UDC 519.86:005.32:65.013
JEL Classification: C31, C57, C71
DOI: 10.15587/2706-5448.2024.310570

Anton Riabenko,
Elina Tereschenko,
Anna Bakurova,
Andrii Pyrozhok,
Olexiy Kuzkin

THE GRAPH THEORETIC FORMULATION OF THE TEAM FORMATION PROBLEM BASED ON THE FACTOR OF COMPETITION

The object of the research is to increase the level of productivity of teamwork due to the effective selection of participants who demonstrate the highest level of productivity in cooperation. The presented research is aimed at the mathematical formalization of the problem of team formation based on the results of a series of competitions using graph-theoretic approaches. Each competition in this series involves teams with the same number of participants. The composition of the team necessarily changes for each subsequent competition. After the competitive series, the obtained information about the teams' composition and their results is evaluated for the success of the interaction of the participants, which can be used in the formation of successful teams. A graph-theoretic formalization of the team formation problem on a complete undirected weighted graph has been developed. The set of vertices of this graph corresponds to the set of potential participants. Each edge is weighted with a number that reflects the quality of the interaction between the two participants. A valid solution is to cover the graph with cliques, the size of which is determined by the number of team members. A mathematical model of a two-criterion problem with MAXSUM and MAXMIN criteria was built, where the first criterion evaluates the overall success of the created teams, the second criterion evaluates the «weakest link», allowing to choose the option that maximizes the minimum edge weights for each clique. A two-criterion objective function defines a Pareto set consisting of all Pareto optima in the set of admissible solutions. The algorithmic problem of finding the complete set of alternatives, which is a subset of the Pareto set of minimum power when the condition of equality of the objective functions for the complete set of alternatives and the Pareto set is fulfilled, is considered. The weight of the edges of the graph is calculated using the scores obtained during the series of competitions. In practice, the research results can be used as a basis for the development of team building techniques.

Keywords: *teamwork, pareto set, multi-criteria objective functions, graph, multi-criteria optimization, competition.*

Received date: 23.06.2024
Accepted date: 28.08.2024
Published date: 30.08.2024

How to cite
Riabenko, A., Tereschenko, E., Bakurova, A., Pyrozhok, A., Kuzkin, O. (2024). The graph theoretic formulation of the team formation problem based on the factor of competition. Technology Audit and Production Reserves, 4 (4 (78)), 25–30. https://doi.org/10.15587/2706-5448.2024.310570

1. Introduction

Increasing the efficiency of work groups and teams is the main task for modern organizations in the conditions of dynamic changes and global challenges of economic development. Currently, the accepted approach is to view teams as complex dynamic systems that exist in a specific context, develop as members interact over time, and evolve and adapt as situational demands unfold [1]. Team members are united by the implementation of joint activities. Team members have common goals, values, complementary skills, take responsibility for final results, are able to perform any intra-group roles. The effectiveness of the team's activity is evaluated by the indicators of achieving the specified result within the specified time, the level of quality of the work performed, the efficiency of the use of resources, the expansion or retention of the «niche» of its activity. The monitoring of the team's competitiveness is based on indicators that are combined into groups of production and economic indicators, indicators of the team's market stability, and indicators of the team's psychological stability. Monitoring of the first two groups of indicators is important for the team to enter the area of successful development. The main characteristic of system monitoring is the schedule of their movement by calendar periods, which allows to record and monitor changes. The periodicity of monitoring is set for each indicator separately from one month to six months depending on the specifics of the team's activities. The indicators of the first two groups are determined by the field of professional activity of the team. Monitoring of the third group of indicators is related to aspects of psychological support in the field of team activity, which allows to significantly increase the effectiveness of the team as a whole. Diagnostic monitoring methods and techniques should ensure:
– objectivity and statistical nature of the information used;
– comparative nature of assessments;

ISSN 2664-9969

– multi-criterion nature of integral assessments;
– minimization of the used criteria;
– use of additional information and organization of selective target studies.

