The analysis of the optimum equilibrium to a game and theory model of hierarchic game under conditions of a mixed joint project management *

Liubava Chernova [1,†], Sergiy Titov [1,* †], Serhii Chernov[1,†], Lyudmila Chernova[1,†] and Nataliia Kunanets[2,3†]

[1] *Admiral Makarov National University of Shipbuilding, Heroes of Stalingrad, 9, Mykolaiv, 54025, Ukraine*
[2] *Lviv Polytechnic National University, Bandery, 12, Lviv, 79013, Ukraine*
[3]*Lviv National University named after I.Franko Universitetska, 1, 79000, Lviv, Ukraine*

Abstract

The article provides an analysis of the optimum equilibrium to a game and theory model of hierarchic game under conditions of a mixed joint project management. The authors considered a situation providing for a project being managed both by the head organization and by several contractor companies. They proposed a mathematic model enabling determination of the optimum strategies of each party and finding the Nash equilibrium in the game. The analysis results can be useful for efficient management of joint projects under conditions of competition and cooperation between contractors and the head organization.
The paper shows an approach to analysis and synthesis of management in matrix structures of the project management based on the game and theory modeling in hierarchic game systems.

Keywords

IT project, Agile management methodology, management of organizational processes, evolutionary modeling, management efficiency, theory model, hierarchic game

1. Introduction

Modern projects become more and more complicated and have many components depending on several participants. Under such conditions, it is important to have efficient models of management taking account of the hierarchic structure and interaction between different participants. The project management under modern conditions includes elements of competition between various contractors or partners. The use of the method of optimum equilibrium of a game and theory model of hierarchic game under conditions of a

Proceedings of the 5th International Workshop IT Project Management (ITPM 2024), May 22, 2024, Bratislava, Slovak Republic
* Corresponding author.
† These authors contributed equally.
19chls92@gmail.com (L. Chernova); ss1-ss10@rambler.ru (S. Titov); 19chsk56@gmail.com (S. Chernov); lyudmylachernova@gmail.com (L. Chernova); nek.lviv@gmail.com (N. Kunanets)
0000- 0001-7846-9034 (L. Chernova); 0000-0001-8772-9889 (S. Titov); 0000-0002-9069-0409 (S. Chernov); 0000-0002-0666-0742 (L. Chernova); 0000-0003-3007-2462 (N. Kunanets)

mixed joint project management enables successful implementation of complicated projects based on joint initiatives.

2. State of the research problem

Creation of a team became the basic method of combining resources and experience for attaining a particular purpose with distribution of risks and win at the same time. The team management is important for a proper and efficient settlement and management of conflicts. The advantages and success in conflicts settlement enables enlarging the project scale [1]. Failure of a joint project has a negative impact both upon the parties involved and upon its implementation success [2]. The article [3] describes an approach to solving a planning optimization problem subject to resources coordination and with account taken of integration and cooperation difficulties [4]. In the opinion of researchers [5], the hybrid project management is an approach combining conventional and flexible project management methods to utilize the merits of each approach and to avoid demerits at the same time. The authors also analyzed the strong and weak sides of the hybrid approach in general. The paper [6] confirms the reasonability of using the project, program and portfolio management methodology for solving the problem of developing the integrated organization management strategy. It proposes a model of managing a system of equipment based on information technologies with account taken of application of the project and portfolio management methodology. The work [7] presents approaches to evaluating success of a project based on a multi-criterial analysis and integrated approach to fuzzy situational management with production rules [8]. The research proposed approaches to evaluating the energy potential of the organization in which the project is implemented, the authors provided a conceptual approach to assessing the organization condition [9, 10] The scientists presented a game and theory tree of useful programs for taking decisions in competitive scenarios [11], they showed an example of a real-time strategic game [12]. The article proves that hierarchic game modeling contributes to using the most modern approach to joint decision taking and information forecasting among the agents [13-19].

The understanding of the optimum strategies and the equilibrium between the project participants helps to efficiently implement them and ensures competitive advantages. Using the method of game and theory model analysis enables determining the optimum solutions for project managers and companies participating in joint projects. This facilitates avoiding conflicts and safeguards the optimum usage of project resources.

