1 + 1,...,x_{n(i)}^1 + n\right\}, \tag{4}$$

where

$\overline{X_1}$ – number of potential clients (Web-users);

$\left\{x_{1(i)}^1 + 1,...,x_{n(i)}^1 + n\right\}$ set potential orders;

n – some number of natural series;

i – VMBE product type;

$N_{i\cdot\min}$ – minimum allowable number of orders of the *i*-th type of product for transferring an application for production.

The essence of the method is to determine the minimum batch of each product, which ensures the profitability of production on VMBE.

$\left\{x_{1(i)} + 1,...,x_{1n(i)} + n\right\}$ *condition* $\geq N_{i.\min}$ – the number of orders required to achieve profitability of the *i*-th type of product, in this case

$$N_{i.min} \to \min,$$

$$\left\{x_{1(i)} + 1,...,x_{1n(i)} + n\right\} \to \max. \tag{5}$$

Simulation subsystem to calculate the required maximum production volume of the *i*-th type of VMBE products:

$$N_{i.\min} = x_{1n(i)} * n, \tag{6}$$

where $x_{1n(i)}$ – order for the *i*-th type of products; n – number of units of the *i*-th type of products.

The implementation of the method provides flexibility in the organization of production on the VMBE, taking into account the dynamics of the changing market conditions.

Achieving the constancy of the flow of orders is possible when applying the VMBE product informativeness method, which is based on the application of a set of agents in the form of one-page web resources. Initial data for the development of the method were a set of indicators:

$$A =< P, O, SS, K, g, f >, \tag{7}$$

where $P = \{Pi\}$, $i = \overline{1,N}$ – product range of VMBE; $O = \{Oi\}$, $i = \overline{1,N}$ – volume of each product in the VMBE product range; $SS = \{SS_1, SS_2, SS_3, SS_4\}$ – coefficient of seasonality; $K \supset K\sim$ – the number of visits to the online store; $K\sim$ – a set of online store visitors who have entered into a VMBE product delivery agreement; g – a function that reflects the visit of a VMBE online store to a potential customer, $g: A \to K$; f – a function that reflects the conclusion of an agreement with a potential VMBE client, $f: A \to K\sim$.

