The game model of investing in the academic cloud

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Article Info

Article history:

Received Feb 24, 2024
Revised Aug 14, 2024
Accepted Sep 6, 2024

Keywords:

Academic cloud
Fuzzy information
Investing
Multistep quality game
Optimal strategy
Preference set

ABSTRACT

The article analyzes approaches to the use of cloud technologies in the process of teaching students at large universities. The model of the academic cloud of a modern university is considered. Examples of software and functional platforms that meet the needs of students in electronic learning resources are given. The deployment models of the cloud-oriented educational environment that includes private cloud infrastructure as a service (IaaS) and platform as a university service are analyzed. The cost of deploying an academic cloud based on the educational institution's infrastructure and renting infrastructure from a vendor is compared. A multifactorial model for evaluating investment options in the university cloud in the context of fuzzy information is proposed. In contrast to the known approaches to solving such a problem, our model assumes that the dynamics of the financial states of the players are set through a system of discrete equations. These equations describe the dynamics of multidimensional variables. The latter made it possible to consider the general problem of investing in the academic cloud within the framework of a game scheme for tasks in a fuzzy formulation, with the financial resources (FR) available to the educational institution. Preference sets and optimal financial allocation strategies for building an academic cloud are found.

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1. INTRODUCTION

Information and communication technologies (ICT) have long been fundamental to the information society and have had a significant impact on education. Leading universities have been using cloud applications and technologies (CAT) for many years to improve the efficiency of educational and scientific work. Student access to multi-service information networks and data banks via the Internet has become a key task of modern universities, providing extraterritorial learning, flexible choice of programs and expanded access to resources. However, as the COVID-19 pandemic has shown, many universities information and educational environments do not cover the full range of necessary services. Works [1], [2] emphasize the inconsistency of the organizational and functional structures of IT departments with modern requirements. Therefore, the creation of new approaches to the formation of educational environments based on cloud technologies remains an urgent task. A developed IT infrastructure allows universities to work in a single information space, which is a competitive advantage. The introduction of a cloud-based learning environment (CBLE) promotes quality learning and professional development of students [2], [3]. According to [4], as of 2020, about 70% of North American universities have transferred their administration systems to cloud structures, and more than 50% have implemented cloud systems to improve scientific collaboration. The effectiveness of using CBLE is determined by various indicators, such as financial, quantitative and qualitative. An important aspect remains the study of risk factors for academic cloud deployment. Forecasting future states of CBLE is difficult due to the difficulty of identifying long historical series.

The main factors destabilizing the university cloud include the constant progress of hardware and software, instability of exchange rates and the economic and political situation. This makes it difficult to assess the cost-effectiveness of using cloud technologies at a university. Existing approaches to assessing the investment attractiveness of deploying a CBLE for universities often do not take into account: the dynamics of the financial conditions of the players; interaction and mutual influence of projects; unclear information and instability of external factors [5]-[7].

In this publication, we offer our view on the problem of assessing the investment attractiveness of an CBLE deployment scheme using game theory methods. This allows mathematical analysis and selection of more suitable solutions. Two schemes are being considered: private cloud (private university cloud), which is customized for specific business tasks of the university and infrastructure as a service (IaaS) [8]-[10].

A game multifactor model for assessing investment options in a university cloud under conditions of fuzzy information takes into account the dynamics and interaction of players' financial states. It is also possible to model and analyze the impact of information uncertainty, which provides more informed decisions on the choice of cloud services, which improves the quality of the educational process and optimizes financial investments. The proposed model allows already at the analysis stage to make informed decisions and optimize the use of university IT resources.

2. REVIEW AND ANALYSIS OF THE LITERATURE

Many researchers believe that an effective way to improve universities' information and educational environment is to combine computer-based learning methods using cloud computing [5]-[7]. The advantages of using cloud technologies to provide electronic (mobile) training are described in [8]-[10]. As noted in [11]-[13], most of the usual forms of education have become virtually unsuitable for the sustainable development of the education sector. This is due to the fact that traditional IT used in education does not keep up with the dynamically changing demand for specialists in different fields. Research by Xiao and Wang [11] note that the traditional mode of e-learning is based on the use of the Internet. Most of the information and educational environment components are located inside educational institutions. This leads to many problems. Such problems include the need for large investments in hardware and software components of the information and educational environment.

Research by Negru and Cristea [12] consider various models for the construction of cloud structures. Cloud service providers offer a wide portfolio of services, and customers get access to them under a specific financial agreement. It is always possible to come to a compromise between what a cloud provider can offer in terms of resources (software or hardware), the cost of services, and what customers are willing to pay.

Today, cloud spending models are formed based on service models: IaaS, platform as a service (PaaS), and software as a service (SaaS). If we talk about the field of education, where financial resources (hereinafter referred to as FR) are usually limited, then for the university management at the stage of choosing a particular service model for a cloud structure, there is a need to predict the cost of an academic cloud for a certain period. This, in turn requires the construction of cost models, which must be accurate and error-free.