Since the 1980s, the number of studies devoted to the search for methods of increasing the effectiveness of teamwork in various areas of human activity has remained consistently high [1–15]. Research is devoted to teamwork in corporations [2], medicine [3], industry [4, 5], sports [6], creative teams, innovative activities, education [6, 7], agriculture [8]. In [1], a review of 50 years of research devoted to teamwork was carried out. The authors defined the research object «Team» as a dynamic system that evolves and adapts under the influence of the external environment and transforms over time due to the interaction of its members. This makes the formalization of problem statements and descriptions, the selection of quality criteria, as well as the development of evaluation methods and the setting of experiments relevant. Among the indicators that are studied are the indicator of team trust [9], social cohesion [10], motivation, the level of proactive participation in achieving development results, the need for knowledge and technical support to achieve results [2], collective intelligence (CI) [11]. In [9], a retrospective analysis of the conducted experiments on team trust assessment was carried out, the weaknesses and strengths of the applied approaches were identified. According to the authors, the development of an experiment to assess team trust should be based on the multi-level nature of this research object, should reflect the dynamics of the development of trust during the life of the team, and should develop new methods of assessing team trust without interfering in the personal space of team members. The work [5] is devoted to the development of a two-stage decision-making methodology. At the first stage, the task of forming a team with the maximum qualification of employees is solved. The minimization of the total inventory level and the fluctuation of the average idle time of a cell worker are two criteria of the worker allocation problem in the second stage. Work [12] proved that team competitions lead to an increase in the team's work efficiency. The aspect of gamification is indicated as one of the influencing factors on team development in methodical materials [4]. Various approaches to setting up the experiment and mathematical formalizations are used. The authors of the work [13] chose the Disclosure games approach to solve the problem of effective communication in a team through feedback. The non-linear nature of the relationship between task characteristics, team productivity and the skills of its members was studied [14]. The authors chose a rating in the form of a weighted product of the best and worst ratings with certain degree indicators. The paper [15] investigates the modern type of team cooperation in industrial cyber-physical-social systems [11] and proposes an approach based on hidden Markov models, Hidden Markov model (HMM) for creating conditions for cooperation of a team of specialists and agents with the application collective intelligence (CI) indicator.

The analysis of the literature on this topic indicates the relevance of developing methods for effective selection of team members. *The object of research* is to increase the level of productivity of teamwork due to the effective selection of participants who demonstrate the highest level of productivity in cooperation. *The purpose of the presented research* is the mathematical formalization of the problem of team formation based on the results of a series of competitions using graph-theoretic approaches. Each competition in this series involves teams with the same number of participants. The composition of the teams necessarily changes for each subsequent competition. After the competitive series, the obtained information about the team composition and their results is evaluated for the success of the interaction of each pair of participants, which can be used in the formation of target groups.

2. Materials and Methods

Let's build a mathematical model of the formation of the set of teams on a complete undirected graph $G=(V,E)$, $|V|=n, |E|=n(n-1)/2$. Set of vertices $V=\left\{v_i \mid i=\overline{0,n-1}\right\}$ is according to the number to a set of independent participants that must be combined into m teams with a given number of k members in each team. Each edge $e_{ij}\in E$ has a numerical weight w_{ij} that reflects the level of cooperation productivity of two participants v_i and v_j.

An admissible solution of the problem is a disconnected subgraph $x=\left(\tilde{V},\tilde{E}\right),\tilde{V}\subset V,\tilde{E}\subset E$, whose connectivity components are m cliques of dimension k. Each clique represents a group of participants who are united in one team. Number of clicks $m=[n/k]$, where $[n/k]$ – integer part from ratio n/k. Number of vertices $r=\left|V/\tilde{V}\right|=n-[n/k]k$ are according to the number of participants who will not enter any of the teams.

