Запропоновано модель управління інвестиційним процесом, на прикладі інвестування в інформаційні технології (IT) з урахуванням багатофакторності даного процесу. Відмінність даної моделі від раніше розроблених полягає в тому, що, по-перше, вона розглядає інвестиційний процес як складну структуру, для якої недостатньо її моделювання як одно факторної категорії. По-друге, запропонована модель заснована на рішенні білінійної багатокрокової гри якості з декількома термінальними поверхнями. Рішення отримано в рамках схеми нового класу білінійних багатокрокових ігор, які описують взаємодію об'єктів в багатовимірному просторі. Розгляд інвестиційного процесу у такій постановці дає можливість адекватно описати процес пошуку раціональних стратегій гравців в ході інвестування в інформаційні технології. Проведене дослідження дозволило реалізувати програмний код моделі в середовищі імітаційного моделювання MatLab. Розроблено програмний продукт – система підтримки прийняття рішень «IT INVESTMENT». Математичне ядро СППР засноване на застосуванні нового класу білінійних диференціальних ігор. Запропоноване рішення дозволяє відшукувати оптимальні стратегії інвестування для потенційних інвесторів, а його застосування дозволило зменшити розбіжності даних прогнозування і реальної віддачі від інвестування, наприклад в проекти у сфері IT. Отримане рішення дозволило графічно показати перевагу інвесторів в процесі інвестування в проекти у сфері IT з урахуванням багатофакторності у багатовимірному просторі. Показано, що такий підхід в сукупності з застосуванням комп'ютерного моделювання та СППР дає інвестору широкі можливості для аналізу і вибору раціональних фінансових стратегій

Ключові слова: оптимальні стратегії інвестування, підтримка рішень, багатокрокова гра, програмний продукт

DEVELOPMENT OF A MODEL FOR DECISION SUPPORT SYSTEMS TO CONTROL THE PROCESS OF INVESTING IN INFORMATION TECHNOLOGIES

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1. Introduction

It is needless to prove that at present information technologies (IT) are beginning to rank first in the context of bringing the economy of any country to the forefront of the world. Understanding this fact sheds light on the problem of ever-increasing investments in various IT areas, such as cloud computing, cybersecurity, Data Mining, Big Data, Smart City, etc. Ignoring this circumstance [1, 2] may lead to significant economic lag from other countries. However, it should be noted that there may be risks on the way of the IT development caused by the lack of an investment man-agement strategy. This makes it a relevant task to develop models, as well as software products based on them [3, 4], which address the field of investments in IT.

As it was noted, success in the IT field is largely driven by investments in this area. The process of investment in IT is characterized by many factors, such as the allocation of financial resources to fund priority or non-priority ITs, the consideration of complex relationships between financial flows by investors. In addition, it is also possible that a conditional investor is a group of investors with divergent interests, etc. The specified circumstances lead to that the problem cannot be described by any single factor, which results in multi-di-

mensionality. Solving multidimensional problems typically requires the development of a toolkit that is not identical to the toolkit developed for a one-dimensional case. Papers by the scientists representing schools of Academicians L. S. Pontryagin and N. N. Krasovsky prove this. When solving the problems on determining investment strategies, there are difficulties due both to the complexity of the developed models and approaches and the lack of a toolset to determine actual values when assessing risks. It should be noted that the complexity of the models makes it a very difficult task to develop the algorithms and implement them in software products, such as decision support systems (DSS) [4, 5].

Note that in the field of DSS development, the software products used in the investment problems [4, 6] do not provide an opportunity to determine the rational recommendations and strategies for IT investment.

This drawback can be eliminated by using the models in the DSS that are based on the application of the theory of multistep quality games with multiple terminal surfaces [7].

2. Literature review and problem statement

It was noted in papers [6, 7] that in order to improve the productivity and effectiveness of the evaluation of such projects, it is advisable to involve the potential of various computerized systems and, in particular, the DSS. However, for many subject areas, for example, for the task of assessing investments in IT, the available DSS does not address the cases with a set of investor strategies.

According to the authors of publications [8, 9], it is advisable to use not only traditional methods and models [10], when analyzing the models and the algorithms used to evaluate the IT investment projects. For example, in papers [11, 12], it was stated that, for all its appeal, the hierarchy method (the T. Saati method) [13] and the expert methods [9, 10, 14], widely used in the DSS, were in most cases not suitable for the synthesis of forecasting estimates. This is especially true for the problem of choosing by an investor of the rational strategies of investment of their financial resources in a particular IT project. The latter circumstance is a drawback in the T. Saati method.