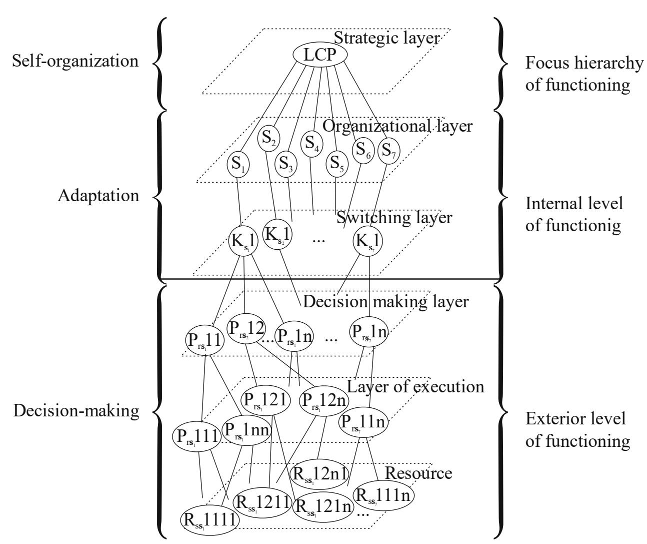

Fig. 7. Hierarchical structure of LCP on VMBE

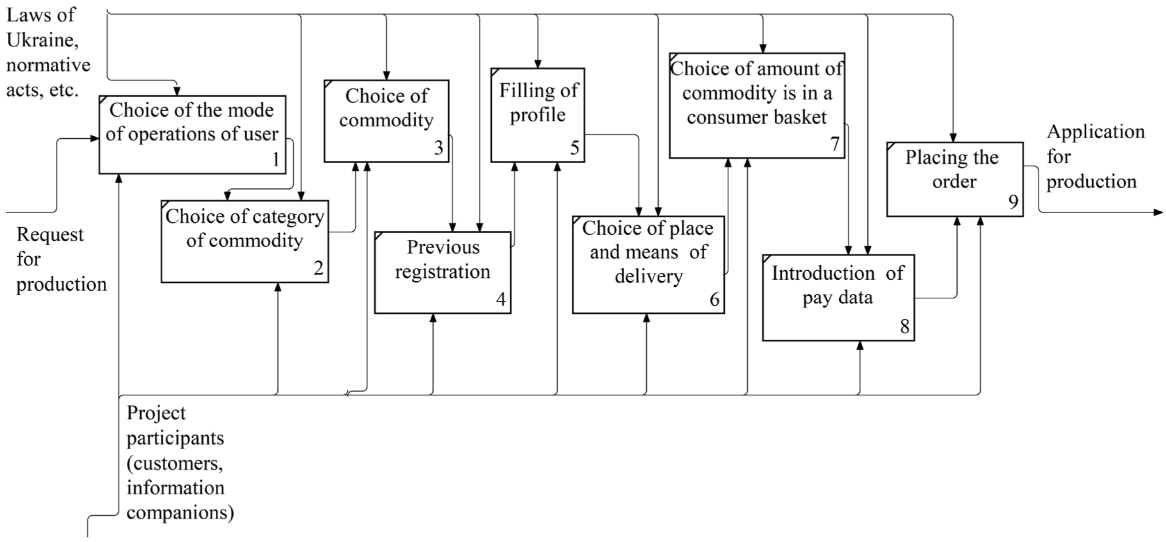

Fig. 8. Process model of VMBE information and analytical portal

4. 2. Method for providing an alternative choice of subcontractors in the organization of virtual production

The essence of the method is to develop a community of software and hardware agents that automatically place production orders during the organization of technical preparation of production within the framework of VMBE. At the same time, the capabilities of subcontractors for the manufacture of components for the subsequent assembly of products are taken into account. Specificity of the being solved problem determines the need to develop two types of agents – simple reflective agents and a complex structured software agent. The mission of reflective agents is to transfer the target firmware control programs (TFCP) to the equipment of subcontractors. The software agent will select subcontractors, as well as distribute production orders between them, taking into account the features and capabilities of each subcontractor. Agents of the first type, obviously, should have a hardware-software nature, and their number should correspond to the number of production tasks formed at the stage of technological preparation of VMBE production.

The initial data for the implementation of the method were the results of the technological preparation of production on VMBE in the form of a combination of TFCP, as well as the following standards in force in the field of creating multi-agent systems: the language of interaction of agents KQML (Knowledge Query and Manipulation Language); KIF (Knowledge Interchange Format) []; agent platform FIPA (Foundation for Intelligent Physical Agents), based on the reaction of the system to events of the outside world ("reactive architecture").

In general, the method for providing an alternative choice of subcontractors consists of three stages: development of the architecture of simple reflective agents (mediators); development of the architecture of an intermediate agent (facilitator); creation of an integrated system (agency).

1. Develop a set of mediating agents whose sole mission is to transfer the appropriate TFCP to the subcontractor.

2. Develop a facilitator agent whose mission involves the following tasks: providing a mechanism for transmitting messages within a multi-agent system, routing messages to their destination; converting incoming messages into the presentation format of the recipient; monitoring the current state of mediating agents. The nature of these tasks determines the need to use in the development of a sophisticated architecture of an agent, such as BDI (Belief-Desire-Intension), since the presence of such functional blocks as "desires", "beliefs" and "preferences" makes it possible to fully reflect the alternative in the task of selecting a subcontractor to complete the production order.

3. To integrate the entire range of agents within the framework of VMBE, create an agency.

Based on the use of the developed multi-agent system as an element of the global information environment for computer support of business processes on VMBE, the FIPA standard is the most suitable for developing systems of this type. For integration, another type of agent was used – Wrapper, which performs service functions of communication between nomenclature agents.

As a result of the application of the developed method, coordination of the distributed functioning of agents in the organization of production within the framework of VMBE is ensured.

4. 3. Method of provision of information support for steady demand for VMBE products

The generalized description of the method contains four stages, three of which are implemented when creating a multi-agent web-based environment, and the fourth – directly in the implementation of the method:

– development of an online store selling VMBE products;

– development of the main site of VMBE with the implementation of the functions of informing users of K about: VMBE structure, additional characteristics of products, discounts, service;

– development of a set of reflexive agents in the form of doorway sites, the number of which coincides with the nomenclature P of products produced by VMBE. In addition to information about a specific product type, the agent carries information about VMBE;

– formation of the VMBE product release plan based on the analysis of market conditions (this stage is realized directly in the process of functioning of the multi-agent web-based environment).