3. Mixed joint project management

The mixed joint project management is an approach including combined elements of various methodologies and approaches to project management aimed at optimization of results and assurance of a successful project result. This approach is distinguished with its flexibility and adaptiveness to enable using various methods and approaches depending on certain project needs and conditions. Particularly, it enables the project teams to be more flexible and adaptive to changes that may happen throughout the project period. Mixed management allows using the best practices from various methodologies, such as Agile, Waterfall, Lean, etc., for attaining the optimum results. A mixed management enables balancing the requirements to the product development period and its quality, budget and risks, which assures successful project implementation with minimum expenses and risks. Using various methods and approaches can contribute to increase of the project efficiency providing more exact reflection of the client needs and better utilization of resources. It also facilitates development of the cooperation and communication culture in the team. The teams learn to interact and to share their knowledge and experience, which helps increasing the efficiency of work. The main objective of the mixed management consists in achieving successful project results by means of combining various methods and approaches corresponding to the project conditions and needs in the best way. Taken in general, mixed management of a joint project permits the teams to be more flexible, adaptive and efficient in project management ensuring the attainment of results desired.

The analysis of the optimum equilibrium of a game and theory model to hierarchic game can take the key part in a mixed management of joint project, to ensure the following:

Determination of strategies. The analysis of the game model enables identifying the optimum strategies for each project participant under conditions of competition or cooperation. This can be useful for development of action plans and decision taking aimed at achieving the planned results.

Assessment of risks. The game equilibrium analysis helps assessing possible risks and consequences of various strategies for all project participants. This allows avoiding unexpected problems and solving conflicts before their escalation.

Optimization of resources. The game model analysis helps determining the optimum distribution of resources among the project participants with account taken of their own objectives and restrictions. This helps utilizing the resources efficiently and maximizing the total profit from the project.

Planning and decision taking. Based on the optimum game equilibrium analysis, it is possible to develop planning and decision-taking strategies facilitating the attainment of the harmony and joint purposes of the project.

Management of conflicts. The game model analysis allows identifying possible sources of conflicts and developing strategies of their management. This can include a search for compromise solutions or development of conflicts solving mechanisms. Therefore, the analysis of the optimum equilibrium to a hierarchic game theory and game model is an important tool for efficient management of a joint project, which enables avoiding conflicts, optimizing utilization of resources and attaining the joint objectives.

For analyzing the optimum equilibrium to a game and theory model of a hierarchic game under conditions of a mixed management of a joint project, the following algorithm is to be carried out:

Step 1. Determining the participants. First, all the project participants having effect upon its results are to be identified. These can be various contractors, partners, clients and other parties.

Step 2. Determining the strategies. Possible project management strategies are to be determined for each participant. These can be such solutions as assumption of risk, fulfilment of tasks within a prescribed period, negotiations with other participants, etc.

Step 3. Construction of a game and theory model. Based on determined participants and their possible strategies, a game and theory model is developed to reflect interaction between the participants and their possible action variants.

Step 4. Equilibrium analysis. Various methods are used for analyzing the game theory for determining the optimum equilibrium between the participants. These can be Nash analysis, a decision based on dominating strategies or other methods.

Step 5. Assessment of results. As soon as the equilibrium is found, its effect on the project results is to be assessed. Such factors are to be taken into account as the resources utilization efficiency, risks minimization and participants' needs satisfaction.

Step 6. Solution of the optimum strategy: Based on the analysis results, the optimum project management strategy is to be chosen for each participant with the aim at attaining the best results for all parties.

It is reasonable to use this algorithm for analyzing the optimum equilibrium to a game and theory model of hierarchic game under conditions of a mixed joint project management and selection of strategies to the best satisfaction of the needs of all participants.

4. The problem of mixed management of centers above the game participants

Let us consider a problem of mixed management by project managers of the actions of team members presented from the game and theory side. We might have a two-level system U, which consists on the top hierarchic level of n project managers C_1, C_2, ..., C_n, whose actions are aimed at the controlled objects, team members having different functions, A_j, $j = 1, \ldots, m$. A hierarchic game contains two types of participants to this game, project managers C_i and executing team members A_j, $U = G = \{ C_1, C_2, \ldots, C_n, A_1, A_2, \ldots, A_m \}$. (Fig. 1)

In multilevel systems, one and the same player can be the project manager and an executive at the same time, i.e. it can fulfil instructions of the game participants occupying higher hierarchic levels. Depending on their behavior strategies selected, game participants can be characterized by the level of activity having effect on the position and behavior strategy selection of all hierarchic system participants. Participants' behavior strategies are represented on the set of their positions by target functions putting their wins in correspondence with strategy vectors.

