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MATHEMATICAL MODEL OF THE BUSINESS PROCESS OF HIGHER EDUCATION INSTITUTIONS BASED ON ONTOLOGICAL ANALYSIS

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Improving the quality of the educational process and bringing it up to modern standards is a complex task that requires a systematic approach and the development of a strategy for improving the quality of service and efficiency. This work examines the specifics of information modeling within an ontological approach to distributed information environments, as well as the essence of ontological analysis of management business processes for the educational process in higher education institutions. An ontological analysis of modeling business processes in higher education institutions and an analysis of the structure, functions, and information flows of organizing and managing educational activities based on a structural approach are conducted. Competence, as an integrated characteristic of the graduate's quality, is considered a result of education. The use of an ontological model of interaction between subjects and objects of the system allows for the evaluation of the system's effectiveness and the construction of a management model, enabling the forecasting of critical business processes that may lead to a decrease in decision-making efficiency and disruptions in the functioning of higher education institutions and their units. The paper proposes a concept for the mathematical modeling of ontology and optimization of business processes in higher education institutions under conditions significant for their design. The structural model of the business process proposed in the paper includes both production and service components. The proposed models allow for mathematical modeling and optimization of business processes without constraints on their complexity, as well as the creation of software complexes based on them for numerical (non-descriptive) design of business processes.

Keywords: higher education institutions, information environment, ontology, modeling, business process, reengineering.

Introduction

Creation of conditions on conceptual principles of a modern market economy that would satisfy the economic interests of the main subjects of economic relations in the field of higher education:

- students of higher education — consumers of higher education services;
- higher educational institutions — producers and providers of higher education services;
- state authorities and local governments, corporations, public organizations;
- individuals and legal entities — customers for the production and provision of higher education services.

Education as a type of economic activity involves the production and provision of higher education services in accordance with the definitions of official international and national classifications.

Taking into account the complex nature of the category of economic efficiency and different levels of efficiency in functioning of higher education institutions (HEIs), it is proposed to analyze the efficiency of higher education according to the criteria of economy, productivity, performance, and costs.

Therefore, the higher education system is primarily focused on improving its quality and compliance with modern innovative needs, establishing an adequate relationship between the structure and content of education on one hand and the real needs of the economy on the other. For the simplicity of theoretical analysis, we will limit ourselves to the traditional point of view that educational activity involves the transmission and dissemination of knowledge for the comprehensive and harmonious development of an individual. In the interpretation the role of educational knowledge, its nature, and social orientation, it is worth considering that they can be more general or specific in character. General knowledge is the basis of human intellect, his awareness of the surrounding world; they are the foundation, the basis for acquiring more specific, specialized professional knowledge as an integral component of the mandatory general education of the entire population. Ensuring the accessibility of such knowledge, the universal coverage of the population becomes a function of the general secondary education network. It is known that the presence of specific, usually professional knowledge makes a person a specialist, in demand in any field of activity.

The subject of work in education is quite specific — a human personality, that is constantly in a state of development and is simultaneously a consumer of educational services and a participant in their provision. This is the main difference between the creation of educational services and any other.

Quantitative design of business processes, understood as the numerical optimization synthesis of the structure, factors, and parameters of a business process, despite its relevance, has not yet gained proper development. The paper proposes a concept and methods of mathematical modeling and optimization of business processes in conditions of uncertainty about the future and variability of economic and financial conditions, essential for their design. Such conditions include future demand and selling price for the final educational product, the amount of financial resources, the prices of production factors, possible opportunities (favorable future events), and risks (unfavorable future events), as well as market conditions.

The structural model of the business process introduced in the paper includes both production and support as well as service links. The proposed models and

methods allow for mathematical modeling and optimization of the business process without restrictions of its complexity in the conditions of its future development, taking into account the uncertainty of the economic situation and financing, as well as to create software complexes for numerical (non-descriptive) design based on them. The relevance of the topic arises from the growing interest in the issue of data integration in various fields of activity related to the accumulation and effective use of information.

The functioning of an organization or enterprise requires automation that combines a set of administrative and educational processes. In educational institutions it is important to organize the management of units for the provision of educational, methodical and research services. Higher education in Ukraine, as well as other spheres of industrial and non-industrial activities, is increasingly feeling the pressure of the market. Acquiring new responsibilities and freedoms, management processes become more and more adequate in accordance with those used in the field of entrepreneurship. HEIs faced a number of problems related to effective management processes. This is caused, first of all, by insufficient funding in general and budget funding in particular. Research into the peculiarities of information modeling, including the creation of an ontological approach to distributed information environments, as well as an ontological approach to the application of similar models in different subject areas, is relevant [1, 2]. The challenges that determine the transformation of the essence of higher education in Ukraine contribute to its orientation toward understanding and satisfying the educational needs and demands of youth as direct users of the services provided by higher education institutions.