Models for DSS, which relate to analysis and evaluation of investors' strategies in the context of the actions of the two parties (players), were proposed in papers [7, 15, 16]. According to [17, 18], a general approach to the model, which is based on the game theory, is the assumption that one of the sides of the investment process is seen as a set of potential threats. These threats may arise from incompetent, inconsistent actions of investors. This will result in a loss of capital spent on a project, particularly in the IT field. Existing DSSs do not eliminate this drawback.

In articles [16, 18], it was noted that for this class of problems, the most appropriate models describing the behavior of a complex system are the models based on the game theory.

An analysis of research into this field [12, 15] has revealed that most of the models and algorithms presented in papers [14, 17–20], do not provide actual recommendations to investors in IT-related projects. This is especially true of the aspects of finding rational strategies for mutual financial investment in such projects. This is not taken into consideration in the existing DSS.

We also note that the approaches described by the authors of [19–22] do not make it possible to find effective recommendations and strategies for managing investments in IT enterprises. It is especially necessary to consider the multifactor nature of this problem and a rather large range of possible rational strategies, on which an investor needs to concentrate.

Articles [5, 15, 17, 18, 23, 24] show that the approaches of the game theory are most effective in the problems involving more than two decision-makers. This is due to the fact that they allow taking into consideration many factors, primarily in terms of information security of various types, such as the lack of information about the actions of another player, the lack of information about the state of another player, about the classes of strategies of another player. In addition, the dynamics assigning the motion of objects is very important. For example, in the case of the dynamics that exist in the considered task, it is impossible to apply the Cauchy formula to find a solution to the differential analog of this system, which means that the approaches of school by L. S. Pontryagin [23] are not applicable here. And in the case of using immeasurable counteractions by the opposing player, the approaches of the school of N. N. Krasovsky [24] are not applicable here.

These circumstances suggest that it is appropriate to continue research into the development of new models and software products that can provide the decision-making support procedures in the process of the search for rational investment strategies. In particular, this challenge remains unresolved for the IT sector, for example, in the context of obtaining a forecasting estimate for the feasibility of a particular strategy of an investor.

3. The aim and objectives of the study

The purpose of this paper is to develop a model for decision support systems for choosing the rational strategies related to mutual investment in information technologies, taking into consideration the multifactor character of this process.

To accomplish the aim, the following tasks have been set:
– to construct a model based on the theory of multi-step quality games with multiple terminal surfaces for a decision support system in the course of the selection of rational strategies by investors in the IT field;
– to perform computational experiments in the MATLAB simulation environment to prove the model's performance;
– to implement via software a decision support system in the course of selecting rational strategies by investors, taking into consideration the multifactor character of the problem.

4. A model based on the theory of multi-step quality games for a decision support system in the course of the selection of rational strategies by investors

In addressing the challenges associated with the development of a particular sector of the economy, one of the most important factors is the possibility of the financial support of innovative and advanced technologies in this area. Such an important area as the IT, which currently defines the place of a country in the global economic hierarchy, is not an exception. However, the problem of financing (investment) of any sphere requires its reasonable implementation, as any

magnitude of financial resources (FR) can be spent without any appropriate effect. And here, it is necessary to resort to the reputed decision-making methods to help solve the problem of reasonable financing the IT. Among these methods, it is possible to separate the game theory, optimal management techniques, optimization methods, and others. One of the most effective methods and models in the problems of finding the rational strategies for investors are the methods of the game theory and, in particular, the method of multi-step quality games. We will consider the problem of financing the IT within the given method by attracting financial resources (*FinR*) of investors. The use of the apparatus of multi-step quality games makes it possible to provide financing with all sorts of factors in mind, in particular, taking into account the multiplicity of approaches to the construction of effective IT at an enterprise. And this may make it possible to develop the DSS-based game models, such as software products (*SP*), that enable making rational decisions on the investment of financial resources in the development of such technologies.

Papers [7, 15, 23, 24] show that the situations described in the research are classic game situations, and such situations can be most effectively solved only by game methods.

The model proposed in this paper is based on an analysis of the process of financing information technologies by investors, for the case their character is multifactorial.

The model is a continuation of papers [7, 15] and is based on solving a bilinear multi-step quality game with multiple terminal surfaces. The problem is considered in the statement that is standard for a multi-step quality play with multiple terminal surfaces.

There is a dynamic system in a multidimensional space run by two players (investors). The system is set by the system of bilinear multi-step equations with dependent movements. The terminal surfaces S_0, F_0 are set and sets of strategies (U) and (V) of the players are determined. The goal of the first player (further referred to as *Inv*1) is to bring the dynamic system through his control strategies onto terminal surface S_0 no matter how the second player (further *Inv*2) acts. The goal of *Inv*2 is symmetrical.