Due to the application of the described method, a special environment is rolled up and maintained in the hypermedia space (Fig. 9), which ensures not only the increase of information content of the VMBE products, but also the planning of the production of these products on the basis of the analysis of the market conditions.

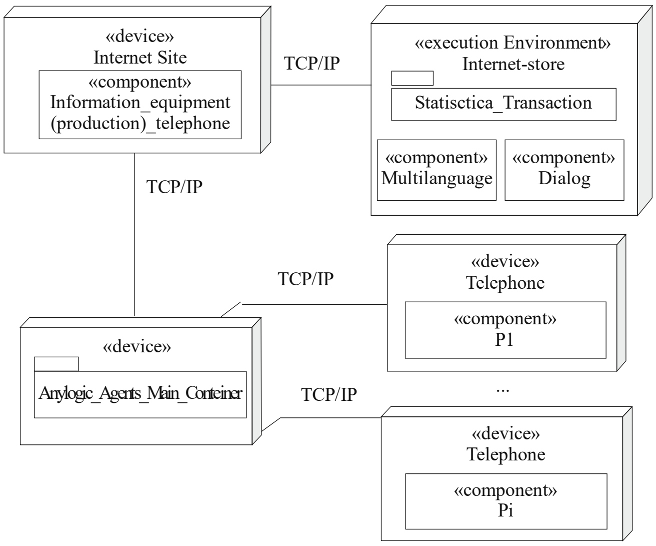

Fig. 9. The multi-agent web-based environment architecture (MDA notation) provides VMBE products informativeness

Thus, the essence of the described method is to increase the informativeness of the VMBE products by developing and deploying in a hypermedia environment, based on technology WebMining and multi-agent technology, a set of information satellites (doorways), representing a community of reflexive agents whose mission is to target potential customers on VMBE products. Due to the application of the method, in the Internet environment the information system will be deployed, focused on the potential customer of VMBE products.

In the course of the research, the description of the VMBE information and control space as a set of typical decision support blocks (DSB) was made. This description allowed, on the one hand, to give a detailed description of the internal properties of the position in space, any of the DSBs, and on the other hand, to describe the relative properties of the positions of the DSB by introducing special metrics. The structure of the metric space gives an idea of the ontology of the structure of the DSB in the IIS VMBE.

The formal model of the ontological system of the IIS VMBE is based on the concept of "Lightweight ontology", and is presented as triplet S:

$$So =< qmeta, \{Opr\}, M > \qquad (8)$$

where $qmeta$ – upper level ontology (metaontology); {Opr} – set of subject ontologies and ontologies of domain problems; M – the model of the output engine associated with the ontological system S.

The ontological system of the IIS VMBE consists of three components: meta-language "Design and technological documentation for the production of VMBE products"; Subject Ontology "Life cycle of VMBE products"; related ontologies of queries "Consumers" and "Service of sold products".

5. Research results of the organization of business processes in VMBE

As a result, the program implementation of the VMBE IIS in the form of a multi-agent system, in which the formation of agents and coordination of their activities is carried out. This construction of the VMBE IIS enabled the implementation of the alternative method of selecting subcontractors for the organization of virtual production using multi-agent technology. The essence of the method is to develop a community of software and hardware agents that carry out the automatic placement of production orders during the organization of technical preparation of production within the framework of VMBE, taking into account the capabilities of subcontractors for the manufacture of components for the further assembly of products.

Specificity of the solved problem determines the necessity of developing two types of reflexive agents whose mission is to transfer the equipment of the subcontractors of the target control software firmware, and the only software agent of the complicated structure that will choose the subcontractors, as well as the distribution of production orders between them, taking into account the features and capabilities of each subcontractor. Agents of the first type, obviously, should have the hardware and software nature, and their number should correspond to the number of production tasks formed at the stage of technological preparation of production VMBE.

The general structure of the method of providing alternatives to the selection of subcontractors consists of three stages: the development of the architecture of simple reflexive agents (mediator); development of the architecture of the intermediate agent (facilitator); creation of an integrated system (agency).