The set of all admissible solutions on the graph $G=(V,E)$ are denoted by $X=X(G)=\{x\}$. The formula:

$$\mathcal{N}\left(m_1,m_2,\ldots,m_n\right)=\frac{n!}{m_1!,m_2!,\ldots,m_n!(1!)^{m_1}(2!)^{m_2}\ldots(n!)^{m_n}}$$

determines number $\mathcal{N}\left(m_1,m_2,\ldots,m_n\right)$ of unordered partitions of the set with cardinality n of the subset among which for each $i=\overline{1,n}$ there are $m_i\geq 0$ with i elements, where $\sum_{i=0}^{n} i m_i = n$ [16]. The formula is used for to find the cardinality of the set of admissible solutions:

$$|X|=\frac{n!}{m!(k!)^m}. \quad (1)$$

The vector objective function:

$$F=\left(F_1,F_2\right), \quad (2)$$

is defined on the set of admissible solutions.

It consists of the criteria:

$$MAXSUM: F_1=\sum\nolimits_{e_{ij}\in\tilde{E}} w_{ij}\rightarrow\max, \quad (3)$$

$$MAXMIN: F_2=\min_{e_{ij}\in\tilde{E}} w_{ij}\rightarrow\max. \quad (4)$$

The first criterion evaluates the overall level of performance of all teams. The second criterion evaluates the «weakest link», allowing to choose the option that maximizes the minimum weights of the edges of the subgraph x.

On the set of admissible solutions, the vector objective function defines Pareto set $\tilde{X}$, consisting of all Pareto optimal solutions. The algorithmic problem of finding a complete set of alternatives X^0 is considered. The complete set of alternatives X^0 is subset of Pareto set with minimal cardinality and the condition of equality $F\left(X^0\right)=F\left(\tilde{X}\right)$ fulfilled [17].

The series will consist of separate competitions, in each of which teams with the same number of participants participate. A mandatory condition is to change the composition of the teams for each subsequent competition.

To calculate edge weight w_{ij}, let's use the formula:

$$w_{ij} = \frac{\tilde{N}_{ij}}{N_{ij}}, \qquad (5)$$

where $\tilde{N}_{ij}$ is the number of team wins in cases where members v_i and v_j participated, N_{ij} is the total number of team where members v_i and v_j participated.

3. Results and Discussion

Three illustrative examples of the application of the mathematical model (2)–(5) are considered below. The first example considers the structure of the set of admissible solutions for given values n та k. In the second example, the issues and features of the practical application of building a series of competitions are considered. In the third illustrative example, the application of the vector objective function (2)–(4) is demonstrated. Pareto set and the set of admissible solutions are obtained by brute force for all admissible solutions.

The first illustrative example demonstrates how teams of $k=2$ members are built for a set of $n=5$ participants. According to model (2)–(4) graph $G=(V,E)$, $|V|=n=5$, $|E|=n(n-1)/2=10$, $V=\{v_i \mid i=\overline{0,4}\}$ is defined. The admissible solution is the disconnected subgraph $x=(\tilde{V},\tilde{E})$, $\tilde{V}\subset V$, $\tilde{E}\subset E$, the connectivity components of which are $m=2$ cliques with cardinality $k=2$, since $m=[n/k]=[5/2]=2$. One vertex does not belong to subgraph x, since $r=n-[n/k]k=1$. According to formula (1) cardinality of the set of admissible solutions is equal to $|X|=5!/2!(2!)^2=15$. The elements of the set of admissible solutions X is presented in Table 1.

Table 2 presents the dependence of the set of admissible solutions' cardinality on n and k in cases of values not exceeding 11. It should be noted that the formulation of the task requires that the composition of the teams necessarily change for each subsequent competition, i. e. the case $n=k$ has no practical application.