The formulated problem generates two problems, from the point of view of the first ally-player and from the point of view of the second ally-player [15].

The study examines the problem from the point of view of the first ally-player. The problem from the point of view of the second ally player will not be considered, as its solution is similar due to symmetry. The solution is to find the sets of preferences for W_1 and W_2 players, that is, the set of initial states of players and their strategies that enable the objects to bring the system onto the given surface.

In problem 1, an ally player is interpreted for *Inv*1, the opponent player is interpreted for *Inv*2. Conversely, in problem 2, an ally player is interpreted for *Inv*2 and the opponent player – for *Inv*1. Both players are trying to invest in their FR in IT.

We believe that for the assigned period of time [0, *T*] (*T* – natural positive number), *Inv1* has the set $h(0)=$ $=(h_1(0),...,h_n(0))$ of financial resources ($h_i(0)$ – FR for the development of the *i*-th IT). Accordingly, *Inv*2 – $f(0)=$ $=(f_1(0),...,f_n(0))$ ($f_i(0)$– FR for the development of the *i*-th IT). These sets determine the magnitude predicted at moment *t*=0, magnitude *FinR* of players for each information technology).

Describe the dynamics of the change in *FinR* for the players as follows:

$$h(t+1) = B_1 \times h(t) + [(A_1 + R_1) - E] \times U(t) \times$$
$$\times h(t) - [(A_2 + R_2) - E] \times V(t) \times B_2 \times f(t); \quad (1)$$

$$f(t+1) = B_2 \times f(t) + [(A_2 + R_2) - E] \times V(t) \times$$
$$\times B_2 \times f(t) - [(A_1 + R_1) - E] \times U(t) \times B_1 \times h(t), \quad (2)$$

where $h(t) \in R^n$, $f(t) \in R^n$, $U(t)$, $V(t)$ are the square matrices of order n with positive elements $u_i(t)$, $v_i(t) \in [0, 1]$, on the diagonals of diagonal matrices $U(t)$, $V(t)$, respectively; B_1, B_2 are the matrices of the transformation of FR of *Inv*1 and *Inv*2 at their successful implementation in the IT, which are square matrices of order n with positive elements g_1^{ij}, g_2^{ij}, respectively; A_1, R_2 are the diagonal matrices with positive elements, characterizing the percent plate of *Inv*2 for financial investments and shares of investment return of *Inv*2, related to investments of *Inv*1 in the IT; A_2, R_2 are the diagonal matrices with positive elements, characterizing the percent plate of *Inv*1 for financial investments and the share of investment return of *Inv*1, related to investments of *Inv*2 in the IT;

E is the single matrix.

The interaction ends when the conditions are met:

$$(h(t), f(t)) \in S_0, \quad (3)$$

$$(h(t), f(t)) \in F_0, \quad (4)$$

where

$$S_o = \bigcup_{i=1}^n \{(h; f) : (h; f) \in R^{2n}, h \geq 0, f_i < 0\},$$

$$F_o = \bigcup_{i=1}^n \{(h; f) : (h; f) \in R^{2n}, f \geq 0, h_i < 0\}.$$

If condition (3) is met, we believe that the procedure of financing IT enterprises is completed. That is, *Inv*2 did not have enough financial resources to continue the investment procedure, at least one of the information technologies.

If condition (4) is met, we also believe that the procedure of investment in the IT enterprise is completed. That is, *Inv*1 did not have enough financial resources to continue the investment procedure, at least for one of the information technologies.

If both conditions (3) and (4) are not met, we believe that the investment procedure continues.

Values ($h(T)$, $f(t)$) show the result of the investment procedure on the planned interval [0, T].

The above process is considered as a part of the positional multi-step game scheme with complete information [22].

As already noted, due to the symmetry, we will limit ourselves to the consideration of the problem from the position of *Inv*1. The second problem is solved in a similar way. Determining a pure strategy and a set of preferences of the first player was given in papers [12, 15].

A solution to problem 1 is to find many "preferences" of *Inv*1 and its optimal strategies. The problem is stated similarly in terms of *Inv*2.

Here are the conditions under which the solution of the game is found, which is the set of "preference" of W_1 and the optimal strategies *Inv*1. These conditions will be set by matrix inequalities.

1) $(A_1 + R_1) - E > 0, (A_2 + R_2) - E > 0;$

2) $(A_1 + R_1) - E > 0, (A_2 + R_2) - E \leq 0;$

3) $\left(A_1+R_1\right)-E\le 0,\left(A_2+R_2\right)-E>0;$

4) $\left(A_1+R_1\right)-E\le 0,\left(A_2+R_2\right)-E\le 0.$

All the other variants of the ratios of the elements of these matrices.