At the same time, during the period of society's reorientation from the industrial paradigm to the informational one, the decisive factor in the country's development becomes the level of intellectual potential of the nation in general and the level of intellectual development of each individual in particular. Considering this, the educational process in higher education institutions should have an adaptive and anticipatory nature, which determines a quick and adequate response of the educational process content to new challenges, demands, and needs of consumers of educational services provided by higher education institutions. An important research direction in this field is the application of a mathematical apparatus designed to represent terminological knowledge about the subject area, an ontological approach. Ontologies allow specifying the structure and semantics of terms in the data integration system and information sources.

Literature analysis and description of the problem

The university education system serves as the main means of preparing highly qualified professionals capable of creative perception of rapid changes in economic activities. The market is equally oriented towards the direct consumers of higher education services — students, and the buyers of labor — enterprises and institutions. Currently, higher education institutions actively practice business processes in their activities to preserve pedagogical and scientific assets, which is reflected in literary sources. The research was based on publicly available descriptions of the actual business processes in the active universities of Kyiv, Rivne and other higher education institutions, presented in various literary data and on Kyiv National University of Construction and Architecture own materials, at the same time, the goal of creating a voluminous review material was not set, since for further research it is enough to exist such processes [3].

The features of managing educational business processes are relevant in the conditions of the unprofitability of private higher education institutions. This re-

quires additional scientific research in this field, based on the principles of quality by E. Deming [4], the Kaizen concept [5], and Business Process Reengineering by M. Hammer and J. Champy [6].

In modern conditions characterized by a high degree of uncertainty, one of the promising approaches in forecasting is scenario analysis [7].

In a market-based economic system, ensuring the profitability of higher education institutions becomes relevant through business process management [8]. Higher education institutions face the same challenge as commercial structures: to be competitive, i.e., to operate economically efficiently, and to prepare qualified professionals who meet the requirements of the modern labor market [9, 10].

As known, there are currently three models of higher education development in the world:

- market-oriented (United Kingdom and the United States);
- state-oriented (Scandinavian countries);
- mixed (Central European countries).

Another type is also distinguished today — the «supportive state», where the state plays a role as a regulator of access to higher education, practically does not interfere in the internal management issues of higher educational institutions, establishes and supports general rules for all universities. The main function of the state is to establish quality standards of education and control their compliance.

Studying business processes to improve the efficiency of higher education institutions involves understanding and modeling all business processes, building a strategy that contributes to the growth of all indicators, with a clear assessment of acquired knowledge and the effectiveness of the institution's overall functioning [11].

Managing the active system of a higher education institution involves constructing a model of the system's behavior over time under specified external and internal conditions, depending on the implemented control influence. A higher education institution can influence internal environment factors by implementing a management system. The model of the higher education institution's system management is based on the unity principle of primary and auxiliary types of activities and centralized management. Primary types of activities of a higher education institution include educational activities, research activities, and production activities. From the perspective of business process reengineering technology, primary types of activities of a higher education institution correspond to primary business processes. These are sequences of actions that start with one or more inputs and end with the creation of a product or service required by the consumer. In turn, primary types of activities are divided into subtypes, corresponding to partial business processes. Auxiliary types of activities that support the implementation of primary types of activities (primary business processes) correspond to supporting business processes that do not have a direct impact on the customer. The interaction between primary and auxiliary types of activities is ensured based on informational support, the functioning of the quality system, and a unified regulatory framework. The totality of management influences on primary and auxiliary types of activities (primary and supporting business processes) forms the systemic management of the university.

One of the critical factors is the intensification of information exchange within the higher education institution, considering the possibility of one department participating in various business processes. This task becomes increasingly relevant with the increase of information volumes and the need for their rational processing.

The business model of a higher education institution is an interconnected and time-ordered set of business processes within the institution. The correct and adequate

creation of information models of business processes becomes a guarantee of the organization's success in the future. The essential characteristic of the concept of a business model is the system of relationships between the organization (its resources, capabilities, competencies), the consumer market (volumes, segments, value needs), and partners (possible participants in the product creation: designers, distributors, marketers, public organizations).

Most business models involve:

- a sequence of actions;
- partners in the value chain from raw materials to the customer;
- a value proposition for the customer;
- a way of delivering to the customer;
- internal resources or the potential to organize them.

Formalizing and modeling the management business process enables making managerial decisions for the effective administration of the higher education institution. Moreover, business processes consist of specific operations, and their execution is practically applied through economic modeling. Engaging in the analysis of business processes requires identifying issues and developing a strategy to enhance service quality and institution efficiency.

Objective

Based on ontological analysis of the business processes in the management of the educational process in higher education institutions and management technology, investigate the essential aspects that lead to ensuring the quality of educational services, taking into account the formation of corresponding general and specific competencies for institution management based on information modeling of business processes for the electronic document workflow system. Formulate and describe a mathematical model of the ontology of business processes in higher education institutions.

Research methods

Modeling is an important tool for understanding and describing subject areas, and ontology helps structure knowledge and definitions. In general, the use of mathematical models in ontology is a powerful tool for analyzing and understanding subject areas. An ontological model is a description of the subject area that:

- utilizes elements of a metamodel;
- strives to explicitly replicate key aspects of the subject area as fully and accurately as possible.