Table 1

The elements of the set of admissible solutions X for $n=5$, $k=2$, $m=2$

No. x	The vertexes of clique 1	The vertexes of clique 2	The vertex does not belong to subgraph x
1	0, 1	2, 3	4
2	0, 1	2, 4	3
3	0, 1	3, 4	2
4	0, 2	1, 3	4
5	0, 2	1, 4	3
6	0, 2	3, 4	1
7	0, 3	1, 2	4
8	0, 3	1, 4	2
9	0, 3	2, 4	1
10	0, 4	1, 2	3
11	0, 4	1, 3	2
12	0, 4	2, 3	1
13	1, 2	3, 4	0
14	1, 3	2, 4	0
15	1, 4	2, 3	0

Table 2

The dependence of the cardinality of the set of admissible solutions by n and k

n/k	2	3	4	5	6	7	8	9	10	11
2	1	–	–	–	–	–	–	–	–	–
3	3	1	–	–	–	–	–	–	–	–
4	3	4	1	–	–	–	–	–	–	–
5	15	10	5	1	–	–	–	–	–	–
6	15	10	15	6	1	–	–	–	–	–
7	105	70	35	21	7	1	–	–	–	–
8	105	280	35	56	28	8	1	–	–	–
9	945	280	315	126	84	36	9	1	–	–
10	945	2800	1575	126	210	120	45	10	1	–
11	10395	15400	5775	1386	462	330	165	55	11	1

The second illustrative example is devoted to the practice of building a series of competitions.

First, the theoretical approach is considered, and then the experimental work is presented.

The most probable number of entries of a pair of players to one team in a series of $\aleph$ competitions is estimated theoretically. The most probable number of event occurrences in $\aleph$ independent trials, in each of which the event occurrence probability is equal to p, $q=1-p$, is determined by the formula $\aleph p - q \le k \le \aleph p + p$ [18].

Consider the experiment in which 8 players are divided into two teams of 4 players. The calculation of the probability p that a pair of players will enter the same team in each of the independent trials is determined by the formula $p=|X_6|/|X_8|$, where $|X_8|=8!/2!(4!)^2=35$ – the total number of possible teams of 8 participants with four players according to the formula (1), $|X_6|=6!/(2!)(4!)=15$ – the total number of possible teams of 6 players, where one team combines four players and one team consists of two players according to the formula (1), since one pair is recorded. the probability of a pair of players entering the same team in each of the independent trials is constant and equal to $p=|X_6|/|X_8|=15/35=3/7$. The series of $\aleph=8$ competitions is planned. Then the most probable number of occurrences of pairs of players in one team in a series with $\aleph=8$ competitions is equal to $k=3$ or 4.

Let's build an experiment in which 8 players are divided into two teams of 4 players in series of $\aleph=8$ competitions, so that each pair of players plays for the same team at least twice (Table 3).

Table 3

Distribution of players by 2 teams

No. competition	The composition of the team 1	The composition of the team 2	Winner
1	0, 2, 3, 4	1, 5, 6, 7	team 2
2	0, 2, 3, 6	1, 4, 5, 7	team 2
3	0, 1, 2, 3	4, 5, 6, 7	team 2
4	0, 1, 3, 5	2, 4, 6, 7	team 2
5	0, 2, 6, 7	1, 3, 4, 5	team 1
6	0, 1, 4, 6	2, 3, 5, 7	team 1
7	0, 1, 2, 5	3, 4, 6, 7	team 2
8	0, 4, 5, 7	1, 2, 3, 6	team 2

Players are marked with indexes from 0 to 7 inclusive. The distribution of the number of occurrences is shown in Fig. 1. The maximum number of entries in one team is 5 (for example for a couple (v_0, v_2)), and the average value of the number is 3.43, which corresponds to the theoretical estimates.