Let us introduce the following designations.

$$Q_1=\left(A_1+R_1\right)\times B_1,$$

$$D_1=\left[\left(A_2+R_2\right)-E\right]\times B_1;$$

$$F_1=\left(A_2+R_2\right)\times B_2,$$

$$S_1=\left[\left(A_1+R_1\right)-E\right]\times B_1;$$

$$Q_{k+1}=Q_k\times\left\{Q_k+D_k\times S_k\right\}\times B_1,$$

$$D_{k+1}=D_k\times\left\{F_k+Q_k\times D_k\right\}\times B_2;$$

$$F_{k+1}=F_k^2+S_k\times D_k,$$

$$S_{k+1}=S_k\times Q_k+F_k\times S_k.$$

Within these designations for case 1, the preference set W_1 is determined as follows:

$$W_1=\bigcup_{T=1}^{\infty}W_1^T; \tag{5}$$

$$W_1^T=\bigcup_{i=1}^{T}\left\{\begin{array}{l}\left(h(0),f(0)\right):\left(h(0),f(0)\in R_+^{2n}\right),\\ Q_1\times h(0)\ge D_1\times f(0),...,Q_T\times h(0)\ge\\ \ge D_T\times f(0),\left\{F_T\times f(0)<S_T h(0)\right\}_i\end{array}\right\}/W_1^{T-1}. \tag{6}$$

The optimal strategies of player 1 will be $U^*(j)=E$ for $j=1,...,T$.

For cases 1–3, the sets of preference of player 1 and his optimal strategies are found in a similar way. The problem is also similarly solved by ally player 2.

5. Computational experiment to find rational strategies for investors

The computational experiments were performed in the MATLAB environment. They were based on the initial data, which were taken for calculations under the AP06751068 grant "Development of a decision support system for the selection of strategies for investing in tools of cybersecurity of crucial computer systems of the national scale" (Republic of Kazakhstan – RK), as well as on the investment projects in the IT sector at the enterprises in Kyiv and Kyiv oblast (SRW "Information and software, mathematical modeling of complex systems" (No. s/r 0114U005430, Ukraine).

Fig. 1–3 show the results of modeling the sets of preferences of investors. Fig. 1 shows the preference area of player 1, that is, the set of the initial financial resources that have the property that if the investment process starts with them, it will end as follows: player 1 will have the remaining financial resources for investment, and player 2 will not. In Fig. 1–3, the values x (designated in the figures as $H1$), y (designated as $H2$) are the financial resources of investor 1.

Variable z (designated as $W1$) is the financial resources of investor 2.

Case 1.

Suppose that the following assumptions are met:
– investor 1 is represented by two-dimensional FR;
– investor 2 is characterized by one-dimensional FR;
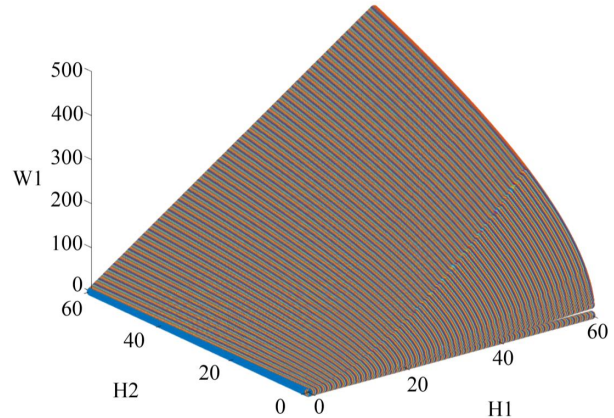– investor 2 chooses all the components of his strategy in an optimal way.

Fig. 1. Preference set of investor 1 for case 1

In Fig. 1, the preference area of investor 1 is under the reduced surface in the positive orthant ($H1$, $H2$, F).

Case 2.

Let the following assumptions be true:
– investor 1 is represented by two-dimensional FR;
– investor 2 is characterized by one-dimensional FR;
– investor 1 does not "control" the second component of his strategy, that is the second component may have any value.

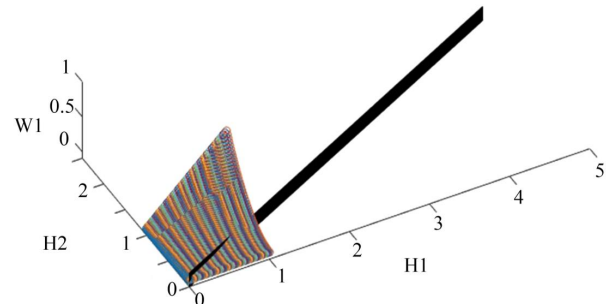Fig. 2 shows the set preference of investor 1 for case 2.