Characteristics of ontological models include:

- the use of universal knowledge description tools;
- orientation toward the structuring and storage of knowledge;
- can be applied to plan future states of the described subject area based on possibility theory.

Ontological modeling is the process of constructing, developing, processing, and using the ontology of a specific subject area. Mathematical models in ontology are formalized descriptions of the subject area using mathematical concepts and methods. They enable the representation of knowledge about the subject area in the form of formal structures, which can be used for the analysis, comparison, and forecasting of various aspects of this domain. Mathematical models in ontology describe concepts, the relationships between them, and the rules of inference that define logical connections and laws according to which the subject area operates.

Basic principles of constructing mathematical models in ontology include:

- formalization of knowledge about the subject area;

- hierarchical structure where concepts and relationships are organized in the form of a tree or graph;
- validation and verification — the model must be checked for consistency with knowledge about the subject area and compliance with formal rules and constraints.

This approach has several advantages:

- formal languages allow the specification of formal rules and constraints, define relationships between concepts, and perform logical operations on them;
- formal languages provide precision and clarity in describing the model and enable automatic analysis and inferences based on the model;
- extensibility and flexibility to accommodate changes and additions in the subject area are achieved through the use of a modular structure.

Advantages of mathematical models in ontology:

- 1) accessibility, clarity, and formalization;
- 2) universality in different contexts;
- 3) automation; they can be used for the automatic processing and analysis of information.

During the development of a knowledge-based system, ontology of the subject area is typically used, representing a set of definitions of concepts and relationships between them. Ontology defines the knowledge structure of this domain, and ontology terms are also used in problem-solving tasks. Knowledge-based systems allow for changes in knowledge but do not permit changes in ontology, as ontology is fixed during the creation of the intelligent system. However, there are subject areas where both the knowledge system and the conceptual system (ontology) can change. Additionally, in complexly structured subject areas, ontology sections may have a similar structure, and a higher-level ontology can be used to define it. Ontology defines the system of concepts in the subject area, indicating the set of terms for denoting concepts and the relationships between the meanings of these terms. For each term, ontology specifies the scope of the concept it represents. Among the terms in ontology, there are those used during knowledge formalization (knowledge ontology) and those used for specifying input and output data for tasks.

A multilevel ontology of the subject area is modular. The modularity of the ontology makes its description easily modifiable: in the case of changing related concepts, it is sufficient to modify their definitions in only one module. This property of the ontology enables the creation of intelligent systems in which both knowledge and ontologies can be changed.

In the modeling of business processes in higher education institutions, there is a problem in the technologies for analyzing large volumes of data, which is associated with the constant growth of information volumes that need to be processed. Therefore, improving the efficiency of big data analysis based on the use of ontology with the application of associative rules is a solution that allows effective work with unstructured data. Data integration is necessary for higher education institutions where information is scattered across various specialized systems built at different times and for different purposes. This is essential for improving efficiency and providing higher quality knowledge from a variety of structured data sources. Mathematical models of ontologies allow for a more precise and formalized description of subject areas and conducting various analyses and computations based on such models.

Since ontology construction covers all stages of data structuring, the ontological approach is proposed for use as a tool for solving the structuring task itself.

A mathematical model of a data integration system based on ontology will make it possible to directly use the obtained data for practical tasks in accordance with the formal model. Issues related to the optimality of organizing business processes should be

considered only as a certain graph-analytical basis for analyzing the educational, scientific, economic, and other activities of higher education institutions, flexible description of the semantic relationship of terms, integrity constraints, rules of logical derivation.

Research results

A higher education institution is an open integrated resource and socio-pedagogical system characterized by integrity, structure, and adaptability, with information and communication at its core. It is designed to implement the educational process with the main task of providing quality educational services that ensure the development and self-realization of individuals, essential for the formation of competitive human capital.

The educational process is a complex object consisting of a large number of separate subsystems and generally does not have an adequate formal description. A systemic approach allows for analyzing the development and functioning of the education system, taking into account the requirements of the state, society, and citizens in both the short and long term. Higher education institutions represent a three- or four-level organizational-technical hierarchical structure (institution–faculty–department–laboratory), open in the conditions of a market economy. The main tasks of the functioning of this organizational structure include planning, control, organization, and representation in the field of higher education.

Functioning subjects of a HEI include economic entities and participants in the education system (students, teachers, auxiliary staff).

Functioning objects of a higher education institution encompass students, applicants, teachers, auxiliary technical staff, administrative and managerial staff of the rectorate, deans' offices, and departments, educational programs, syllabi, methodological guidelines, tests and exam recommendations, library resources, computer-technical facilities. The periodicity and cyclicity of the functioning of a higher education institution follow the academic year, with two semesters, breaks, credit sessions, examination sessions, and certification. Activities include the preparation of bachelor's theses, master's theses, doctoral dissertations, as well as coursework and projects for students. Individual tasks and calculation-graphic works are also part of the educational process.