At the same time, the system participants' behavior strategies are subordinated to the behavior reasonability, in other terms – to their target function maximization. This approach separates the subset of priority actions from the set of all possible actions. In the system equilibrium concept selected, the game participants, while acting without cooperation, i.e. selecting their optimum behavior strategies without cooperation with other players, have to move to the Nash equilibrium point.

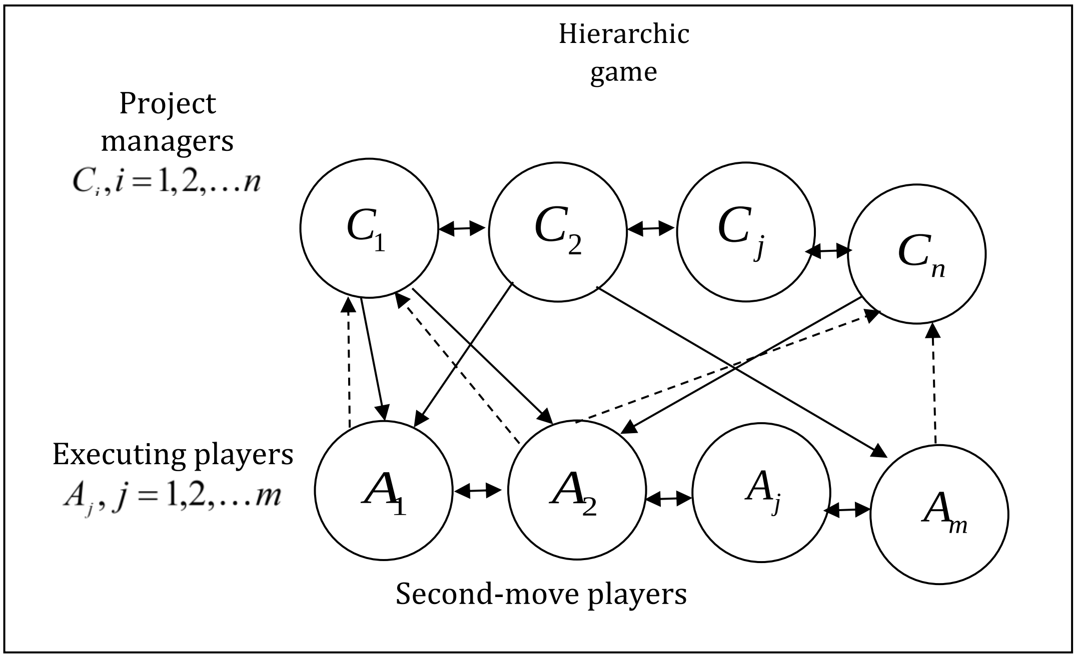

Figure 1: A game and theory model of hierarchic game

Follows:

$$X_{C_1} == \left\{ x^{C_1}_1, x^{C_1}_2, \ldots, x^{C_1}_l \right\},$$

$$X_{A_1} == \left\{ x^{A_1}_1, x^{A_1}_2, \ldots, x^{A_1}_m \right\}.$$

Let the total set of selected strategies be equal to:

$$x == \left\{ x^{C_1}_l, x^{A_1}_m \right\} = \left\{ x_1, x_2 \right\}.$$

For each of the participants of base system G_1, the following target functions are ascertained:

$$\mathrm{W}_{C_1} == \mathrm{W}_{C_1}\left(x^{C_1}_l, x^{A_1}_m \right)$$ - target function of project manager C_1,

$$\mathrm{W}_{A_1} == \mathrm{W}_{A_1}\left(x^{C_1}_l, x^{A_1}_m \right)$$ - target function of player A_1.