In studies [13]-[16], the authors conduct a detailed analysis of existing models of cloud computing costs. As shown in studies [17]-[19], despite the growing popularity of ready-made corporate solutions and special Internet portals in the field of cloud technologies, the obvious advantages of using them, most educational institutions are focused on building their own cloud-oriented educational environment, that is, a corporate academic cloud, see Table 1. Therefore, a number of questions arise, answers which will allow us to conclude the feasibility and prospects of creating an academic cloud in an educational institution. What services and resources should it provide? What is the structure of such a cloud? What technical and software solutions will be most attractive for an educational institution? Which model of academic cloud placement will be the most economically justified?.

From the author's point of view [17]-[19], the academic cloud should provide support for each academic discipline with a full range of electronic learning resources and services. Secondly, the academic cloud should provide students with access to software products that are used in the educational process, for example, programming environments, modeling, forecasting, project management, mathematical and statistical packages, and geoformation systems. Thirdly, software and technology platforms that ensure the functioning of the academic cloud should give users the opportunity to single sign-on, measure the number of services provided in time and resource indicators, provide services at the user's request, provide wide access to the network, have tools and flexible resource allocation.

Table 1. Comparative characteristics of the costs of deploying an academic cloud

Types of costs (types of FR required for the implementation of the solution)		Privat cloud	IaaS	PaaS
CBLE infrastructure		Network equipment of the local level of the University's CBLE		
		CBLE university server	The vendor of cloud services provides the capacities	
		Server rack		
		Data storage		
Software	Virtualization	Proxmox free (or Solus Virtual Manager (SolusVM), Archipel, TotalCloud, and clearVM)	Provided by the vendor	
	OS	OS Linux (or Windows)	Provided by the vendor at the user's choice	
	Software platforms	Libre Office (MS Office, Microsoft 365, Google Doc, WPS Office, and SoftMaker FreeOffice)		
		Moodle (or Uchi.pro, PlayPosit, Edmodo, Google Classroom, Emdesell, Mirapolis, and Collaborator)		
		Prints (or PrintNode, Air Sharing, and ezeep)		
		Joomla (or Prodáct, VirtualityCMS, LPmotor, CMS S3, and Ecwid)		
		MediaWiki (or Raneto, Notejoy, Docsify.js, Twiki, SlimWiki, MyBase.pro)		
		Free Mind (or Lucidspark, MindManager, Zen Flowchart, Open Mind, GitMind, Wind-up, and Edraw Mind)		
Service		Hardware administrator	Serviced by a vendor	
		Academic cloud administrator	Serviced by a vendor	
		Engineers (for example, by faculty)		
		Content managers		
Utility costs		Electricity to the server	Serviced by a vendor	
		Internet traffic		
Content		Additional resources aimed at the implementation of the educational process (full-text electronic copies of manuals, electronic training courses, video materials, and virtual laboratories)		

The proposed academic cloud model can be deployed based on the university's own infrastructure and on renting cloud infrastructure according to the IaaS model when the required amount of dynamic resources (computing and storage), virtual servers, network infrastructure is provided at the request of the university, or according to the PaaS model, when the entire information technology infrastructure, including operating systems, database management system, communication software, computer networks, servers. The data warehouse is fully provided and managed by the provider, which determines the set of available types of platforms and managed platform parameters. Depending on the chosen deployment option, you can estimate the cost of creating a «cloud» on your own infrastructure by the type of a private cloud or by renting infrastructure from IT companies by the type of IaaS or platforms by the type of PaaS (Table 1).

Note that, as shown in [17]-[20], universities are fully aware of the benefits of scalability, flexibility, and availability of cloud technologies after migrating to the cloud. But sometimes, an educational institution may face operational inefficiency in choosing one model of a cloud solution for implementing its educational activities. This often happens as a result of the discrepancy between the actions of the relevant IT departments of educational institutions and the long-term strategy. Optimizing the costs of a cloud solution, especially for universities, is an endless and evolutionary process of improvements throughout the life cycle of IT systems used in training and organizational work.

As shown in Volozhenin [21], methods of statistical forecasting of cash flows from the introduction of cloud technologies can be applied if the selected IT project already exists and functions. Accordingly, additional investments are required because investing money is only necessary to increase the capacity or scale of the cloud solution. If an IT project, including cloud solutions, is only being developed and designers do not have statistical data on costs, it is better to use, for example, a gaming approach or an expert approach to assess the solution's benefits. This will make it possible to get a more realistic assessment of the decision being made and its consequences. The game approach, in our opinion, is more complex since it allows us to take into account hidden problems during multifactor modeling. Such problems include, for example, the risks associated with introducing a non-optimal academic cloud model, potential additional costs, for example, and to ensure the protection of information in the academic cloud. Our proposed model contributes to a deeply mathematically sound university cloud deployment model choice. The above calculations and results may be useful for creating educational institutions and various companies transferring their business processes to cloud structures in cloud services.

The aim of the work is to develop mathematical models that allow us to assess the attractiveness of investing in an academic (university) cloud as part of a multistep quality game with fuzzy information. In the course of the study, the following tasks were solved: i) development of a model based on game theory (multistep quality game) to assess the attractiveness of investing in a university cloud as part of a multistep quality game with fuzzy information and ii) conducting computational experiments using the Python language (Pycharm Professional programming environment).