Fig. 2. Preference set of investor 1 for case 2

For case 2, the preference set of investor 1 will be less (by including one set in another one). According to the problem statement, the part of the space adjacent to the orthant R_2^+ is preferable for investor 1. This fact is clearly illustrated by Fig. 1, 2.

Case 3.

Let the following assumptions be true:
– investor 1 is represented by one-dimensional financial resource;
– investor 2 is represented by one-dimensional financial resource;
– investor 1 does not "control" the first component of his strategy, that is the first component may have any value.

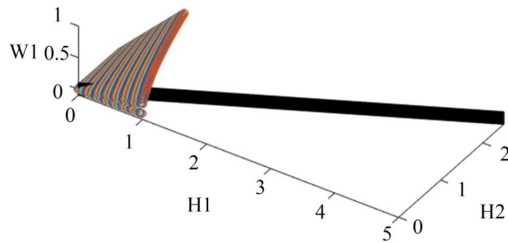Fig. 3 shows the trajectory of the financial resources of the parties for case 3.

Fig. 3. Preference set of investor 1 for case 3

For case 3, the set of preferences of investor 1 will be smaller (by including one set in another).

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6. Software implementation of the decision support system in the course of investing in information technologies

The developed model refers to the class of such models that make it possible to constructively find a solution to the problem depending on the ratios of parameters that determine the problem. This enabled the implementation of the DSS in the field of IT investment. In addition, the DSS also includes the modules related to finding the optimal investor' strategies for the following cases:

1) mutual financial investment;
2) incomplete information about the financial state of the second party;
3) obtaining additional data by investor 1;
4) with the fixed time of completion of investors' interaction, etc. It is the totality of the algorithms for solving these and other problems that allows us to argue about the creation of the DSS computational core.

The general form for assigning original data in the DSS "Choice of the rational strategy for investing in information technologies" (IT INVESTMENT) is shown in Fig. 4. The data in Fig. 4 were selected to illustrate the complexity of the considered model, and the variables on the form were taken from history in the DSS database. If the solution related to finding the preference area of investor 1 was not found, the DSS will give the corresponding message.

Any options for investors' actions acceptable in the problem statement can be considered with the help of "THE INVESTMENT" DSS. Note that the system can only manifest itself in the output it gives, in particular, in the form of charts, the indication of the values of optimal investment strategies, etc.

The main windows of the DSS with the calculation results and visualization of the investors' preference areas are shown in Fig. 5. DSS makes it possible to visualize the calculation results both in text-output format for an investor and in the form of the 2D (Fig. 5, *a*) or 3D chart (Fig. 5, *b, c*).

The DSS is implemented in the software environment Visual Studio 2019.

When testing the DSS "IT INVESTMENT", the situations discussed above were considered. The cases where players' strategies bring them to the appropriate terminal surfaces were explored. On the plane, the abscises axis is the financial resources of investor 1 ($H1$). The ordinate axis is the financial resources of investor 2 ($H1$).

The lower part of the window, Fig. 5, shows the conclusion generated by the DSS in the process of searching for the rational strategies by investors, as well as the area of intersection of the preference set of investor 1. The rational strategy of an investor is shown in Fig. 5 by the gray-blue line for a 2D chart or by the plane for the 3D chart.
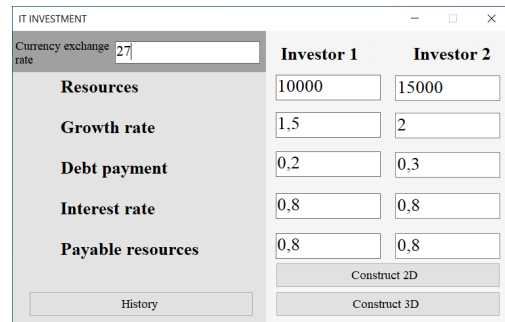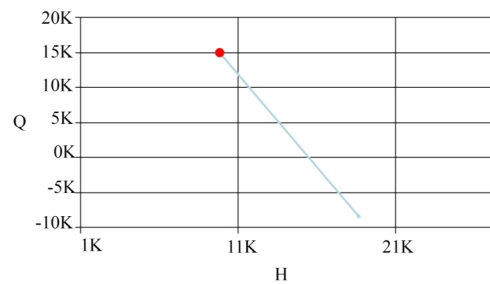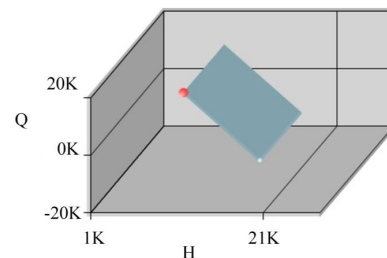

