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RISK ASSESSMENT OF INVESTMENT LOSSES AIMED AT THE DEVELOPMENT OF SMART CITY SYSTEMS

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ABSTRACT

In the article is suggested a model for the computing core for the decision support system (DSS) in assessing the risks of investment loss during the dynamic planning (DP) of SmartCity development. Unlike existing solutions, the suggested model gives specific recommendations for assessing the risks of loss. If the risk forecast is unsatisfactory, flexible adjustment of the investment process parameters is possible in order to achieve an acceptable financial result for the parties.

The novelty of scientific results consists in the fact that for the first time it is suggested to apply a new class of bilinear multi-step games. This class allowed us to adequately describe the process of risk assessment of investment loss, using the example of dynamic planning for the placement of players' financial resources in SmartCity projects. A distinctive feature of the considered approach is the use of tools based on the solution of a bilinear multi-step game of both quality with several terminal surfaces and a degree game solved in the class of mixed strategies. Computational experiments were carried out in the Maple mathematical modeling package. An DSS was developed in which a risk assessment model is implemented. The developed DSS allows you to reduce the discrepancy between the data of forecasting the risks of investment loss during SmartCity and real return on investment.

The model presented in the paper is based on solving a linear multistep degree game using the results of solving a multistep quality game with multiple terminal surfaces. The problem in the article is considered in the statement, standard for a multi-step game.

Keywords: *Risk Assessment, Investment Loss, Multi-Step Games With a Quality Of Several Terminal Surfaces, Decision Support System*

1. INTRODUCTION

Without financial support of innovative and advanced information technology (IT), that serves as basis of creating and developing urban infrastructure, it is impossible to solve the problems of dynamic planning of Smart City [1], [2], [3].

However, investing in SmartCity IT requires analytical support for dynamic planning tasks. Such support, for example, through the widespread use of decision support systems (DSS) or expert systems (ES), will avoid the many risks of losing financial resources due to the diversity and complexity of implementing IT in SmartCity infrastructure projects. In this direction, in addition to the development of information systems (IS) and DSS aimed at the tasks of managing various processes in SmartCity (transport, water and energy security, etc.), DSS are very important, allowing to assess the risk of investment loss [4], [5].

As always, to help solve the problem of assessing the risks of investment loss, you have to resort to already proven methods to finding a solution to this problem. Among such methods, one can single out game theory, optimal control methods, multicriteria optimization methods, and others [4], [5], [6]. One of the most effective approaches is to use the methods of game theory and, in particular, the methods of multi-step games of quality, the framework of which fits well the problem of assessing the loss of investment in IT when attracting financial resources by investors [4], [6]. The use of multi-step games of quality allows the risk assessment of the loss of financial resources, taking into account all sorts of factors. In particular, taking into account the tasks of dynamic planning of SmartCity development and the multiplicity of approaches to building effective IT for SmartCity infrastructure projects. And this can make it possible to develop, based on the game models of DSS, for example, software products (PP) that allow, for example, SmartCity municipalities to make rational decisions using risk assessment of the loss of investments in IT and IP.

All of the above determines the relevance of further research on the development of mathematical models and methods for assessing the risk of investment loss, aimed at the development of information technologies and systems, in the context of the dynamic development planning of SmartCity.

2. LITERATURE REVIEW

In [7], [8] was shown, that Smart city development projects characterized by a high degree of uncertainty and riskiness, in particular for an investor who expects to increase his financial resources during the implementation of such projects.

As shown in [9], [10], for large projects in the field of urban studies, success often depends on the planning and optimal choice of strategies for the development of urban infrastructure, taking into account all factors affecting the system, as well as taking into account and overcoming various kinds of uncertainties and risks. However, variables taking into account the presence of risks are absent in these works.

Studies [11], [12] showed that planning and forecasting the development of SmartCity is associated with overcoming various kinds of uncertainties, non-linearities and risks posed by the system itself and the external environment in which SmartCity operates. The presence of various types of uncertainties, such as situational uncertainty, inaccuracy and uncertainty of various parameters of the system and the external environment, insufficient information about the system, non-linearity and stochasticity of processes occurring both in SmartCity and in the external environment, as well as a large number of risks - all these signs make the problem of solving the tasks of the SmartCity infrastructure DP weakly structured and difficult to formalize [11].