Functions of the organizational and technical structure of an educational institution include:

- provision of the educational institution;
- administration of the educational institution;
- coordination within the educational institution system;
- external coordination and reporting of the educational institution.

Information sources of an educational institution include students at all levels of education, manuals, lecture summaries, methodological recommendations, administrative and economic orders and directives, regulations, orders, and regulations of the Ministry of Education and Science, laws of Ukraine.

A business process is a sequence of behavior within the organizational structure that forms a system and has the function of achieving a goal. A business process is a coherent, integrated set of works, implemented taking into account the specified requirements, which ensures the achievement of the necessary final result for obtaining profit, which can change depending on the factors of the market situation. In education, business processes represent interconnected educational and developmental activities of students and teaching staff aimed at implementing educational standards and professional training programs to prepare qualified specialists

in a specific field of activity. A business process consists of functions that are parts of the business process and can be considered as independent business processes.

The concept of a business process is at the basis of the process approach to the analysis and synthesis of the activities of the educational institution. The process approaches you to consider the organization's activities as an interconnected system of business processes, each of which interacts with other business processes or the external environment.

A business process is created to achieve a global goal, which is the release of a final product. Therefore, the optimization of the business process should be carried out for the entire structural model of the process as a whole, as a system. In addition, the volume of output and the selling price of the planned product, as well as the volumes of purchased production factors, are controlled factors by the owner of the business process and, therefore, variables in the optimization mathematical model.

A business process is a sequence of actions (sub-processes) aimed at achieving a specified result. It represents a system of sequential, purposeful, and regulated types of activities, in which inputs to the process are transformed into outputs, process results, which represent value for consumers, through control and the use of resources. The key properties of a business process include being a final and interconnected set of actions defined by relationships, motives, constraints, and resources within the final set of subjects and objects that unite into a system for common interests with the aim of obtaining a specific result, alienated or consumed by the system itself.

Business processes are divided into:

- core. Business processes of educational institutions include the process of «University faculty activity oriented towards students», based on the «Knowledge modules in business processes in higher education» (Fig. 1);
- ancillary. These processes result in ancillary outcomes of educational activities that add value constrained by costs but do not ensure revenue generation;
- auxiliary. Processes designed to support the vital functions of core and ancillary processes;
- management processes. These processes encompass the entire range of management functions at the level of each business process and the overall business system;
- development processes. These processes involve improving the produced educational service, technological development processes, and innovative processes.

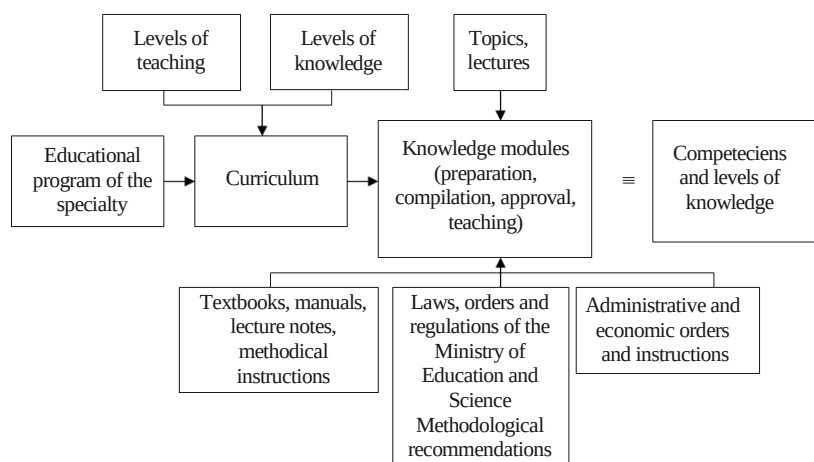


Fig. 1

Meanwhile, the producer himself forms his employment and makes an independent decision regarding the release of educational services, based on his own forecasts of future demand and supply.

A business process is a set of completed tasks performed to obtain educational services that have a measurable consumer value for a specific consumer or market segment. The process is formed by a flow of interconnected tasks within the organization, passing from one employee to another or from one department to another. These tasks are also processes, but they are internal in nature.

The value of educational services is determined by the degree of compliance of their properties, cost, and related services with consumer expectations. Only under such conditions will the service find its buyer. An important component of the definition of a business process is the presence of a specific consumer or market segment, where its primary output is located. Consumers are often divided into groups, each of which has a specific set of requirements. Dividing consumers into groups makes it possible to establish general and specific requirements for each of the groups. The class of consumers forms the class of the process, and the groups represent its variations.

The business system of the organization itself includes: business processes; suppliers of operational and strategic information managing the business process; supporting processes; and the ultimate consumer of the main output. When forming information for management, the requirements and expectations of external subjects interested in the functioning of the educational institution are taken into account. Since business processes satisfy the interests of external consumers (as well as other subjects) and the interests of the organization itself, the relationships between the business system and the external environment should be carefully examined and studied.