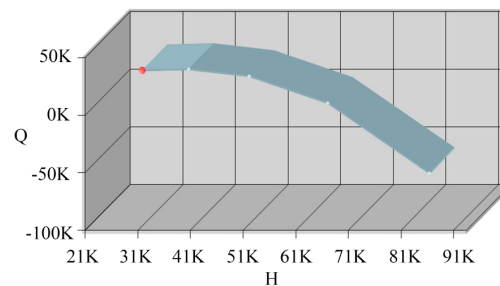Fig. 4. General view of the DSS module "IT INVESTMENT"

In this case, player 1 achieves the aim of interaction by applying his optimal strategy. This means that player 2 loses his financial resource despite his counteraction to player 1.

a

In this case, player 1 achieves the aim of interaction by applying his optimal strategy. This means that player 2 loses its financial resource, despite his counteraction to player 1.

b

In this case, player 1 achieves the aim of interaction by applying his optimal strategy, that brings player 2 to the loss of financial resource, despite his optimal counteraction. In this case, the advantage of player 2 in the growth rate enables him to give serious counteraction to player 1, which enables him to increase his magnitude of financial resources over a definite time interval.

c

Fig. 5. Results of operation of the DSS "IT INVESTMENT": *a* — example of the two-dimensional chart; *b* — example of a three-dimensional chart for two computational points; *c* — example of a three-dimensional chart for five computational points

Fig. 5 illustrates the situation where investor 1 has an advantage in the ratio of initial financial resources, that is they are in his preference set.

The developed apparatus of finding the optimal strategies of players significantly "facilitates" solving a problem of developing the rational behavior of investors. In particular, it happens when a problem is described by a large number of parameters, which makes it impossible to find a solution to a problem without using the DSS. That is why there is no need to talk about finding the model that gives a better result. This was not the aim of the research. A better option might be suitable for a case where it is possible to find solutions to a problem in this statement through other approaches. If these opportunities do not exist, such a question is rhetorical.

The DSS implemented the proposed model based on the application of the methods of the theory of differential games. The developed DSS allows reducing the discrepancies in forecasting data and real return from the IT investment.

7. Discussion of results from experiments on searching for the rational strategies of investors

The model proposed in the article is the advancement of papers [7, 15]. However, the approaches proposed in [7, 15] do not make it possible to find a solution to the model outlined in this paper, as it is more complex than those models because it takes into consideration some additional factors (for example, incomplete information for an investor, the possibility to assign the options that are analyzed by the IT using fuzzy sets, etc.), which are not taken into account in models [7, 15].

Fig. 1 shows the preference set W_1 for investor 1 for case 1. The obtained result in this problem statement is close to the result given in [15]. This proves the correctness of the solution when stating the problem explored in the framework of this article.

In Fig. 2, the area of preference of investor 1 will be found as a result of the intersection of the preference set of investor 1 from Fig. 1 (in Fig. 2, it is a colored surface) and the hyperplane (in Fig. 2, the hyperplane is shown in black). The "decrease" of the preference set of investor 1 is determined by assumption 3 for case 2. Note that for case 2, the preference set of investor 1 is the part of the preference set of investor 1 (from Fig. 1), which is adjacent to axis $0H1$.

In Fig. 3, the area of preference of investor 1 will be found as a result of the intersection of the preference set of investor 1 from Fig. 1 (in Fig. 3, it is the colored surface) and a hyperplane (in Fig. 3, the hyperplane is shown in black). The "decrease" of the preference set of investor 1 is due to assumption 3 for case 3. Note that for case 3, the preference set of investor 1 is a part of the preference set of investor 1 (from Fig. 1), which is adjacent to axis $0H2$.

Fig. 5, $a–c$ illustrates the situation when, despite the advantage of investor 2 over investor 1 in terms of the rate of growth of his financial resources, the ratio of parameters is such that the initial financial resources of investors are in the preference of player 1. Therefore, according to the results of this article, investor 1 has his optimal strategy, which leads his counterpart-investor to the loss of his financial resources. This is seen clearly, both in two-dimensional and in three-dimensional cases. The result obtained in "IT INVESTMENT" is not clearly visible because the problem is complex, multidimensional. However, the existence of the interpretation form of the solution as textual clues for a decision-maker makes its interpretation easier than operating mathematical concepts, such as a hyperplane or a balance beam.

The results of computational experiments show the effectiveness of the proposed tools to solve the task of managing the financial resources by the parties, taking into consideration the multifactor character.