Dynamic planning of SmartCity development includes various methods for processing quantitative and qualitative information, modeling methods [12], optimization and decision-making methods at different stages of building plans [13], [14], risk assessments and uncertainty [15], [16], [17], [18].

Uncertainties occur with any type of SmartCity development planning. In the tasks of dynamic planning (DP) of SmartCity development, uncertainties are associated with risk. Risks are inherent in any activity, and with the development of scientific and technological fields, the number of existing and potential risks increases significantly.

Today, the risk management process is considered as a key area of applied management, which requires paying considerable attention to the study of risk areas and the main types of risks, the search for effective methods for their assessment, control and monitoring, as well as the creation of appropriate risk management systems.

Risk analysis in various applications is a very broad and rapidly growing industry. The effectiveness of solving any problem mainly depends on the correctness and soundness of decision-making at all stages of solving problems, regardless of the complexity of the tasks that are being solved, which in turn is impossible without taking risks into account. To manage any process or to solve planning problems, you need to be able to analyze the risk, assess its degree, anticipate the consequences of the decision and not go beyond the acceptable limits of risk. That is, for the effective solution of the tasks of the DP, it is necessary to identify the risk, anticipate it, trying to reduce it to the lowest possible level.

The classic definition of risk is given in the work of F. Knight [19]. According to this definition, risk situations are characterized by known probabilities. Moreover, the risk is defined as any unpredictable changes in the state of the system.

In [17], [18], the authors define risk as the mathematical expectation of losses through the choice of a particular solution. In [20], the following definition of risk is given: "Risk is the probability of losses or loss of income in comparison with the predicted option."

In [21], [22], was considered the concept of multifactorial risks. A quantitative assessment of the degree of risk, as well as the possibility of constructing confidence intervals by a known probability, allows more reliable influence on the process under study in order to reduce the risk [21].

Since solving SmartCity dynamic planning tasks is a knowledge-intensive process that requires systematic application of various approaches and methodologies, and which is impossible without the use of modern methods of mathematical modeling, methods, algorithms and software for developing adequate models and making decisions based on them, the topic of research in the framework of this article it seems to us very relevant.

3. THE PURPOSES AND TASKS OF THE RESEARCH

The purpose of the research is to develop a model for the computing core of a decision support system during the assessment of investment loss risks during the dynamic development planning of SmartCity.

To achieve this purpose, it is necessary to solve the following tasks:

1) To develop a model for assessing the risks of investment loss during the dynamic planning of SmartCity development, based on the use of the mathematical apparatus of multi-step quality games with several terminal surfaces;

2) Perform computational experiments using the mathematical package of modeling Maple;

3) Develop a software module for a decision support system in the process of assessing the risks of investment loss.

4. METHODS AND MODELS

4.1. Problem formulation

The model proposed in this paper is based on a risk analysis of the process of financing by IT investors for SmartCity for the case of their multifactorial nature and multiple choice alternatives.

The model is a continuation of our work [4], [6], [23], [24], [25] and is based on the solution of a bilinear multistep degree game using the results of solving a multistep quality game with several terminal surfaces. The problem is considered in the formulation standard for a multi-step game of degree.

There is a dynamic system in multidimensional space, which is controlled by two players (investor, then investor 1 ($Inv1$) and investor 2 ($Inv2$)). The system is defined by a system of bilinear multistep equations with dependent motions.

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

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

Here $t = 0,1,..., T$; $x^+ = \begin{cases} x, & x \geq 0; \\ 0, & x \prec 0; \end{cases}$ $x \in R$;

$T -$ natural number;

$h(t) \in R^n, f(t) \in R^n, U(t), V(t) -$ square matrices in n order with positive elements of $u_i(t), v_i(t) \in [u_1^*,..., u_K^*] \times [v_1^*,..., v_M^*]$, $u_l^* \in [0,1], l = 1,..., n$;

$v_l^* \in [0,1], l = 1,..., n$; $K, M -$ natural numbers; on the diagonals of diagonal matrices, respectively $U(t), V(t)$;

B_1, B_2 - transformation matrix of the financial resources (FR)) $Inv1$ and $Inv2$ upon their successful implementation in IT, which are square matrices in n order with positive elements of g_1^{ij}, g_2^{ij}, respectively;

$A_1, R_1 -$ diagonal matrices with positive elements that characterized with interest rate $Inv2$ for financial investments and its return $Inv2$ in relation of investment $Inv1$;

$A_2, R_2 -$ diagonal matrices with positive elements that characterized with interest rate

$Inv\ 1$ for financial investments and its return $Inv\ 1$ in relation of investment $Inv2$;

E - unit matrix.