3. METHODS AND MODELS

3.1. Statement of the problem and research methods

As is known, to ensure the effective development of a CBLE for universities, financial support is necessary. At the same time, it is necessary to invest FR in such cloud services that provide universities with a high-quality level of service. The high-quality level of such services ultimately contributes to the high-quality training of future specialists. This can be done using various approaches based on an analysis of the selection of appropriate cloud services. In this article, to solve the problem of choosing cloud services, we use the tools of game theory, in particular, multi-stage quality games with fuzzy information. The vagueness of information is a factor that, as a rule, is present in reality. The use of game theory expands the possibilities for solving the problem of choosing services, along with, for example, optimization methods. During the study, the following methods were used: analytical to analyze scientific and technical literature on the problem of introducing cloud technologies in the field of education, to analyze the features of the functioning of the software and hardware infrastructure of a higher educational institution; game theory methods for solving the problem of choosing the optimal, from the point of view of multifactorial, model for deploying an academic (university cloud). A methodology was used to solve the problem based on the developed model of a bilinear multi-step game of the quality of multidimensional objects with fuzzy information.

The article will consider two projects: i) Project 1. «private cloud» (private university cloud), which allows the university to customize it for its specific business tasks; and ii) Project 2. «IaaS» where infrastructure is considered as a service. Since, when using the PaaS model, all resources (software and allocation of structural elements of the system.) are dictated by the vendor, this model is not considered as an investment option in the CBLE within the framework of our study. It is assumed that two players with FR invest in these two projects. At the same time, we note that the financing of these projects is interrelated. Financing in one project causes a desire to «improve» the quality of your project with additional financing and vice versa.

Let's describe the interaction of the players. The interaction between the players will take place discretely in time. It happens this way. The first player at the moment of time $t = 0$ has a set of FR, which is intended for the development of Project 1. The set is a vector $x(0) = (x_1(0),\dots,x_K(0))$ of K dimensions, where K is the number that corresponds to the number of instruments for the development of Project 1. Each component of this vector indicates the amount of the FR intended to finance the corresponding instrument for the development of Project 1, see Table 1.

The second player at the moment of time $t = 0$ has a set of FR, which is intended for the development of Project 2. The set is a vector $y^{\xi}(0) = (y_1^{\xi}(0),\dots,y_M^{\xi}(0))$ of M dimensions, where the number corresponds to the number of instruments for the development of Project 1. Each component of this vector indicates the amount of FR intended to finance the corresponding instrument for the development of Project 1, see Table 1.

At the same time, it is assumed that in the interaction of players, from an informational point of view, there is a situation in which the first player does not know at the time $t = 0$ exactly the condition $y^{\xi}(0)(y^{\xi}(0) \in R_+^M)$ of the second player. He only has access to information that the state of the second player belongs to a fuzzy set $\{\Omega, m(.)\}$, where Ω is a subset R_+^M, and $m(.)$ −state member ship function y^{ξ} lots $\Omega, m(y^{\xi}) \in [0,1]$ for $y^{\xi} \in \Omega$.

Denote:

- A is the order K matrix with positive elements. The matrix A is the transformation matrix of the set of FR (vector) of the first player and is an «analogue» of the rate of change (growth or decrease) of his set of FR (for example, for those solutions and products for the academic cloud that were shown in Table 1);
- B is the order M matrix with positive elements. The matrix is the transformation matrix of the set of FR (vector) of the second player and is an «analogue» of the rate of change (growth or decrease) of his set of FR;
- S_1 is the dimension $M \times K$ matrix with positive elements s_1^{ij}, which are the ratios of the values of the FR of the following form: in the numerator is the value of the FR, going to the development of the unit of

efficiency increase i-development Project 2 of the second player. In the denominator is the value of the FR, going to the development of the unit of efficiency increase j-development Project 1 of the first player;

- S_2 is the dimension $K \times M$ matrix with positive elements s_2^{ij}, which are the ratios of the values of the FR of the following form: in the numerator is the value of the FR, going to the development of the unit of efficiency increase i - development Project 1 of the first player, and in the denominator is the value of FR, going to the development of a unit of increasing efficiency j-development Project 2 second player;
- Through $\mu_j (j = 1, \dots, M)$ such values $\mu_j \geq 0, \sum_{j=1}^{M} \mu_j = 1$, which are elements of the diagonal matrix Ξ order M, with diagonal elements μ_j. The matrix Ξ characterizes the "structure" of the FR set of the second player. Element μ_j means a share j-the values of the FR set of the first player, which shows the transformation of this set into j-the value of the FR set of the second player. That is, if $(x_1, \dots, x_K)$ the set of FR of the first player, then in j-the value of the FR set of the second player will be converted to the FR set of the first player, equal to $\mu_j \cdot (y_1, \dots, y_M)$.
- Through $\lambda_j (j = 1, \dots, K)$ such values $\lambda_j \geq 0, \sum_{j=1}^{K} \lambda_j = 1$, which form a diagonal matrix Λ order K, with diagonal elements λ_j. The matrix Λ characterizes the «structure» of the FR set of the first player. Element λ_j means a share j-the values of the FR set of the second player, which shows the transformation of this set into j-the value of the FR set of the first player; that is, if $(y_1, \dots, y_M)$ the set of FR of the second player, then in j-the value of the FR set of the first player will be converted to the FR set of the second player, equal to $\mu_j \cdot (y_1, \dots, y_M)$.

Remark 1.