Compared to the existing models described in [8, 12], the proposed model improved the indicators of performance and predictability for an investor an average by 8–11 %. This statement was obtained based on the comparison with actual calculations for investment projects in information systems in Ukraine and Kazakhstan. The DSS received copyright registration certificate No. 90553.

It should be noted that the considered model requires observing a series of limitations, in particular the condition for the non-negativeness of the matrix elements that assign the dynamics of the process is important. In turn, the elements of the matrix depend on the characteristics of the investment object in question and will be knowingly different if, for example, we are talking about the IT investments related to cybersecurity (where it is necessary to take into consideration risks, vulnerabilities and threats), and investment in the Smart City technologies (where it is necessary to take into consideration the priority and the order of implementation of information technologies).

Consideration of these models is a promising direction for solving problems in the field of investment, for example, in information systems and technologies, Smart City, banking and industrial sector of the economy. It deserves attention in the future and is defined as the prospect of continuing research, the deployment of a fully-fledged DSS based on this model in the problems of evaluating the investment projects in various areas. It is possible to test DSS not only in investment and financial projects in the area of the digital economy but also in the related areas, for example, when selecting strategies for investor groups.

8. Conclusions

1. A mathematical model based on the theory of multi-step quality games with several terminal surfaces for a decision support system in the course of the selection of investors' rational strategies has been developed. The problem of financing the company's information technologies and systems was chosen as an example. The model is focused on practical application in the software-algorithmic unit of decision support systems (DSS). The proposed DSS will be useful in the process of the search for rational strategies by investors. The model used in the mathematical core of the DSS is based on the toolkit of bilinear multistep quality games with multiple terminal surfaces. The article, unlike the existing ones, is the first to deal with a new class of bilinear multi-step games. The resulting solution of this class of games allowed displaying adequately in the multi-dimensional space the preference sets of investors in the process of investing in IT projects, taking into consideration the multifactor character. It was shown that this approach, combined with the use of computer simulation and the DSS, gives an investor more opportunities to analyze and choose rational financial strategies.

2. Computer simulation of investors' strategies and their preference sets based on the developed model was carried out employing the MATLAB software. The computer model has made it possible to reduce the discrepancies in the results of the forecasting estimate of the strategies for investors and selected options on average by 8–11 %.

3. The software product – the decision support system "IT INVESTMENT", based on the application of a new class of bilinear differential games, was developed. The DSS makes it possible to find the optimal investment strategies for potential investors. The software product was implemented in the programming environment Visual Studio 2019. The developed apparatus of finding the optimal strategies of players with the help of "IT INVESTMENT" makes it possible to significantly facilitate the problem of generating the rational behavior that investors face when the problem is described by a large number of parameters, which makes it impossible to find a solution to the problem without using DSS. In addition, the use of DSS has reduced discrepancies in forecasting data and actual return on investment, such as in IT projects. The proposed solution and the DSS make it possible to choose the optimal financial component of the investment strategy at any ratios of parameters describing the process.

References

1. Zuboff, S. (2015). Big other: Surveillance Capitalism and the Prospects of an Information Civilization. Journal of Information Technology, 30 (1), 75–89. doi: https://doi.org/10.1057/jit.2015.5

2. McArthur, D. (2002). Investing in digital resources. New Directions for Higher Education, 2002 (119), 77–86. doi: https://doi.org/10.1002/he.74

3. Madon, S., Krishna, S. (2018). The Digital Challenge: Information Technology in the Development Context. Routledge, 386. doi: https://doi.org/10.4324/9781315196978

4. Woodard, C. J., Ramasubbu, N., Tschang, F. T., Sambamurthy, V. (2013). Design Capital and Design Moves: The Logic of Digital Business Strategy. MIS Quarterly, 37 (2), 537–564. doi: https://doi.org/10.25300/misq/2013/37.2.10

5. Bai, C., Sarkis, J. (2016). Supplier development investment strategies: a game theoretic evaluation. Annals of Operations Research, 240 (2), 583–615. doi: https://doi.org/10.1007/s10479-014-1737-9

6. Zanella, A., Bui, N., Castellani, A., Vangelista, L., Zorzi, M. (2014). Internet of Things for Smart Cities. IEEE Internet of Things Journal, 1 (1), 22–32. doi: https://doi.org/10.1109/jiot.2014.2306328

7. Akhmetov, B. S., Akhmetov, B. B., Lakhno, V. A., Malyukov, V. P. (2019). Adaptive model of mutual financial investment procedure control in cybersecurity systems of situational transport centers. NEWS of National Academy of Sciences of the Republic of Kazakhstan, 3 (435), 159–172. doi: https://doi.org/10.32014/2019.2518-170x.82