A business system is a connected set of business processes, the ultimate goal of which is the production of goods or services for the purpose of making a profit. The business system is a projection of the mission, goals, and strategies of the educational institution's business. The business system is considered both as an enterprise as a whole and any of its subdivisions. Optimizing the efficiency of managing the business processes of the educational institution is of particular importance, and the practical application of the theory of self-organization of complex ordered systems in the stages of analysis and synthesis of educational service systems at various hierarchical levels, i.e., the synergy of the educational institution's activities.

In relation to consumers, processes are categorized as external or internal. The client (consumer) of the process is the entity (individual, legal entity, functional unit, another process, etc.) that uses the results (outputs) of the process. For the process client, the value and the time of delivering the result (process output) are important. Accordingly, external and internal process clients are distinguished. External clients are considered in relation to the institution as a whole or in relation to the institution's business processes. External clients of the educational institution include not only consumers of educational services but also other stakeholders. Among them are the state, potential employers, ministries and agencies, as well as organizations that use the results of the activities of higher education institutions (information, financial and material resources, personnel). Internal clients of processes are functional units — executors and processes that use the results of the process execution (output). Concerning the creation of additional value, main, auxiliary, and management processes are identified.

On a set of business processes, relationships are defined based on properties such as result formation (in terms of the level of influence on value-added formation), by the place in the value formation chain, in relation to the organization's clients, by types of

activities tied to the management cycle, by functional features, and by the focus of management activities. Based on the approach to the classification of business processes in an educational institution concerning the creation of additional value, specifically «the production of a high-quality competitive graduate of a higher education institution», the following main, auxiliary, and management processes can be identified, forming typical business processes of the higher education institution (Fig. 2).

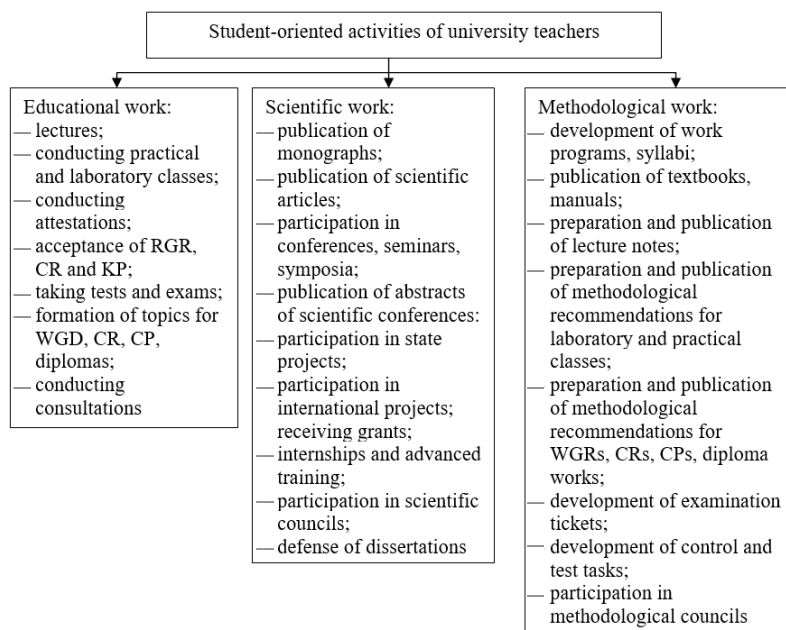


Fig. 2

The directions of the main processes outline the activities of the higher education institution, namely:

- informational and cultural-educational direction (processes that shape key competencies necessary for self-realization, active civic engagement, social harmony, and the ability to find employment in society);
- auxiliary processes do not directly add value but enhance the worth of the results of the core processes (services, information). Such processes include information support, technical equipment maintenance, administrative and economic activities;
- management processes constitute a special group ensuring the implementation of the management cycle in the higher education institution: planning, organization, motivation, control, improvement. These encompass strategic management, tactical management, personnel management, budget management, and others. Summarizing the above, we have the following basic categories: core processes, auxiliary processes, and management processes. In this regard, it should be noted that such a division is quite conditional.

Two approaches were used to classify the business processes of the educational institution:

- in relation to the consumers of the results of processes;
- in relation to the creation of additional value.

Measurement and analysis of process indicators — each of the educational business processes has its measurable consumer value. The results of internal processes should also be measured, including:

- service indicators — numerical values characterizing the service as the result of the process (absolute volume of services, volume of services relative to ordered or necessary, number of errors and failures during service delivery, list of provided services, list of provided services relative to necessary);
- customer satisfaction indicators of the process — numerical values characterizing the degree of satisfaction of the consumer with the results of the process;
- process execution time indicators;
- technical process indicators;
- process cost indicators;
- process quality indicators (improvement of the quality of interaction of involved departments, improvement of manageability of business processes, reduction of execution time of business processes, reduction of costs for the execution of business processes, improvement of the quality of results of business processes).

Regulation of processes allows for a clear distribution of responsibilities and authority at all levels of management, leading to improved coordination of departmental and personnel activities and increased efficiency of communications within the educational institution.