If there is a set of FR $x = (x_1, \dots, x_K)$ of the first player, then if you perform the operation: $S_1 \cdot x$, then we will get M - dimensional vector, which «as it were» means a set of FRS of the second player. However, this product makes it possible to define only one component of this M - dimensional vector (of the second player). This follows from the fact that the entire vector $x = (x_1, \dots, x_K)$ will be equivalent in efficiency to only this one component. For the other components of the FR set of the second player, there is no longer an FR set of the first player that would be equivalent in efficiency to this component of the second player. The entire set of FR of the first player «went» to «equalize» in efficiency with one component of the set of FR of the second player. Therefore, it is necessary to split the set of FR into parts so that it is possible to «equalize» the effectiveness of the sets of FR of the second player for all its components. This is done by introducing a set: $\lambda_j (j = 1, \dots, M)$:$\lambda_j \geq 0, \sum_{j=1}^{M} \lambda_j = 1$. Note that the selection of these coefficients can be made in other ways, not necessarily as described above.

The same is true for the set of FR of the second player. Within the framework of these designations and remarks, 1 of the state $x(1)$ and $y^{\xi}(1)$ at a moment in time $t = 1$ are determined from the relations:

$$x(1) = A \cdot x(0) - U(0) \cdot A \cdot x(0) - \Lambda \cdot S_2 \cdot V(0) \cdot B \cdot y^{\xi}(0) \quad (1)$$

$$y^{\xi}(1) = B \cdot y^{\xi}(0) - V(0) \cdot B \cdot y^{\xi}(0) - \Xi \cdot S_1 \cdot U(0) \cdot A \cdot x(0) \quad (2)$$

We will conduct a step–by–step explanation of the relations (1) and (2). At the beginning, we will describe the actions of the first player and the second player.

- Step 1: the first player increased the set of his FR with $x(0)$ before $A \cdot x(0)$.
- Step 2: the first player allocated a part of his FR set for the development of his tools in Project 1 in the form of a set of FR $U(0) \cdot A \cdot x(0)$. Here $U(0)$, a diagonal matrix of order K, consisting of elements $u_i(0)$: $u_i(0) \geq 0, \sum_{i=1}^{K} u_i(0) = 1$.
- Step 3: the first player determined (based on the statistics of the implementation of previous similar projects) the structure (share) of their sets of FR corresponding to the instruments of Project 1, for effective competition with Project 2 of the second player for each instrument of Project 2. Therefore, for each component of the set of FR of the second player. This structure is defined by diagonal elements $\mu_j (j = 1, \dots, M)$: $\mu_j \geq 0, \sum_{j=1}^{M} \mu_j = 1$, which make up the diagonal matrix Ξ.
- Step 4: the first player, highlighting his set of FR $U(0) \cdot A \cdot x(0)$, leads to the corresponding reaction of the second player. It additionally highlights a set of FR as equal $\Xi \cdot S_1 \cdot U(0) \cdot A \cdot x(0)$, in order to compete with Project 1.

Similarly, the actions of the second player are explained.

- Step 5: the second player increased the set of his FR with $y^{\xi}(0)$ до $B \cdot y^{\xi}(0)$.
- Step 6: the second player allocated part of the set of his FRS for the development of his tools in Project 2 in the form of a set of FRS $V(0) \cdot B \cdot y^{\xi}(0)$. Here $V(0)$ is a diagonal matrix of order M, consisting of elements $v_i(0)$: $v_i(0) \geq 0, \sum_{i=1}^{M} v_i(0) = 1$.

- Step 7: the second player has determined (based on the statistics of the implementation of similar previous projects) the structure (share) of their sets of FR corresponding to the instruments of Project 2 for effective competition with Project 1 of the first player for each instrument of Project 1. Therefore, for each component of the set of FR of the first player. This structure is defined by diagonal elements $\lambda_j (j = 1, \dots, K)$: $\lambda_j \geq 0, \sum_{j=1}^{K} \lambda_j = 1$, which make up the diagonal matrix Λ.
- Step 8: the second player, highlighting his set of FR $V(0) \cdot B \cdot y^{\xi}(0)$, leads to the corresponding reaction of the first player. It additionally allocates a set of FR, equal $\Lambda \cdot S_2 \cdot V(0) \cdot B \cdot y^{\xi}(0)$, in order to compete with Project 2.

Thus, the sets of FR players $x(1)$ and $y^{\xi}(1)$ at a moment in time $t = 1$ are determined from the ratios (1) and (2). The terms of the end of the trading session at the time $t = 1$ there will be fulfillment of the conditions (3) and (4):

$$\left(x(1),\ y^{\xi}(1)\right) \in S_0 \text{ with confidence} \geq p_0, (0 \leq p_0 \leq 1) \tag{3}$$

$$\left(x(1),\ y^{\xi}(1)\right) \in F_0 \text{ with confidence} \geq p_0 \tag{4}$$

$$\left(x(1),\ y^{\xi}(1)\right) \in D_0 \text{ with confidence} \geq p_0 \tag{5}$$

$$\left(x(1),\ y^{\xi}(1)\right) \in H_0 \text{ with confidence} \geq p_0 \tag{6}$$

where S_0, F_0, D_0, and H_0 such:

$$S_0 = \cup_{i=1}^{M}\{(x,y):(x,y) \in R^{K+M}, x \geq 0, y_i \prec 0\}$$

$$F_0 = \cup_{i=1}^{K}\{(x,y):(x,y) \in R^{K+M}, x_i < 0, y \geq 0\}$$

$$D_0 = \{\cup_{i=1}^{K}\{(x,y):(x,y) \in R^{K+M}, x_i < 0\}\} \cap \{\cup_{i=1}^{M}\{(x,y):(x,y) \in R^{K+M}, y_i < 0\}\},$$

$$H_0 = R_{+}^{K+M}$$

If condition (3) is met, then we believe that the procedure for investing in Project 2 is reliable $\geq p_0$ finished, as Project 1 turned out to be more efficient. If condition (4) is met, then we consider that the procedure for investing in Project 1 with certainty $\geq p_0$ finished, as Project 2 turned out to be more efficient. If condition (5) is met, then we believe that the procedure for investing in both Projects with confidence $\geq p_0$ is finished, as they turned out to be equally effective. If (6) is fulfilled, the procedure for investing in Projects continues for the time points $t > 1$.

The process described by systems (1) and (2) for the procedure of investing is considered within the framework of the scheme of a positional multistep game with fuzzy information [22]. Due to the symmetry, we will limit ourselves to considering the problem from the first player's position. The second task is solved similarly. The solution to problem 1 is to find the set of «preferences» of the first ally player W_1 and its optimal strategies $U_*(.)$. Similarly, the task is set from the point of view of the second player ally.

The first player in task 1 is considered an ally player, and the second player is considered an opponent player in problem 2. On the contrary–the second player is considered an ally player, and the first player is an opponent player. The task of the procedure for investing in Projects by means of a system of discrete equations generates at each moment of time t a collection of pairs of fuzzy sets $\{\Gamma_t, n_t(.)\} \times \{\Omega_t, m_t(.)\}$ which reflect the process of transition from the initial states of the players $(x(0), y^{\xi}(0))$ in subsequent states when players apply control actions.

It is assumed that the first player at each moment $t (t \in [0,1,2, \dots])$ his condition is known $x(\tau)$ для $\tau \leq t$. The following conditions are met: $x(\tau) \geq 0$, if the reliability of such states $n_\tau(x(\tau)) \geq p_0$ and $x(\tau) \notin R_{+}^{K}$, if the reliability of such states $n_\tau(x(\tau)) < p_0$, and also the values of the realizations of the strategy of the first player are known $U(\tau)(\tau \leq t)$, allocated for interaction with the second player. Define the function $F(.): X \to R+, f(x) = \{sup\, m(y)$ for $y \leq x, x \in R^M, f(x) = \{sup\, m(y)\}$. Denote by Φ^*– a lot of such functions, through $T^* = [0,1,2, \dots]$ – the scope of the temporary variable change.

Definition*:* in pure strategy, $U(.,.,.)$is the first player called a set of functions $u_i(.,.,.): T^* \times R_{+}^{K} \times \Phi^* \to [0,1], (i = 1, \dots, K)$, such that $u_i(t, x, F) \in [0,1], (t \in T^*, x \in R_{+}^{K}, F \in \Phi^*)$. The second player chooses his strategy $V(.)$based on any information. We define a set of initial states that have the property. Property: f the game starts from the initial states, then the first player can choose his strategy $U_*(.)$ provided at one point in time *t* to fulfill condition (3). At the same time, this strategy, chosen by player 1, contributes to preventing the second player from fulfilling condition (4) at previous points in time.

The set of such states will be called the preference set of the first player W_1, and the strategies $U_*(.)$ the first player having the specified properties will be called his optimal strategies. Thus, the goal of the first player is to find the preference set, as well as to find his strategies, using which he will get the fulfillment of condition (1). The formulated game model corresponds, according to the classification of decision theory, to the problem of decision–making in conditions of fuzzy information. Such a model of investing in a university cloud is a linear multistep quality game with several terminal surfaces with fuzzy information. Finding the preference sets of the first player and his optimal strategies depends on many parameters.

To describe the preference sets of the first player, it is necessary to enter a number of notations and values. Let us define the set $S(p_0) = \{c(0): F(c(0)) \geq p_0\}$. For anyone $x \in R_+^M$ consider the set $L_x = \{z: z = l \times x, l \in R_+\}$. For anyone $x \in R_+^M$ consider the set $Q(x, p_0) = S(p_0) \cap L_x$. Define the vector $\delta(x, p_0): \delta(x, p_0) = inf\{\delta^*: \delta^* \in Q(x, p_0)\}$. Consider the set $\Delta(p_0) = \{\delta(p_0): \exists x \in R_+^M: \delta(p_0) = \delta(x, p_0)\}$. Here are the conditions that make it possible to find a solution to the game, i.e., the set of «preferences» W_1 and optimal strategies $U_*(.)$ for the first ally player.