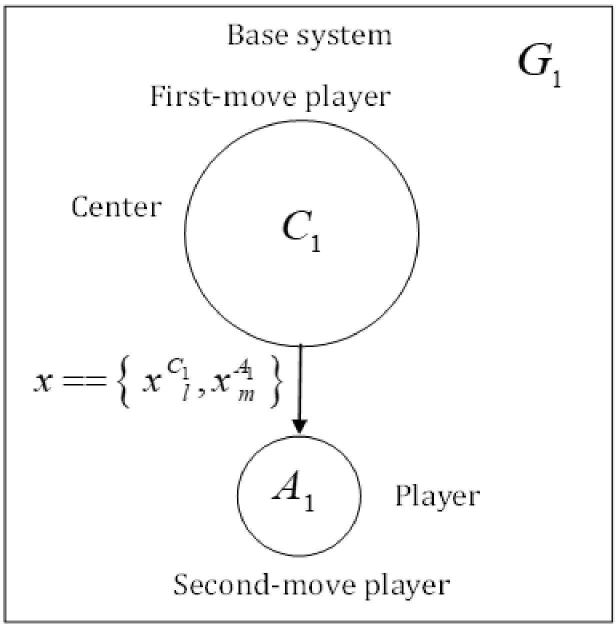

Figure 2: Base linear model

The two-level linear system G_1 is the base model of the hierarchic game theory. (Fig. 2) It consists of one project manager C_1 as a managing body on the top hierarchic level, and one executive A_1 - on the bottom level. We interpret our first base game and theory model G_1 as a normal game $U = \{ C_1, A_1 \} \equiv G_1$, in which two players C_1 and A_1 are participating. For each participant of game G_1, sets of all possible behavior strategies are determined as

A certain real number being the player's win is put by target functions in correspondence with each solution vector $\{ x_1, x_2 \}$.

The full normal form of hierarchic game G_1, which models this simplest linear system, contains the following set: players, strategies and target functions

$$G_1 == \{ C_1, A_1, X_{C_1}, X_{A_1}, W_{C_1}, W_{A_1} \}.$$

In hierarchic game G_1, strategy $x^{C_1}_l$ is chosen by project manager C_1 first, and only after that, subject to the project manager selected already known, the second player – member of team A_1 selects its strategy $x^{A_1}_m$.

The target function of center $W_{C_1} == W_{C_1}\left(x^{C_1}_l, x^{A_1}_m \right)$ depends on both the selected own strategy $x^{C_1}_i \in X_{C_1} == \{ x^{C_1}_1, x^{C_1}_2, \ldots, x^{C_1}_l \}$ and the strategy of player A_1 $x^{A_1}_j \in X_{A_1} == \{ x^{A_1}_1, x^{A_1}_2, \ldots, x^{A_1}_m \}$. The value of the win of executive A_1 is defined by its target function $W_{A_1} == W_{A_1}\left(x^{C_1}_{l}, x^{A_1}_{m}\right)$, which depends on the same variables in the same way. In view of this, we have a hierarchic game of two players in normal form. Should there be no additional conditions of selecting the strategies, the game is to be solved by selecting a Nash equilibrium.

If it is supposed that the project manager selected a management strategy and let it know to executive A_1, the respective hierarchic game is called game G_1. Let us consider possible behavior of the second player subject to the first player's strategy being known.

The set of actions, on which the executive's target function maximum is acquired with the fixed selection of center, is defined under the formula:

$$W_{A_1} == \arg\max W_{A_1}\left(x^{A_1}_{j} \in \left\{x^{C_1}_{l}, x^{A_1}_{m}\right\}\right).$$

The set of solutions to game G_1 depends on strategy $X_{C_1} == \left\{ x^{C_1}_{1}, x^{C_1}_{2}, \ldots, x^{C_1}_{l} \right\}$ of the center's behavior. If center C_1 and executive A_1 are aware of the supposed sets and target functions, the center can forecast the reaction of player A_1 upon its action. Having the possibility to use its own target function $W_{C_1} == W_{C_1}\left(x^{C_1}_{l}, x^{A_1}_{m}\right)$, the center can confidently forecast the behavior of player A_1 from the supposed set of its strategies $X_{A_1} == \left\{ x^{A_1}_{1}, x^{A_1}_{2}, \ldots, x^{A_1}_{m} \right\}$. In the vast majority of cases, there are several variants of such behavior strategies of the second player. Therefore, canonical assumptions of the decision-taking theory are to be introduced into consideration. These assumptions consist in optimistic and pessimistic criteria.