Based on the fact that the VMBE is essentially part of the global information environment, the FIPA standard is the most suitable for the development of such systems. Fig. 10 shows the integration scheme of agents with the help of a special agent – Wrapper, which performs the functions of the interaction of reflexive agents.

Due to the application of the developed method, the coordination of the distributed operation of agents for the organization of production within the framework of VMBE is provided.

The formal model of the process of selecting subcontractors Gs for ordering S is presented, taking into account the input information on conditions, terms and quality

$$GS = AS, DS, CD, TA, ED, PE, AT, A, C, D, E, \qquad (9)$$

where AS – a set of all technological order operations S; DS – a set of units (operations) that includes an order S; CD – subcontractors to perform a plural operation DS; TA – a set of requirements for the subcontractor selection process; ED – a set of elements that are part of the operation; PE – set of parameters of elements of ED operation DS; $A\ T, AD$ – reflections are specified by the technological operations of making the order; CD – the mapping is determined from the database; EP, DE – are from the design documentation of manufacturing order (device).

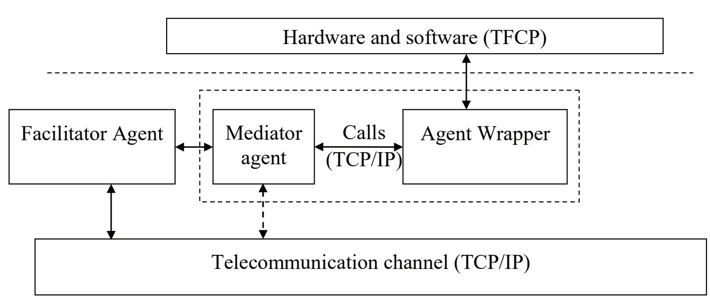

Fig. 10. The scheme of integration of agents within a single VMBE information space in accordance with the FIPA standard

In accordance with the stated principles, a method of information support for decisions on the feasibility of producing a certain type of product on the VMBE was developed, with the use of OLAP technology, which is based on the representation of the most significant indicators of the functioning of VMBE in three-dimensio-nal space using a spiral model. The application of this method makes it possible to predict trends in the market, and, based on this forecast, to formulate decisions on changes in the nomenclature of VMBE products. The essence of the method is to organize decision support by the head of the VMBE regarding the prospects for the further release of any product from the product range of the virtual enterprise, through the retrospective presentation of the statistics of the products, indicating the profit. This method consists of the following steps:

– formation on the basis of statistical information on the release and sale of a specific product from the range of products manufactured on the VMBE, in the form of a two-dimensional data array;

– converting the resulting two-dimensional array to the multidimensional OLAP data cube obtained in the previous step;

– bringing the multidimensional OLAP cube to a three-dimensional view (number of quarters by years, volume of issue in pieces, value of profit in conventional units;

– construction of an LCP model to visualize the process of evaluating the feasibility of a product; while the model is able to reflect the initial stage of the LCP when the break-even point has not yet been achieved and the release of such a product for the VMBE is unprofitable;

– formation of one of the following types of solutions: the feasibility of further release of the product without its modernization; the need to upgrade the product; removal of the product from production.

Implementation of the described method in the framework of creation of the IIS of VMBE management LCP provides the opportunity for the top manager of VMBE to substantiate decisions on the prospects for the production of any product according to the product range of VMBE products using the above model. When the break-even point of production is reached, in the analysis of the model, it is necessary to conduct strategic planning properly, to modernize the product in accordance with purchasing power and to continue the production of such a product or to complete this project.

In this case, the use of OLAP technology allows to visualize not only the stages of "run-release", but also to assess the need to stop further production, using the developed model of LCP assessment for VMBE. The construction of models of this type facilitates the extension of the LCP VMBE.

To assess the effectiveness of the implementation of the research results, an analysis of the financial and economic activities of a typical VMBE engaged in the production of a wide range of marking devices for 2015–2017 was carried out (Table 1).