3.2. Solution of problem 1

The solution to the above multipara metric problem depends on the ratio of the parameters that determine the confrontation procedure between the allied player and the second opponent player. Let us introduce this notation. Denote by $\hat{\Sigma}_1$ plenty:

$$\hat{\Sigma}_1 = \Sigma_* - \cup_{i=1}^{K} \Sigma_i,$$

$$\Sigma_* = \{(x(0), \delta(p_0)) : (x(0), \delta(p_0)) \in R_+^{K+M},\ A \cdot x(0) - \Lambda \cdot S_2 \cdot B \cdot \delta(p_0) \in R_+^K\}$$

$$\Sigma_i = \left\{(x(0), \delta(p_0)) \in R_+^{K+M},\ \left(A \cdot x(0)\right)_i = \left(\Lambda \cdot S_2 \cdot B \cdot \delta(p_0)\right)_i, i = 1, \ldots, K;\right\}$$

Next, we additionally introduce the following notation: $E -$ the unit matrix of order M.

$$Q_1 = \Xi \cdot S_1,\ Q_k = \{(G_{k-1} \cdot B \cdot \Xi \cdot S_1 - Q_{k-1} \cdot A)^+ + Q_{k-1} \cdot A\};$$

$$G_1 = E + \Xi \cdot S_1 \cdot \Lambda \cdot S_2, \quad G_k = (Q_{k-1} \cdot A \cdot \Lambda \cdot S_2 - G_{k-1} \cdot B)^+ + G_{k-1} \cdot B +$$

$$(G_{k-1} \cdot B \cdot \Xi \cdot S_1 - Q_{k-1} \cdot A)^+ \cdot \Lambda \cdot S_2, k = 2, \ldots$$

$$x^+ = \begin{cases} x, x \geq 0; \\ 0, x < 0; x \in R; \end{cases}$$

$$\alpha_i^{k,j} = \begin{cases} 1,\ (G_k \cdot B)_{ij} = 0, \\ \frac{(Q_k \cdot A \cdot \Lambda \cdot S_2)_{ij}}{(G_k \cdot B)_{ij}}, \quad (G_k \cdot B)_{ij} \neq 0, k = 1, \ldots \end{cases}$$

The process of finding the preference sets of the first player depends on the ratio of the parameters that determine this confrontation of the parties.

Consider the case 1. $A \cdot \Lambda \cdot S_2 \geq \Lambda \cdot S_2 \cdot B$. Let the assumption be fulfilled, that $\forall k = 1, \ldots, and\ \forall i: 1 \leq i \leq M$ exists $m(i): 1 \leq m(i) \leq M$, in which:

$$(Q_k \cdot A \cdot \Lambda \cdot S_2)_{im} \geq (G_k \cdot \Lambda \cdot S_2)_{im}, 1 \leq i \leq M, 1 \leq m \leq M, k = 1,2, \ldots \quad (7)$$

inequality (6) does not hold.

Then, the process of constructing preference sets continues in time, and the preference sets of the first player will be a countable number. Based on the principle of optimality of R. Bellman [23], the preference sets of the first player are «built» step by step. First, the preference set is built in one step. Then in two steps. Thus, there is a preference set for the first ally player. In the set Σ_1, there is a union of preference sets Σ_1^k for the first ally player [22] for a specific number of steps, i.e., $\Sigma_1 = \bigcup_{k=1}^{\infty} \Sigma_1^k$. Within the framework of the above notation, a record of the preference sets of the first ally player Σ_1^k it looks like this:

$$\Sigma_1^k = \bigcup_{i=1}^{M} \{(x(0), \delta(p_0)) \colon (x(0), \delta(p_0)) \in R_+^{K+M}, A \cdot x(0) - \Lambda \cdot S_2 \cdot B \cdot \delta(p_0) \in R_+^M,$$

$$(Q_k \cdot A \cdot x(0))_i > (G_k \cdot B \cdot \delta(p_0)_i\}.$$

The optimal strategy $U_*(.,.,.)$, which is defined by the elements $u^*(.) = (u^{*,1}(.), \ldots, u^{*,K}(.))$of the first player–ally, which are diagonal elements of the matrix $U_*(.,.,.)$, in the field of preference Σ_1^k, it is written as follows:

$$u^{*,j}(x,\delta) = \begin{cases} 1 - [(\Lambda \cdot S_2 \cdot B \cdot \delta)_j / (A \cdot x)_j], by (A \cdot x)_j > (\Lambda \cdot S_2 \cdot B \cdot \delta)_j; \\ a \in [0,1] by (A \cdot x)_j = 0, (A \cdot x)_j = (\Lambda \cdot S_2 \cdot B \cdot \delta)_j; \\ 0, otherwise; (x,\delta) \in R_+^{K+M}; j = 1, \ldots, M. \end{cases}$$

Preference sets and optimal strategies of the first ally player, in case 2:$\neg(A \cdot \Lambda \cdot S_2 \geq \Lambda \cdot S_2 \cdot B)$ are found in a similar way.

Theorem [22] specifies the conditions that determine the possibility of completing the procedure of player interaction in a finite number of steps with fuzzy information. The theorem. In the area of $\hat{\Sigma}_1$ In the area, the first player can reach the goal:

for a finite number of steps, i.e. $\hat{\Sigma}_1 \subseteq \bigcup_{k=1}^{N_*} \Sigma_1^k,\ 0 < N_* < +\infty$,

if $\underline{lim}_{T \to \infty} \left(\min_{1 \le k \le K} \left(\alpha_k^{T,i} \right) \right) > 1,$ with some i: $1 \le i \le M$;

б) at least by a countable number of steps (or $\hat{\Sigma}_1 \subseteq \bigcup_{k=1}^{\infty} \Sigma_1^k$),

if $\underline{lim}_{T \to \infty} \left(\min_{1 \le k \le K} \left(\alpha_k^{T,i} \right) \right) = 1,$ with some i: $1 \le i \le M$.