Let us consider the optimistic criterion in the beginning. In this case, the second player A_1 will have a positive attitude to managing center C_1 in game G_1. Accordingly, the second player A_1 will select such actions within the set of supposed actions that maximize the target function of the project manager. At the same time, the project manager will also maximize the target function as a reasonable player. Therefore, the optimum management in game G_1 will consist in such a project manager strategy that implements the maximum on the set of supposed actions of such a function, which the values of maximums on the set of supposed actions of the second player (the managed object) have been applied to. For the optimistic criterion, we'll have the following solution:

$$x^{C_1}_{i} \in \arg\max_{x \in X_{C_1}} \max_{x \in X_{A_1}} W_{C_1}\left(x^{A_1}_{j} \in \left\{x^{C_1}_{l}, x^{A_1}_{m}\right\}\right).$$

Taking the pessimistic criterion into consideration, it's not difficult to obtain the maximin concept with respective solution as given below:

$$x^{C_1}_{i} \in \arg\max_{x \in X_{C_1}} \min_{x \in X_{A_1}} W_{C_1}\left(x^{A_1}_{j} \in \left\{x^{C_1}_{l}, x^{A_1}_{m}\right\}\right)$$

The base hierarchic game G_1 can be considered under decision-taking criteria with two solutions. The first is optimistic: $\arg\max_{x \in X_{C_1}} \max_{x \in X_{A_1}} W_{C_1}\left(x_j^{A_1} \in \left\{x_l^{C_1}, x_m^{A_1}\right\}\right)$, and the second: $\arg\max_{x \in X_{C_1}} \min_{x \in X_{A_1}} W_{C_1}\left(x_j^{A_1} \in \left\{x_l^{C_1}, x_m^{A_1}\right\}\right)$ is the maximum guaranteed win of the project manager.

The game and theory modeling, subject to the project manager having selected its own strategy depending on the strategy selected by A_1 team member, will be provided by the second base game G_2. (Fig. 3)

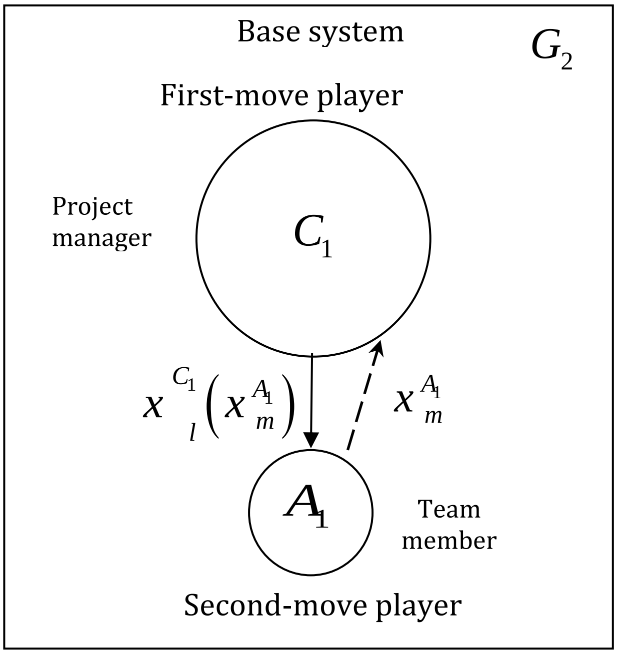

Figure 3: Base linear model G_2

The set of project manager's strategies will already be a function of the second player's strategies

$$x == \left\{ x_l^{C_1}\left(x_m^{A_1}\right), x_m^{A_1} \right\} = \left\{ x_1\left(x_2\right), x_2 \right\}.$$