A process-oriented approach enables cost reduction and increased profitability by optimizing the entire chain of functions within processes, reducing their duration and cost, eliminating duplication, optimizing resource utilization across various processes, and minimizing operational risks. This means that the organization is considered primarily not as a collection of different departments but as a set of business processes through which its activities are realized. Typically, for the study and/or diagnosis of a company as a complex system, structural analysis is applied. Structural analysis is a method of investigating systems, involving a general understanding of the system and its subsequent detailing, i.e., breaking down the system into component elements and representing them as a specific structure. This is especially necessary in cases where studying the system as a whole is not possible due to its complexity. Dividing the system into separate subsystems, which are usually simpler, allows for further analysis.

The structure of a higher education institution divides the means of supporting business processes into three levels of management:

- 1) core managerial business processes (between the rectorate and the leadership of faculties or departments);
- 2) core business processes (between the leadership of faculties and department heads or the leadership of departments and unit heads);
- 3) business processes (between department heads and instructors or between unit heads and department staff).

Higher education institutions use the following systems for management:

- 1) HEI management system;
- 2) department management system;
- 3) decision-making system.

In HEIs, a three-tier management structure is typically used, namely:

- 1) the rectorate headed by the rector of the institution;
- 2) faculties (institutes) led by the dean (director) or departments led by the department head;
- 3) departments led by the department chair or divisions led by the division head.

The structure of the organization's business processes for higher education institutions is shown in (Fig. 3):

- core business processes directly influencing the revenue include student education and research activities, as well as state-owned systems and lease-related processes for renting property;

- service business processes (supporting, provisioning) are processes that do not generate revenue or are cost-intensive, such as personnel management, accounting, and production and economic activities.

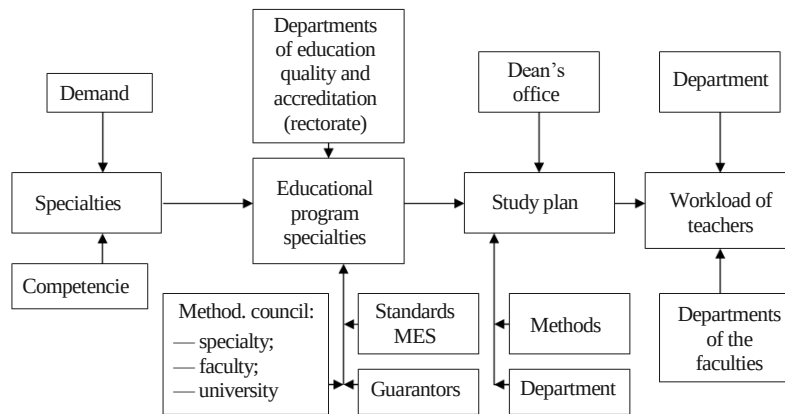


Fig. 3

While designing core business processes, the primary principle is to meet the demand for the future level of education. When designing service processes, it is necessary to focus on the quality of the future level of education. Designing, modeling, and optimizing business processes are carried out in conditions of uncertainty about the future and have an optimization nature.

Business modeling is the activity of identifying, describing, and analyzing existing business processes, as well as designing new business processes. By a business model, we mean a structured graphical description of the network of processes and functions, operations related to data, documents, organizational units, and other objects that reflect the existing or predicted activities of the HEI. Business process modeling allows analyzing not only how the institution works as a whole and how it interacts with external organizations, clients, and suppliers, but also how the activities are organized at each specific department, section, or workplace.

When building a mathematical model of HEI business processes, it is essential to consider the principles of systems theory: for systems consisting of a set containing more than one element, optimizing each element separately does not allow obtaining an optimal solution for the entire system; optimizing the entire system leads to suboptimal solutions for each of its elements.

The mathematical model of the business process of higher education institutions based on ontological analysis will be presented as follows.

Education system in higher education institutions:

$$Sis \equiv \langle Sp, Dc, Pg, EKTC, Bp \rangle,$$

where Sp — specialties of higher education institutions; Dc — disciplines of higher education institutions; Pg — programs of disciplines; $EKTC$ — requirements for specialties of higher education institutions; Bp — business processes of higher education institutions.

Levels of education in HEI:

$$out \equiv out(Sd, Bk, Mg, As, T),$$

where Sd — students; Bk — bachelor's degree students (final year students); Mg — master's degree students; As — postgraduate students; $T = \{t_i\}_{i=1, \overline{n}}$ — duration of study, i — semester number.

Education seekers:

$$In \equiv In(Ab, Prep, Av, Sd, L_{beg}, L_{out}),$$

where Ab — applicants; $Prep$ — instructors; Av — students who have resumed after academic leave; L_{beg} — initial training level; L_{out} — final training and competency level.