Given investment time $T\ (t = 0,1,...,T)$, $T-$natural number; function of investor's winning $K(.)$:

$K(h(T).f(T)) = \{1, h(T) \geq 0, \exists i : f_i(T) \prec 0;$
$\{-1, f(T) \geq 0, \exists i : h_i(T) \prec 0;$
$\{0, in \quad another \quad situations \quad ;$

The sets of values of strategies (U) and (V) players are determined:

$U = [u_1^*,..., u_K^*], u_l^* \in [0,1], l = 1,..., n;$

$V = [v_1^*,..., v_K^*], v_l^* \in [0,1], l = 1,..., n;$

The goal of the first player (further $Inv1$) is to maximize the payoff function, which characterizes the FR that is dynamically planned to invest in the development of SmartCity. The goal of the second player $Inv2$ is to minimize the payoff function. In this statement of the problem $Inv1$, it is interpreted as the representative of the decision maker (RDM1), for example, the representative of an investor who invests a financial resource in part of the common (for both investors) SmartCity development projects. Then player 2 or, $Inv2$ is treated as a representative of another decision maker (DM) 2, investing a financial resource in his part of the common (for both investors) SmartCity development projects.

We will find strategies for rational players and the risks associated with the loss of FR when investing in SmartCity development projects.

4.2. Solution.

Mark T^* by set of $\{0,..., T\}$.

Define pure strategies of players

Pure $Inv\ 1$ called by function $u(.)$: $T^* \times R^n \times R^n \to [u_1^*,...,u_K^*]$; and that $u(t,(h, f)) = u_j^*; in \ \ some \ \ j.$

The pure strategies $Inv2$ – $v(.)$. was defined the same way.

Since there is no such game in the class of pure strategies, a solution will be found in the class of mixed strategies.

Define the mixed strategies of the players.

Denote by the $P[u_1^*,...,u_K^*]$ – the set of probability measures defined by the set $\{u_1^*,...,u_K^*\}$. By $P[v_1^*,..., v_M^*]$ – many probabilistic measures defined in the set $\{v_1^*,...,v_M^*\}$.

Mixed strategies $Inv1$ is called function $\mu(.): T^* \times R^n \times R^n \to P[u_1^*,...,u_K^*]$; that is $\mu(t,(h, f)) = \mu^* \in P[u_1^*,...,u_K^*]$.

Mixed strategy is defined the same way $Inv2$ – $\sigma(.)$.

Since the game under consideration is a matrix, the players have optimal mixed strategies $\{\mu^*(.,.), \sigma^*(.,.)\}$.

To find the optimal mixed strategies, one can use the linear programming apparatus, taking into account the possibility of reducing the finding of optimal mixed strategies and the value of the matrix game to the linear programming problem.

You can find losses or gains (these are losses with a minus sign) by considering the difference $h(T) - h(0)$.

From (1), (2) we can determine the profit of the first investor:

$$\sum_{i=1}^{n}\{(A_1)^{ii} \times U^{ii}(t) \times \sum_{j=1}^{n}(B_1^{ij}) \times h_j^+(t) - (A_2)^{ii} \times V^{ii}(t) \times \sum_{j=1}^{n}(B_2^{ij} \times f_j^+(t)\}; \ (*)$$

Now you can evaluate the financial indicators taking into account risks.

Average profit will be determined as the integral of profit (*) for optimal mixed strategies and written as follows R_{mid}.

Average losses will be determined as the integral of the «component sum of the vector difference» $h(T) - h(0)$ over the optimal mixed strategies and written as:. U_{mid}.

Capital (financial resources) $Inv1$ taking into account risks (losses) will be determined as the integral of the "component sum of the vector" $h(T)$ according to the optimal mixed strategies and written as $C(R)$.

In areas related to investing, in particular, with the multi-project objectives of the development of SmartCity, the risk assessment of the loss of financial resources is carried out using appropriate indicators. We will present them and apply these indicators to assess risks in our task.