Analyzing game G_2 by complete analogy with game G_1, we obtain two possible solutions:

$$x_i^{C_1} \in \arg\max_{x \in X_{C_1}} \max_{x \in X_{A_1}} W_{C_1}\left(x == \left\{x_l^{C_1}\left(x_m^{A_1}\right), x_m^{A_1}\right\}\right) \text{ та}$$

$$x_i^{C_1} \in \arg\max_{x \in X_{C_1}} \min_{x \in X_{A_1}} W_{C_1}\left(x == \left\{x_l^{C_1}\left(x_m^{A_1}\right), x_m^{A_1}\right\}\right) \text{ де}$$

$$x_j^{A_1} \in \arg\max W_{A_1}\left(\left\{x_l^{C_1}\left(x_m^{A_1}\right), x_m^{A_1}\right\}\right).$$

The solution of this game and theory problem contains such a team member management function that consists of two modes: reward mode and punishment mode. A reward is effected if player executes what is necessary for the project manager. A punishment is applied failing this.

Let our game and theory problem have player C as the project manager and player A as a team member. Let the project manager's strategies set already be a function of the second player's strategies. During the game analysis by complete analogy, we obtained two possible solutions: G1 and G2, where G1 represents the reward mode and G2 - the punishment mode.

Now the solution of this game and theory problem includes such a team member management function that consists of two modes: the reward mode and the punishment mode. This mode is applied depending on whether the team member completes the tasks required for successful project implementation or fails to complete them.

For instance, the reward mode may provide for giving bonuses or remuneration to team members for completing their tasks in good time and quality. The punishment mode may provide for imposing fines or dismissal in case of failing to complete or incorrect completion of the tasks.

Therefore, this instance shows how the game and theory model optimum equilibrium analysis can be applied for developing an efficient management strategy by team members under conditions of a mixed joint project management.

Should the analysis of the optimum equilibrium of the game and theory model to hierarchic game be applied for solving this problem, it can be expected that each player would maximize its win with account taken of the other player's actions and its own possibilities.

For example, if the function of the project manager (player C) consists in ensuring efficient work of the team and fulfilling the project in good time, its strategies can include tasks distribution, works completion control and setting-up reward or punishment mechanisms.

Let us try to consider an example of solution aided by analysis of the optimum equilibrium to the hierarchic game theory and game model:

Let player C (the project manager) in our game have the following strategies: G1 (reward mode) and G2 (punishment mode). Player A (a team member) also has its own strategies relative to the project manager's actions.

Analyzing possible combinations of players' strategies, we can find the optimum equilibrium that maximizes the total win of both the parties. This equilibrium can be achieved by means of agreement upon both players' actions in such a way that nobody can get a bigger win by changing its own strategy.

Therefore, the analysis of the optimum equilibrium to a game and theory model can help finding the optimum strategies of the project management and team's participation, which will ensure successful project implementation under mixed management conditions.

5. Conclusions

The obtained results show that the analysis of the optimum equilibrium to a hierarchic game theory and game model can be an efficient tool for solving problems of joint projects management. Using the game theory in the context of a mixed joint project management enables taking account of the differing interests of various project participants and finding the optimum strategies of cooperation between them.

The considered problem solution examples show that the optimum equilibrium can be achieved by means of agreement upon all project participants' actions, which facilitates successful implementation of the project tasks. The research results can be useful for project managers and team members while taking strategic decisions and setting up efficient management mechanisms under conditions of difficult project environments.

Therefore, the analysis of the optimum equilibrium to a hierarchic game theory and game model under conditions of mixed joint project management can assist in solving complicated tasks of management and contribute to successful projects implementation.

References

[1] S. B. Abd-Karim, M. S. Mohd Danuri, D. Marani, and O. Mohamed, "Managing Conflicts in Joint Venture Projects," International Journal of Property Sciences, vol. 4, pp. 1-15, 2014. DOI: 10.22452/ijps.vol4no1.3.

[2] D. S. Kobylkin and O. B. Zachko, "Structural models of safety-oriented management of infrastructure projects decomposition," in Materials of 2020 IEEE 15th International Scientific and Technical Conference on Computer Sciences and Information Technologies (CSIT 2020), vol. 2, Lviv-Zbarazh, 2020, pp. 131–134.

[3] Z. Wang, Q. Deng, L. Zhang, H. Li, and F. Li, "Joint optimization of integrated mixed maintenance and distributed two-stage hybrid flow-shop production for multi-site maintenance requirements," Expert Systems with Applications, vol. 215, p. 119422, 2023. DOI: 10.1016/j.eswa.2022.119422.