There may be a situation in which the $\hat{\Sigma}_1$ the first player in any number of steps may not reach the goal:

в) by $\sup_T \left(\max_{1 \le i \le K} \left(\min_{1 \le k \le K} \left(\alpha_k^{T,i} \right) \right) \right) < 1$

Note 2: note that the presence of a large number of parameters allows them to be controlled to achieve the desired result. The proof of the theorem is given in [22]. The solution from the point of view of the second player-ally is similar. The considered mathematical model allowed us to find a solution to the problem of assessing the attractiveness of investing in a university cloud within the framework of a multistep quality game with fuzzy information. The conditions for the completion of the procedure for investing in the university cloud in a finite time are given if there is a sufficient number of FRS from one of the players with a given degree of confidence.

4. COMPUTATIONAL EXPERIMENT AND DISCUSSION OF RESULTS

4.1. Computational experiment

The model proposed in the paper was implemented in the form of a software module of the decision support system (DSS). Computational experiments were conducted in the PyChar Professional programming environment on a PC with an i7 processor and 32 GB RAM. The computational experiments made it possible to visualize the results of the game, see Figures 1 and 2. The purpose of the computational experiments is to assess the attractiveness of investing players in a particular model of the university cloud.

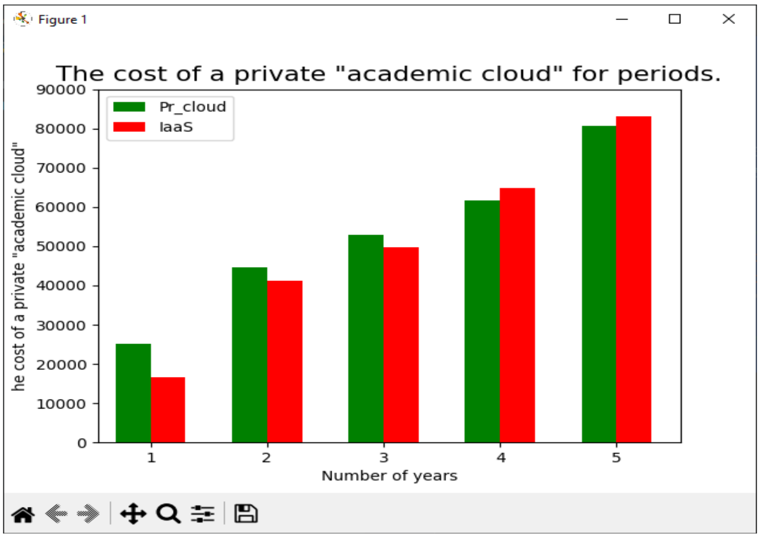

Figure 1. Comparison of the summary results of the cost of the academic cloud by period

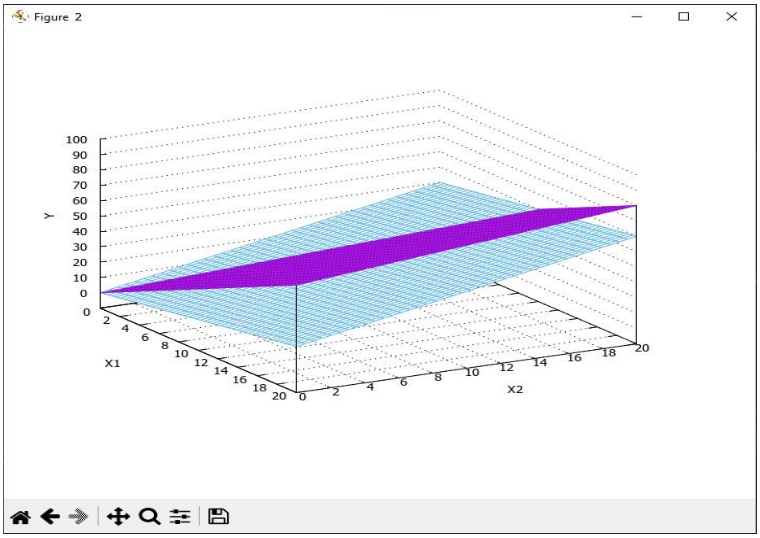

Figure 2. Displaying the results of the experiment in the process of searching for areas of preference for players

The experiment was conducted according to the data on the costs of the academic cloud provided by the National University of Bioresources and Environmental Management of Ukraine (Kyiv, Ukraine) and the Non-profit Joint Stock Company Kazakh National Pedagogical University named after Abai (Almaty, Kazakhstan). In the first stage of modeling, five main blocks were selected to select the academic cloud model, for which FR are needed. The infrastructure, software, maintenance, utility costs, and content blocks are analyzed. To calculate the costs, the analytical data of prices for services of IT corporations were analyzed, in which the main characteristics were the number of processor cores, the amount of RAM, the amount of data storage, and the type of operating system of the IaaS topology. The analytical data on the cost of the IBM Softlayer cloud [24], [25] are taken as a basis, namely, the cost of an annual lease of server capacity for the IaaS model.