RORAC (profit divided by capital, taking into account risks; or more correctly, the average profit divided by capital, taking into account risks) will be defined as: $R_{mid}/C(R)$.

RAROC (average risk-adjusted return divided by capital) will be determined as follows:

$$\left\{ (R_{mid} + U_{mid}) / h_1(0) \right\}.$$

RARORAC (average risk-adjusted return divided by risk-adjusted capital) will be determined as follows:

$$\left\{ (R_{mid} + U_{mid}) / C(R) \right\}.$$

It remains to determine - VAR capital, i.e. risk capital. In other words, this is a financial resource value that allows a player with a high degree of probability to cover possible losses, for example, during the dynamic planning and implementation of SmartCity development plans ([2], [4], [6], [20], [23]). It is written like this.

$$\forall \varepsilon: 0 \prec \varepsilon \prec 1 \exists VAR(\varepsilon) \geq 0:$$
$$P(\omega: \xi(\omega) \prec - VAR(\varepsilon)) \prec \varepsilon,$$

where $\xi(\omega)$ - random amount of losses.

Here is a frequently used calculation of this quantity.

Find the standard deviation (the square root of the variance) of a random variable characterizing the losses. Denote it SU

Consider the difference $U_{mid} - SU$

Various cases are possible.

1) $U_{mid} \leq 0$, then $VAR = |U_{mid}| + SU$.

2) $U_{mid} \geq 0$, $U_{mid} - SU < 0$, then $VAR = SU$.

3) $U_{mid} \geq 0$, $U_{mid} - SU \geq 0$, then $VAR = 0$.

Absolutely symmetrically, these indicators are considered for another investor. Consideration of these indicators for optimal mixed strategies is optional. Instead of optimal mixed strategies, you can use any mixed strategies and, in the same way, define these indicators. Quite widespread [6], [23] is the choice of mixed strategies defined by normal distributions. This circumstance is explained, according to financial analysts, with many years of accumulated statistics.

It should be noted that in fact, standard evasion does not allow one hundred percent opportunity to cover possible losses. There are cases when a fourfold value of the standard deviation does not make it possible to cover losses with one hundred percent probability (probability 1). In the banking sector, $|U_{mid}|$ the value determines the amount of reserves for active operations, and the value SU determines the economic capital of the bank, essentially this is the theoretical value of the capital that you need to have in order to cover possible losses with a high degree of probability.

5. COMPUTATIONAL EXPERIMENTS

5.1. Calculation 1.

We will carry out a computational experiment for the case when the financial flows generated by investors are one-dimensional. This circumstance means that $n = 1$ the matrices that determine the dynamics are numbers. We assume that $B_1 = B_2 = A_1 = A_2 = R_1 = R_2 = 1$.

Then the equations that determine the movement of cash flows will be written as follows:

$$h(t+1) = h^+(t) + u(t) \cdot h^+(t) - v(t) \cdot f^+(t);$$

$$f(t+1) = f^+(t) + v(t) \cdot f^+(t) - u(t) \cdot h^+(t);$$

$h(t) \in R$, $f(t) \in R$, $u(t), v(t)$ – real numbers,

$u(t), v(t) \in [u_1^*, ..., u_2^*] \times [v_1^*, ..., v_2^*]$,

$u_l^* \in [0,1], l = 1,2;$ $v_l^* \in [0,1], l = 1,2;$

We believe that investors take one step. The first investor ($Inv\ 1$) начинает begins investing, having financial resources $h(0) = 0,6056$; $Inv\ 2$ the investment process begins with financial resources $f(0) = 0,3944$. The first player uses a mixed strategy $\sigma(.) = (0.5;0.5)$, which selects $u_1^* = 0$, $u_2^* = 0{,}0826$ with a probability of (0,5) each value. The second player uses a mixed strategy $\mu(.) = (0.5;0.5)$, which selects $v_1^* = 0, v_2^* = 1$ with probability (0,5) each value.

We present the values of the risk assessment indicators for $Inv2$.

RORAC = - 0,2041;
RAROC = - 0,4082;
RARORAC = - 0,061.

It remains to determine - VAR capital, i.e. risk capital.