[4] V. Piterska, S. Rudenko, A. Shakhov, "Development of the Method of Forming of the Architecture of the Innovation Program in the System 'University-State-Business'," International Journal of Engineering & Technology (UAE), vol. 7, no. 4.3, pp. 232–239, 2018. DOI: 10.14419/ijet.v7i4.3.19793.

[5] J. Reiff and D. Schlegel, "Hybrid project management – a systematic literature review," 2022. DOI: 10.12821/ijispm100203.

[6] O. Holovin, V. Piterska, A. Shakhov, and O. Sherstiuk, "Project-based Management of the Production Equipment Maintenance and Repair Information System," pp. 76-85.

[7] J. Babayev, M. Vukomanovic, S. Bushuyev, and I. Achkasov, "Managing Projects Portfolio in Complex Environments Based On Fuzzy Situational Networks," pp. 107-116.

[8] S. Bushuyev, N. Bushuyeva, S. Onyshchenko, and A. Bondar, "Enthalpy is a Measure of the Energy Potential of Development Organizations' Projects," pp. 97-106.

[9] C. F. Camerer, T.-H. Ho, and J.-K. Chong, "A Cognitive Hierarchy Model of Games," The Quarterly Journal of Economics, vol. 119, no. 3, pp. 861–898, 2004.

[10] D. S. Kobylkin and O. B. Zachko, "Structural models of safety-oriented management of infrastructure projects decomposition," in Materials of 2020 IEEE 15th International Scientific and Technical Conference on Computer Sciences and Information Technologies (CSIT 2020), vol. 2, Lviv-Zbarazh, 2020, pp. 131–134.
[11] O. Kovalchuk, O. Zachko, D. Kobylkin, and H. Tanaka, "IT development of HR system in the field of human safety," ITPM 2021, pp. 314–323.
[12] U. Faigle and B. Peis, "A Hierarchical Model for Cooperative Games," in Algorithmic Game Theory, B. Monien and UP. Schroeder, Eds. Springer, Berlin, Heidelberg, 2008, vol. 4997, DOI: 10.1007/978-3-540-79309-0_21.
[13] O. Kovalchuk, D. Kobylkin, and O. Zachko, "Digitalization of HR-management processes of project-oriented organizations in the field of safety," ITPM 2022, pp. 183–195.
[14] O. Kovalchuk, O. Zachko, and D. Kobylkin, "Criteria for intellectual forming a project teams in safety oriented system," International Scientific and Technical Conference on Computer Sciences and Information Technologies (CSIT 2022), Lviv, 2022, pp. 430–433.
[15] V. Piterska, A. Shakhov, "Development of the Methodological Proposals for the Use of Innovative Risk-Based Mechanism in Transport System," International Journal of Engineering & Technology (UAE), vol. 7, no. 4.3, pp. 257–261, 2018. DOI: 10.14419/ijet.v7i4.3.20129.
[16] V. Piterska, A. Shakhov, O. Lohinov, L. Lohinova, "The Method of Transfer of Research Project Results of Institution of Higher Education," in 2019 IEEE 14th International Conference on Computer Sciences and Information Technologies (CSIT), 2019, pp. 77-80. DOI: 10.1109/STC-CSIT.2019.8929887.
[17] P. Fedorka, N. Kunanets, S. Chernov, S. Titov, L. Chernova, L. Chernova, E. Trushliakov, "The project of information system for students knowledge evaluation," CEUR Workshop Proceedings, vol. 3453, pp. 117–127, 2023.
[18] N. Kunanets, O. Artemenko, V. Pasichnyk, V. Kut, A. Ivanchov, "Using react and fuzzy expert systems for better travel experience in local route planning," CEUR Workshop Proceedings, vol. 3426, pp. 372–384, 2023.
[19] V. Pasichnyk, N. Kunanets, V. Yunchyk, M. Khomyak, S. Yatsyuk, V. Muliar, A. Fedonuyk, "Model of the recommender system for the selection of electronic learning resources," CEUR Workshop Proceedings, vol. 3426, pp. 344–355, 2023..