The obtained modeling results for the period from 1 year to 5 years, see Figure 1 allow us to evaluate the attractiveness in a price sense of a model for hosting an academic cloud. As is clear from the results obtained at this stage of the study, already in the 4-5th year of deploying a private academic cloud, the costs are significantly lower compared to the IaaS model. However, risk factors for academic cloud deployment require separate research. Predicting the future states of the academic cloud without using a game model is extremely difficult. Since without a detailed study of the main factors it is difficult to say which option will be more preferable. Therefore, in the matrices A, B, S_1, S_2, Ξ, Λ parameters were specified that characterize the "structure" of the set of FR players, which in computational experiments makes it possible to take into account, for example, the instability of exchange rates and the general economic and political state both in the state and in the international market as a whole.

Figure 2 shows a graphical representation of the experiment results. Two hyperplanes are given, which are the boundaries of two sets. The first set is the "guarantee" set of the first player, which describes sets of FR players that have the property that of them the second player cannot prove the effectiveness of Project 2. This is the set of states of players in R_+^3 the positive orthant, which are located below the hyperplane colored blue. The second set is the set of sets of FR players that have the property that of them the first player can prove the effectiveness (attractiveness) of Project 1. This is the set of states of players in R_+^3 the positive orthant, which are located below the hyperplane colored blue. The second set is the set of sets of FR players that have the property that of them the first player can prove the effectiveness (attractiveness) of Project 1. This is the set of states of players in R_+^3 the positive orthant, which are located below the hyperplane colored purple. Then, if the sets of FR players are "below" these hyperplanes in a positive three-dimensional orthant, then the first player achieves his goal - he proves the effectiveness of Project 1 and the ineffectiveness of Project 2. Considering two projects, we noticed that financing one project inevitably causes a desire to improve the quality of its project with additional funding. This interaction results in a dynamic game where each player seeks to maximize his investment while minimizing the attractiveness of the alternative project to his competitor. Project 1 ("Private Cloud") allows the university to customize the cloud to its specific business needs, providing greater flexibility and control over resources. This benefit is especially important for universities with unique or specific requirements. However, such customizations may require significant initial costs and effort to develop and maintain. Project 2 ("IaaS"), which views IaaS, provides a more standardized approach that can reduce upfront costs and simplify the implementation process. However, this design may be less flexible and limited by the capabilities offered by the service provider.

Our research has shown that, depending on financing parameters and player strategies, preferences can change. If the first player can prove the effectiveness of Project 1 with sufficient FR, he will be able to attract more investment and prove the ineffectiveness of Project 2 for the second player. The reverse is also true. These findings allow universities and other educational institutions to make more informed decisions about their cloud service model, taking into account their financial capabilities and long-term goals. Going forward, more complex scenarios can be considered that include additional factors such as changes in market conditions or technological innovation.

5. DISCUSSION OF THE RESULTS OF A COMPUTATIONAL EXPERIMENT

Thus, the proposed model describes the dynamics of multidimensional variables, which made it possible to consider the general problem of investing in an academic cloud within the framework of a game scheme, taking into account fuzzy information and the FR available to the educational institution. Sets of preferences and optimal strategies for allocating FR for building an academic cloud were identified. The strength of the study is that the use of a game model makes it possible to take into account factors such as instability of exchange rates, economic and political conditions, the ability to predict the financing of Projects in the event of unforeseen circumstances caused by the actions of the enemy player and unclear information about the financial condition of its competitor. At the same time, researchers have the opportunity to use the model in simulation mode, relying on the adequacy of the developed model to the real financing process.

A weakness of the study is that more research is needed into the risk factors associated with academic cloud deployment. And also that the considered model represents a "portrait" of reality that does not fully reflect reality. For example, consideration of a differential model, which takes a differential game as a basis, would make it possible to obtain a better picture of the process under consideration and, therefore, would make it possible to solve the problem taking into account additional factors and obtain a high-quality forecast.

Prospects for future research include developing the model through risk factor analysis to more accurately assess the risks associated with academic cloud deployment. Continued modeling over longer periods is also needed to determine long-term economic benefits. And, taking into account the above, it is necessary to complicate the models of the processes being studied in order to successfully implement the developed algorithms for solving practical problems.

6. CONCLUSION

This paper examines a multifactorial model for assessing investment options in a university cloud under conditions of fuzzy information. Unlike similar models, our model assumes that the dynamics of the players' financial states is specified by a system of discrete equations that describe the dynamics of multidimensional variables. It is shown that the controllability of the process of investing in a university cloud can be described from the point of view of a game approach through a bilinear multi-step game with several terminal surfaces and fuzzy information. The novelty of the model lies in finding a solution to a bilinear multi-stage quality game with several terminal surfaces under fuzzy information. The proposed solution adequately reflects the essence of the problem of choosing a university cloud deployment model.

The results of a computational experiment conducted on data from two large universities in Ukraine and Kazakhstan confirm the effectiveness of the proposed model. The experiment varied various parameters to assess their influence on the choice of cloud service model. The practical significance of the results lies in the possibility of using the proposed model for the selection of cloud services by both educational institutions and companies transferring their business processes to cloud structures. Future research could focus on extending the model to account for additional uncertainties and improve its adaptability to changing cloud market conditions.

ACKNOWLEDGEMENTS

The research was carried out within the framework of the project of the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan No. AP19678846 “Efficiency improvement of hybrid and distance forms of educational process based on university infrastructure development under digital transformation conditions”.

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