VAR = 0,9295

The resulting risk assessments are due to the fact that the initial financial resources of investors are in the area of preference $Inv1$ [6], and therefore, there are controlling influences that allow him $Inv1$ to improve his financial situation. This leads to negative outlooks $Inv2$ in the context of risks. Essentially, negative risk forecasts are due to the fact that the initial states of the players belong to the set of preferences of another investor.

Calculation 2.

Consider the case when the cash flow generated $Inv1$ is one-dimensional and the cash flow generated $Inv2$ is two-dimensional. Let in equations (1), (2):

$$B_1 = A_1 = R_1 = 1; B_2 = \begin{pmatrix} 1 & 2 \\ 0 & 3 \end{pmatrix}; A_2 = \begin{pmatrix} 2 & 0 \\ 0 & 1 \end{pmatrix}; R_2 = \begin{pmatrix} 0.5 & 0 \\ 0 & 1 \end{pmatrix};$$

$$u(t) \in [0,1]; V(t) = \begin{pmatrix} v_1(t) & 0 \\ 0 & v_2(t) \end{pmatrix}; v_i(t) \in [0,1];$$

$$i = 1,2.$$

Players take one step. Financial condition $Inv1$ $h(0) = 150$. The financial condition $Inv2$ is, $f_1(0) = 45$ and $f_2\ 0) = 65$

The first player uses a mixed strategy $\sigma(.) = (0.3;0.7)$, which selects the specified values with probability $u_1^* = 0.2$, $u_2^* = 0{,}09$ (0.3), (0.7). The second player uses a mixed strategy $\mu(.) = (0.1;0.9)$, which selects these values $v_1^* = 0{,}5; v_2^* = 1$ with probability (0,1), (0,9). In addition, it is assumed that he "directs" half of his investments into the financial stream characterized by the first component $Inv1$, and the other half directs into the financial stream characterized by the second component $Inv1$.

We present the values of the risk assessment indicators for $Inv2$.

RORAC = - 0,1054;
RAROC = - 0,3421;
RARORAC = - 0,3057.

It remains to determine - VAR capital, i.e. risk capital.

VAR = 849.295 (million conventional units)

Negative risk forecasts are caused by the fact that the initial states of the players belong to their set of preferences $Inv2$ [6] by another investor.

Many unfavorable forecasts of potential risks $Inv2$ are shown in Fig. 1.

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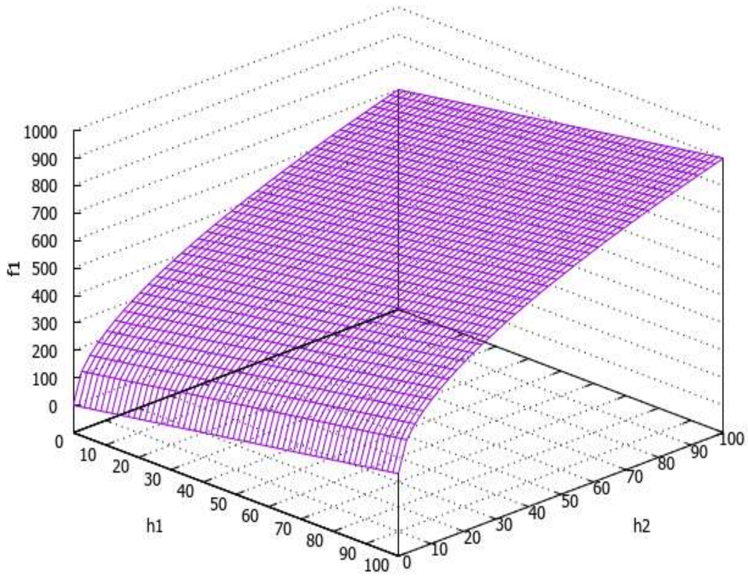

Figure 1: Many unfavorable prognosis of potential $Inv2$ *risks*

Calculation 3.