Table 1

A consolidated table of performance for the typical VMBE for 2015–2017 years

VMBE Production Activity Indicator	2015 year	2016 year	2017 year	2018 year	2019 year	Trend (positive)/(negative)		Growth rates (Δ)
						pos. (↑)/ neg. (↓)	max/ min	
Coefficient of circulating of assets	2	2.4	3.03	3.75	4.4	↑	max	0.65
Coefficient of circulating of circulating assets	2.26	3.26	4.53	5.04	5.43	↑	max	0.39
Coefficient of circulating of account receivable	5.76	7.23	15.78	19.1	23.8	↑	max	4.7
Coefficient of circulating of account payable	2.66	3.06	4.5	5.08	6.92	↑	max	1.84
Coefficient of circulating of inventories	3.04	4.87	3.85	5.02	4.81	↓	min	–0.21
Coefficient of circulating of property asset	38.9	34.93	27.15	26.9	26.01	↓	min	–0.89
A creditor debt ratio to the general assets	0.82	0.64	0.71	0.59	0.68	↑	max	0.09
General liquidity ratio	0.26	0.28	0.008	0.11	0.14	↑	max	0.03
Coefficient of profitability of production	2.2	3.32	2.75	2.98	3.02	↑	max	0.04
Coefficient of profitability of sales	0.0006	0.0064	0.01	0.019	0.021	↑	max	0.002
Coefficient of profitability of direct charges	0.09	0.73	1.38	1.46	1.532	↑	max	0.072

As a result of the analysis, the additive coefficient K is calculated, which shows the efficiency of the enterprise. If $K>1$, then the system is effective. Changing the coefficient K is the total value of the results of the changes in the activity of the sets of the system at a certain point in time. The summary results of the mathematical calculations are shown in Table 1.

6. Discussion of the research results of development of cognitive approach to the organization of business processes in VMBE

Cognitive approach to the organization of business processes in virtual machine-building enterprises within the industry 4.0, which is capable of providing integrated information support for the product life cycle of virtual enterprises, is created. The said approach is implemented through a series of such methodological tools: support in making decisions on the conversion of VMBE production in accordance with the market conditions (Fig. 4, 5), while developing a process model of the information and analytical portal that allows us to formulate a range of products manufactured in accordance with market needs, thereby providing VMBE in just-in-time mode (Fig. 8); provision of alternative choice of subcontractors in the organization of virtual production using multi-agent technology, which, unlike the known, makes it possible to reduce risks in the production of products in VMBE.

In order to evaluate the effectiveness of implementing the stages of product life cycle at VMBE, a method of information support for decisions on the feasibility of production of VMBE is developed, which, unlike existing ones, is based on the use of a model of the life cycle of VMBE products, which allows determining the expediency of further product release and planning measures to extend the life and demand for it.

The application of this method is illustrated by a specific example, which showed that the VMBE efficiency is 6.0816, that is, this enterprise is effective, while the indicator of the efficiency of time use decreased by 32 %, and the economic – by 20 % (Table 1).

The software implementation of VMBE IIS based on multi-agent technology and ontological engineering is offered (Fig. 10), which enables to effectively support the main stages of the product life cycle of the VMBE.

The strength of the proposed approach is to increase the efficiency of the VMBE by reducing the level of uncertainty at all stages of the product life cycle.

The main drawback of the discussed approach is the difficulty of maintaining the level of confidentiality in the web space. In addition, the effectiveness of the developed approach is directly affected by the lack of a mechanism for accounting and risk management of electronic business. The development of such a mechanism should be the main focus of further research.

An assessment of the effectiveness of the developed methodology by analyzing the financial and economic activity of the typical VMBE for the five-year period is carried out. Due to the results of the calculations, the additive coefficient K=6.0816 was obtained, indicating an improvement in the time and economic performance of the virtual enterprise.

In the future, the described approach can be used for a wider class of industrial enterprises.

7. Conclusions

1. The method for flexible transformation of production within VMBE according to market conditions, which, unlike the existing ones, is based on the use of an information-analytical-marketing portal, which ensures the release of only cost-effective products is developed.

2. The method of provision of alternative choice of subcontractors in the organization of virtual production, which, unlike the known ones, is based on multi-agent technology and makes it possible to reduce the level of uncertainty in the functioning of VMBE is developed.

3. The method of provision of the information support for steady demand for VMBE products based on a product life cycle model which, unlike the known ones makes it possible to predict a trend for a change in the range of products that are manufactured or modernized is proposed.

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