Business processes:

$$Bp : \begin{cases} \text{general education} \equiv Bp^1 \\ \text{general professional} \equiv Bp^2 \\ \text{specialized by profession} \equiv Bp^3 \end{cases}, \begin{pmatrix} Bp^1 \\ Bp^2 \\ Bp^3 \end{pmatrix} = Bp^{Par}(t_i).$$

Structure of business processes of a higher education institutions:

$$Str \equiv Str^{Par}(Bp(t_i)),$$

dynamics of the structure according to t_i :

$$Str(Bp(t_i)) = \langle Bp^1(t_i), Bp^2(t_i), Bp^3(t_i) \rangle,$$

where

- $Bp^1(t_i) \equiv Bp_j^1(t_i)$ $j \in J_1$ — a set Bp , that can be compressed through early career guidance;
- $Bp^2(t_i) \equiv Bp_j^2(t_i)$ $j \in J_2$ — a set Bp , that can be compressed through early specialization;
- $Bp^3(t_i) \equiv Bp_j^3(t_i)$ $j \in J_3$ — an absolutely essential set of specialized Bp .

Teachers:

$$Prep = \bigcup_{t_i \in T} (Prep B_p^1 \cup Prep B_p^2 \cup Prep B_p^3).$$

Individuals who have completed education at all levels as of the moment T :

$$out(T) = Sis(In(T), Prep(T), T, L_{out}).$$

Business process system of higher education institution:

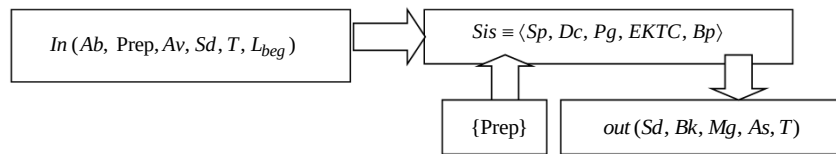


Fig. 4

Let's denote the parameters of the higher education institution's business process:

$$Par = \langle Sp_j, Dc_k, Pg_l, EKTC_m \rangle.$$

Then the generalized criterion for optimizing the higher education institution's business process system can be formulated as follows:

$$S \stackrel{def}{=} \{Crit\{Bp^{Par}(t_i), In(t_i), Ogr(t_i), \{Bp\}_{t_i}, Str\{Bp\}_{t_i}\}\} opt, \\ \rightarrow \max out(T)$$

and partial criteria for optimizing the higher education institution's business process system:

- $K_1 : S \xrightarrow{Res} \min$, where Res represents consumed resources;
- $K_2 : S \xrightarrow{Deg} \max$, where Deg is the provision of the education level;
- $S = S(K_1, K_2)$.

Subprocesses at $\bigcup_{t_i} Bp(t_i)$ allow for merging flows to conduct lectures and identify new Bp based on the criterion of increasing the capacity of lecture flows in each time interval t_i . The methodological basis is the Gantt chart.

We assume that:

- Bp — sections of the chain methodology (CM) of education;
- $Dc_{i,j}$ — the discipline corresponding to the sets of ordered sequences $\{CM_j\}$ of

the specialty Sp_i ;

- $Bp_{k,l}$ — l -subprocess of a process Bp_k ;
- $\sim$ — arrangement;
- $\{Bp_m\}$ — summation of Bp ;
- $\forall i : Sp_i \rightarrow \{D_{i,j}\} \forall$ of specialty $i \exists$ summation of $\{D_{i,j}\}$;
- $\forall i : Sp_i \rightarrow \{D_{i,j}\}^{\sim}$;
- $\forall i, j : D_{i,j} \rightarrow \{Bp_{i,j,k}\}^{\sim}$;
- $\forall i, j : D_{i,j} \rightarrow \{Bp_{i,j,k}\}, \bigcap_i D_{i,j} \neq \emptyset$ — optimization resource through business

processes.

Then, the Bp has its value in terms of costs (ZBp) and significance in terms of revenue (DBp) in the class of $\{Bp(Sp, Dc)\}, \forall t_i$ provided that a specified level of knowledge Deg is achieved.

Requirements of the Ministry of Education and Science:

- $Mz = \bigcup_i Tm_i = \bigcup_i \bigcup_j Lk_{i,j}$, where Mz — is a knowledge module, Tm is a topic, Lk is a lecture;

- course — determined by the number of semesters, measured in hours and credits;
- semester — defined by the number of hours (240) and credits (30);
- discipline — defined as Mz ;
- session — knowledge assessment for disciplines;
- the cost of a knowledge module is $\sum_i (K_i \cdot Norm_i) + ArAu + ArEq$, where K_i is

the number of hours per discipline, $Norm$ is the time norm of the i teacher, $ArAu$ is the cost of renting a classroom, $ArEq$ is the cost of renting equipment;

- $|T|$ — the number of semesters for different types of education (8 — for bachelors, 11 — for masters, 17 — for Ph.D., 21 — for doctors of science).

Then:

- the number of students per semester for whom tuition fees have been received is:

$$out(t_i) \equiv S^{Par, t_i}(In(t_i), Ogr(t_i), \{Bp\}_{t_i}, Str\{Bp\}_{t_i}),$$

- received at the moment is:

$$S_0 = \sum_{i \in T} out(t_i),$$

- the income of the university at the current moment is:

$$S_1 = \sum_{i \in T} \sum_{j \in |Sp|} p_{i,j} \cdot out(t_{i,j}),$$

where $p_{i,j}$ — the cost of tuition for the j specialty in the i semester.