As in calculation 2, we believe that the financial flow generated $Inv1$ is one-dimensional, and the financial flow generated $Inv2$ is two-dimensional. Let in equations (1), (2):

$$B_1 = A_1 = R_1 = 3;\ B_2 = \begin{pmatrix} 2 & 1 \\ 0 & 0.25 \end{pmatrix};$$

$$A_2 = \begin{pmatrix} 1 & 0 \\ 0 & 2 \end{pmatrix};\ R_2 = \begin{pmatrix} 0.5 & 0 \\ 0 & 2 \end{pmatrix};$$

$$u(t) \in [0,1];\ V(t) = \begin{pmatrix} v_1(t) & 0 \\ 0 & v_2(t) \end{pmatrix};$$

$$v_i(t) \in [0,1];$$

$$i = 1,2.$$

Players take one step. Financial condition $Inv1$ $h(0) = 75$. The financial condition $Inv2$ is $f_1\ (0) = 15, f_2\ 0) = 35$

The first player applies a mixed strategy $\sigma(.) = (0.2;0.8)$, which selects the indicated values $u_1^* = 0.4,\quad u_2^* = 0{,}1$ with probability (0.2), (0.8). The second player uses a mixed strategy $\mu(.) = (0.6;0.4)$, that selects $v_1^* = 0{,}3; v_2^* = 1$ with probability (0.6), (0.4) these values. In addition, it is assumed that he "directs" half of his investments into the financial stream characterized by the first component $Inv1$, and the other half directs into the financial stream characterized by the second component $Inv1$.

We present the values of the risk assessment indicators for $Inv2$.

RORAC = - 0,4042;
RAROC = - 0,6431;
RARORAC = - 06757.

It remains to determine - VAR capital, i.e. risk capital.

VAR = 247,386

Negative risk forecasts are caused by the fact that the initial states of the players belong to their set of preferences $Inv2$ [6] by another investor.

Many unfavorable forecasts of potential risks $Inv2$ are shown in Fig. 2

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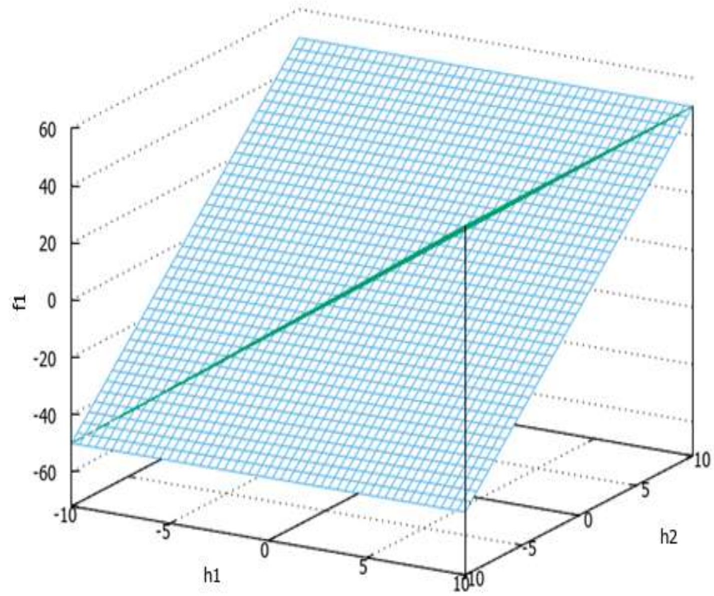

Figure 2: Many unfavorable prognosis of potential $Inv2$ risks.

After testing the mathematical model using the Maple package, the model was implemented in the DSS module to assess the risk of investment loss during the dynamic planning of SmartCity development, see Fig. 3. In Fig. 3 shows the DSS interface, which shows the main results of solving the problem of assessing the risk of investment loss during the development of SmartCity for situation 1. As you can see on the graph in DSS, the solution obtained almost coincides with the solution obtained in Maple.