8. Mithas, S., Tafti, A., Mitchell, W. (2013). How a Firm's Competitive Environment and Digital Strategic Posture Influence Digital Business Strategy. MIS Quarterly, 37 (2), 511–536. doi: https://doi.org/10.25300/misq/2013/37.2.09

9. Tiwana, A., Ramesh, B. (2001). E-services: problems, opportunities, and digital platforms. Proceedings of the 34th Annual Hawaii International Conference on System Sciences. doi: https://doi.org/10.1109/hicss.2001.926311

10. Mazzarol, T. (2015). SMEs engagement with e-commerce, e-business and e-marketing. Small Enterprise Research, 22 (1), 79–90. doi: https://doi.org/10.1080/13215906.2015.1018400

11. Sedera, D., Lokuge, S., Grover, V., Sarker, S., Sarker, S. (2016). Innovating with enterprise systems and digital platforms: A contingent resource-based theory view. Information & Management, 53 (3), 366–379. doi: https://doi.org/10.1016/j.im.2016.01.001

12. Mohammadzadeh, A. K., Ghafoori, S., Mohammadian, A., Mohammadkazemi, R., Mahbanooei, B., Ghasemi, R. (2018). A Fuzzy Analytic Network Process (FANP) approach for prioritizing internet of things challenges in Iran. Technology in Society, 53, 124–134. doi: https://doi.org/10.1016/j.techsoc.2018.01.007

13. Selçuk, A. L. P., Özkan, T. K. (2015). Job choice with multi-criteria decision making approach in a fuzzy environment. International Review of Management and Marketing, 5 (3), 165–172.

14. Kache, F., Seuring, S. (2017). Challenges and opportunities of digital information at the intersection of Big Data Analytics and supply chain management. International Journal of Operations & Production Management, 37 (1), 10–36. doi: https://doi.org/10.1108/ijopm-02-2015-0078

15. Akhmetov, B. B., Lakhno, V. A., Akhmetov, B. S., Malyukov, V. P. (2018). The Choice of Protection Strategies During the Bilinear Quality Game On Cyber Security Financing. Bulletin of the National Academy of Sciences of the Republic of Kazakhstan, 3, 6–14.

16. Lakhno, V., Malyukov, V., Gerasymchuk, N., Shtuler, I. (2017). Development of the decision making support system to control a procedure of financial investment. Eastern-European Journal of Enterprise Technologies, 6 (3 (90)), 35–41. doi: https://doi.org/10.15587/1729-4061.2017.119259

17. Smit, H. T. J., Trigeorgis, L. (2010). Flexibility and Games in Strategic Investment. Multinational Finance Journal, 14 (1/2), 125–151. doi: https://doi.org/10.17578/14-1/2-4

18. Arasteh, A. (2017). Considering the investment decisions with real options games approach. Renewable and Sustainable Energy Reviews, 72, 1282–1294. doi: https://doi.org/10.1016/j.rser.2016.10.043

19. Gottschlich, J., Hinz, O. (2014). A decision support system for stock investment recommendations using collective wisdom. Decision Support Systems, 59, 52–62. doi: https://doi.org/10.1016/j.dss.2013.10.005

20. Strantzali, E., Aravossis, K. (2016). Decision making in renewable energy investments: A review. Renewable and Sustainable Energy Reviews, 55, 885–898. doi: https://doi.org/10.1016/j.rser.2015.11.021

21. Nagurney, A., Daniele, P., Shukla, S. (2016). A supply chain network game theory model of cybersecurity investments with nonlinear budget constraints. Annals of Operations Research, 248 (1-2), 405–427. doi: https://doi.org/10.1007/s10479-016-2209-1

22. Akhmetov, B., Balgabayeva, L., Lakhno, V., Malyukov, V., Alenova, R., Tashimova, A. (2019). Mobile Platform for Decision Support System During Mutual Continuous Investment in Technology for Smart City. Studies in Systems, Decision and Control, 731–742. doi: https://doi.org/10.1007/978-3-030-12072-6_59

23. Nikol'skii, M. S. (2017). A Study of the Generalized Pontryagin Test Example from the Theory of Differential Games. Proceedings of the Steklov Institute of Mathematics, 299 (S1), 158–164. doi: https://doi.org/10.1134/s0081543817090188

24. Krasovskii, N. A., Tarasyev, A. M. (2018). Demand Functions in Dynamic Games. IFAC-PapersOnLine, 51 (32), 271–276. doi: https://doi.org/10.1016/j.ifacol.2018.11.394