Discussion of results

Taking into account all of the above, it can be concluded that the use of this mathematical model of ontology in business forms an optimal structure of business processes for higher education institutions, specifically in pedagogy. This forms the basis for further description and formalization in the form of regulations, which are fundamental for implementing a process-oriented approach to management.

A perspective for further research is the development of effective ways to implement the activity model of higher education institutions based on a process approach, including testing and experimentally verifying the effectiveness of the management model.

It should be noted that the constructed model allows for associating and representing, at the most general level, the resources of applicants, the resources of teachers, and the administrative resources of higher education institutions aimed at obtaining various levels of education. Thus, the constructed model can serve as a representative of the category of mathematical models of the ontology of business processes in higher education institutions and specialize in examples by defining specific types of functions that enter into it.

The presented model makes it possible to construct a class of simulation models for business processes in HEIs. This allows, through available statistics, experimentally investigating the behavior of a specific HEI under modeled external and internal conditions.

Thus, the possibility is realized to build a neural network and train it based on the simulation model, aiming to analyze the real-life functioning of an HEI under various predefined criteria.

One of the further directions for developing the mathematical model of the ontology of HEI business processes is the inclusion of a predictive subsystem. This will enable the determination or prediction of the magnitude and dynamics of the demand for educational services from the HEI.

This subsystem should also implement the identification of a list and the actual identification of force majeure situations. Based on this, it should determine and construct procedures for responding to them under different predefined criteria. To build such a forecasting block in the model, it is necessary to take into account implement the external connections of HEIs at a deeper level of integration into the environment of educational services in Ukraine.

Conclusion

The following tasks were investigated and addressed in the study:

- ontological analysis of modeling business processes in higher education institutions based on electronic document flow, utilizing a structural approach to explore the fundamental business processes of higher education institution;
- an analysis of the structure, functions, and information flows for organizing and managing educational activities in higher education institutions was conducted using a structural approach.

Competence, which integrates the characteristics of the quality of the graduate, is a category of educational outcome. In fact, there is a transition from employment management to competence management. The use of an ontological model for the interaction of subjects and objects in the semantic search system ensures the reuse of its knowledge components, provides the user with a clear understanding of both the system's capabilities and its behavior, and allows for the assessment of the system's level of intelligence. Conceptual aspects of the proposed interpretation of the ontological approach to the problems of education are considered.

The paper introduces the concept and methods of mathematical modeling of ontology and optimization of business processes under conditions significant for the design of HEI business processes. The structural model of the business process, proposed in the paper, encompasses both production and support, as well as service links. The proposed models enable mathematical modeling and optimization of business processes without constraints on their complexity. Additionally, software complexes based on these models can be created for numerical (non-descriptive) design of business processes.

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МАТЕМАТИЧНА МОДЕЛЬ БІЗНЕС-ПРОЦЕСУ В ЗАКЛАДАХ ВИЩОЇ ОСВІТИ НА ОСНОВІ ОНТОЛОГІЧНОГО АНАЛІЗУ

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Покращення якості освітнього процесу відповідно до сучасних вимог — складне завдання, для виконання якого закладам вищої освіти слід дотримуватися системного підходу та розробляти стратегії підвищення ефективності послуг. Досліджено особливості інформаційного моделювання при онтологічному підході до розподіленого інформаційного середовища. Розглянуто сутність онтологічного аналізу бізнес-процесів керування освітньою діяльністю у закладах вищої освіти та технологію менеджменту для надання якісних освітніх послуг з урахуванням відповідних загальних та спеціальних управлінських компетенцій. Проведено онтологічний аналіз моделювання бізнес-процесів у вищих навчальних закладах. Проаналізовано структуру, функції та інформаційні потоки організації й керування освітньою діяльністю на основі структурного підходу з урахуванням того, що компетентність як інтегрована характеристика випускника є категорією отриманої освіти. Онтологічна модель взаємодії суб'єктів та об'єктів системи надає можливість оцінювати ефективність системи та побудованої моделі керування, що сприяє прогнозуванню критичних бізнес-процесів, які можуть призвести до

зниження ефективності ухвалених рішень та порушень у функціонуванні вищих навчальних закладів та їх підрозділів. Пропонується концепція математичного моделювання онтології та оптимізації бізнес-процесів у закладах вищої освіти в умовах, необхідних для їх проектування. Рекомендована структурна модель бізнес-процесу містить як виробничі, так і сервісні засоби. Запропоновані моделі застосовуються для математичного моделювання та оптимізації бізнес-процесів без обмежень їх складності, а також для створення на їхній основі програмних комплексів для чисельного (неописового) проектування.

Ключові слова: заклади вищої освіти, інформаційне середовище, онтологія, моделювання, бізнес-процес, реінжиніринг.

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