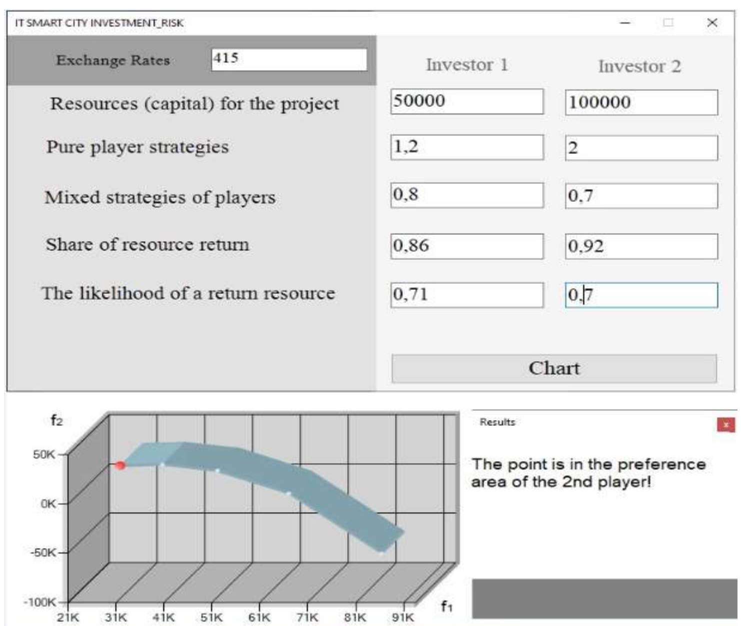

Figure 3: General view of the DSS module for assessing the risks of investment loss during the development of SmartCity

A more convenient and user-friendly DSS interface will allow solving practical problems of assessing the risks of investment loss during the DP of SmartCity development much more efficiently than in the case of using special mathematical packages such as Maple, MathCad or MatLab. And the use of DSS does not require special skills and long training.

6. DISCUSSION OF COMPUTATIONAL EXPERIMENTS'S RESULTS

Fig. 1 shows the surface, which is the boundary of the region of unfavorable prognosis for. This area is located below this surface. It should be noted that the closer the initial financial resources of both investors are located to this border, the more forecasts in the context of risk indicators will be favorable.

Fig. 2 shows the surface, which, as in Fig. 1, is the boundary of the unfavorable forecast region for. This area is located below this surface. As before, we note that the "closer" the initial financial resources of both investors are located to this border, the more forecasts in the context of risk indicators for the second investor will be favorable. We note the fact that the region of the unfavorable forecast for is the region of the favorable forecast for.

7. CONCLUSIONS

A model is suggested for the computing core of a decision support system (DSS) in assessing the risks of investment loss during the dynamic planning of SmartCity development. Unlike existing solutions, the proposed model gives specific recommendations when assessing the risks of investment loss during the dynamic planning of SmartCity development, using the mathematical apparatus of multi-step degree games and quality games with several terminal surfaces. If the risk forecast is unsatisfactory, flexible adjustment of the investment process parameters is possible in order to achieve an acceptable financial result for the parties.

The scientific novelty of the results obtained in the article is that for the first time it is proposed to apply a new class of bilinear multi-step games. This class allowed us to adequately describe the process of assessing the risks of investment loss, using the example of dynamic planning for the placement of players' financial resources in SmartCity projects. A distinctive feature of the considered approach is the use of tools based on solving a bilinear multi-step game, both of quality with several terminal surfaces, and of a degree game, solved in the class of mixed strategies. Computational experiments were carried out using the Maple mathematical modeling package.

The practical significance of the results lies in the fact that the DSS is developed. DSS implements a risk assessment model based on the application of methods of the theory of multi-step games. The developed DSS allows to reduce discrepancies in data on forecasting risks of investment loss during the dynamic planning of SmartCity development and real return on investment.

REFERENCES:

[1] V. Albino, U. Berardi, R. M. Dangelico. "Smart cities: Definitions, dimensions, performance, and initiatives," *Journal of Urban Technology*, 22(1), pp. 3–21, 2015.
[2] M. Angelidou. "Smart cities: A conjuncture of four forces," *Cities,* 47, pp. 95–106, 2015.
[3] V.A. Lakhno, D.Y. Kasatkin, T.S. Kartbayev, K.O. Togzhanova, Zh.K. Alimseitova, B.B. Tussupova. "Analysis of Methods and Information Technologies for Dynamic Planning of Smart City Development," *International Journal of Advanced Trends in Computer Science and Engineering,* Volume 9, No.5. pp. 7496, 2020.
[4] B. Akhmetov, L. Balgabayeva, V. Lakhno, V. Malyukov, R. Alenova, A. Tashimova. "Mobile platform for decision support system during mutual continuous investment in technology for smart city," *Studies in Systems, Decision and Control*, 199, pp. 731–742, 2019.
[5] J. M. Schleicher, M. Vögler, C. Inzinger, S. Fritz, M. Ziegler, T. Kaufmann, S. Dustdar. "A holistic, interdisciplinary decision support system for sustainable smart city design," *In International Conference on Smart Cities*, pp. 1–10, 2016.
[6] B. Akhmetov, V. Lakhno, V. Malyukov, S. Sarsimbayeva, M. Zhumadilova, T. Kartbayev. "Decision support system about investments in Smart City in conditions of incomplete information," *International Journal of Civil Engineering & Technology (IJCIET),* 10(2), pp. 661–670, 2019.
[7] S. Paroutis, M. Bennett, L. Heracleous. "A strategic view on smart city technology: The case of IBM Smarter Cities during a recession," *Technological Forecasting and Social Change*, 89, pp. 262–272, 2014.
[8] Z. Irani, A. Sharif, M. M. Kamal, P. E. Love. "Visualising a knowledge mapping of information systems investment evaluation,"

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Expert Systems with Applications, 41(1), pp. 105–125, 2014.

[9] S. H. Lee, T. Yigitcanlar, J. H. Han, Y. T. Leem. "Ubiquitous urban infrastructure: Infrastructure planning and development in Korea," *Innovation*, 10(2-3), pp. 282-292, 2008.

[10] S. Malekpour, R. R. Brown, F. J. de Haan. "Strategic planning of urban infrastructure for environmental sustainability: Understanding the past to intervene for the future," *Cities*, 46, pp. 67–75, 2015.

[11] M. Hastak, E. J. Baim. "Risk factors affecting management and maintenance cost of urban infrastructure," *Journal of Infrastructure Systems*, 7(2), pp. 67–76, 2001.

[12] Y. Jabareen. "Planning the resilient city: Concepts and strategies for coping with climate change and environmental risk," *Cities*, 31, pp. 220–229, 2013.

[13] G. L. Clark, J. Evans. "The private provision of urban infrastructure: financial intermediation through long-term contracts," *Urban Studies*, 35(2), pp. 301–319, 1998.

[14] K. Wellman, M. Spiller. "Urban infrastructure: finance and management," *John Wiley & Sons*, (2012).

[15] W. F. Fox. "Strategic options for urban infrastructure management," *The World Bank,* 1994.

[16] B. Flyvbjerg. "Cost overruns and demand shortfalls in urban rail and other infrastructure, Transportation Planning and Technology," 30(1), pp. 9–30, 2007.

[17] H. Elsawah, I. Bakry, O. Moselhi. "Decision support model for integrated risk assessment and prioritization of intervention plans of municipal infrastructure," *Journal of Pipeline Systems Engineering and Practice,* 7(4), 04016010, 2016.

[18] G. Yohe. "Risk assessment and risk management for infrastructure planning and investment," *Bridge*, 40(3), pp. 14–21, 2010.

[19] F. H. Knight. "Risk, uncertainty and profit." *Courier Corporation*. 2012.

[20] R. N. Langlois, M. M. Cosgel. "Frank Knight on risk, uncertainty, and the firm: a new interpretation," *Economic inquiry*, 31(3), pp. 456–465, 1993.

[21] P. Duenas, J. Reneses, J. Barquin. "Dealing with multi-factor uncertainty in electricity markets by combining Monte Carlo simulation with spatial interpolation techniques," *IET generation, transmission & distribution,* 5(3), pp. 323–331, 2011.

[22] I. Millet, W. C. Wedley. "Modelling risk and uncertainty with the analytic hierarchy process," *Journal of Multi-Criteria Decision Analysis*, 11(2), pp. 97–107, 2002.

[23] B. B. Akhmetov, V. A. Lakhno, B. S. Akhmetov, V. P. Malyukov. "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, pp. 6–14, 2018.

[24] V. Lakhno, V. Malyukov, N. Gerasymchuk, I. Shtuler. "Development of the decision making support system to control a procedure of financial investment," *Eastern-European Journal of Enterprise Technologies*, 6(3), pp. 35–41, 2017.

[25] D.B. Issaikin, K.T. Sauanova, M.D. Misiura, V. Matiievskyi, R.T. Brzhanov. "Development of methods for changing the resolution of images obtained from smart city CCTV cameras based on algebraic characteristics," *Journal of Theoretical and Applied Information Technology*, Vol. 99, N. 6, pp 1373 – 1385, 2021.