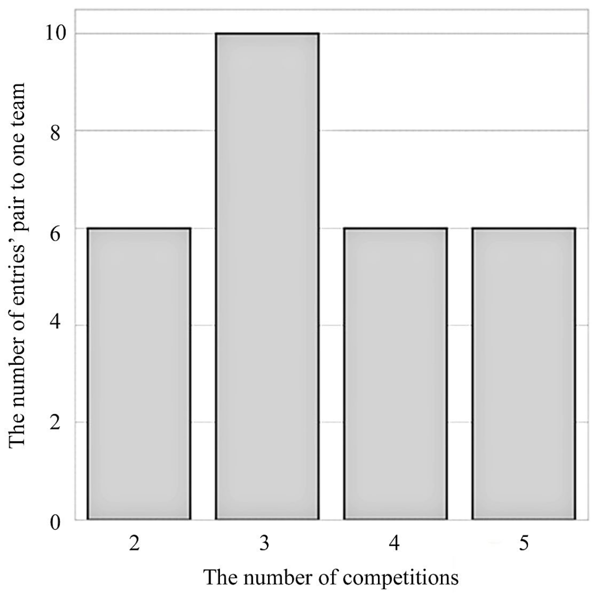

Fig. 1. Distribution of the number of entries of a pair of players to one team depending on the number of competitions

Let's note that it is impossible to distribute players in such a way that each pair is part of the same team exactly twice. The total number of pairs in this example is 28 (a combination of 8 and 2). Taking into account the fact that at least two pairs play for the same team, it is necessary to use 56 pairs. In each competition there are 6 pairs (2 teams of 3 players). The impossibility follows from the fact that 56 is not a multiple of 6. The proposed competition plan is not the only possible one. The total number of team formation options in this example according to formula (1) is equal to $|X| = 8!/2!(4!)^2 = 35$ (Table 2), that is, only 22.8 % of the possible options in our plan are used.

Table 3 presents the composition of the teams in the series of 8 competitions and recorded the winners.

Find the edge weight using the formula (5). A complete list of the values of edge weights in order of decrease and corresponding pairs of participants is given in Table 4. For example, $w_{26} = 0.750$, since pair (v_2, v_6) participants in four competitions (with numbers 2, 4, 5, and 8), of which 3 are victorious for this pair (4, 5, and 8). Also $w_{03} = 0.0$, since pair (v_0, v_3) never participated in the winning team.

The third illustrative example demonstrates the implementation of the brute force and contains all the elements of the set of admissible solutions. The Pareto set and the set of admissible solutions are made up. The goal is to create two teams of three players from eight participants (i. e. $n = 8$, $k = 3$). The set of admissible solutions is set of sudgraphs x, the connectivity components of which are $m = 2$ cliques with cardinality $k = 3$. There are such cases according to the formula (1) $|X| = 8!/2!(3!)^2 = 280$ (Table 2), which determines the cardinality of the set of admissible solutions. After that, it is necessary to calculate the values of the vector objective function (2)–(4) for all elements of the set of admissible solutions. Visualization of these calculations is given in Fig. 2.

Table 4

Values of edge weights and pairs of participant's indexes

w_{ij}	Indexes of participants, (i, j)
1.000	(1, 6), (1, 7), (4, 6), (5, 6), (6, 7)
0.800	(4, 7)
0.750	(2, 6)
0.667	(0, 6), (1, 4), (2, 7), (3, 6)
0.600	(5, 7)
0.500	(0, 7), (2, 4), (3, 7), (4, 5)
0.400	(1, 5)
0.333	(0, 4), (1, 2), (3, 4)
0.250	(0, 1), (1, 3)
0.200	(0, 2), (2, 3)
0.000	(0, 3), (0, 5), (2, 5), (3, 5)

There are two Pareto optimal solutions:

$$x_{229} = ((v_1, v_2, v_7), (v_4, v_5, v_6)), \ x_{260} = ((v_1, v_5, v_6), (v_2, v_4, v_7)).$$

They make up the Pareto set. In this case, the Pareto set is equivalent to the complete set of alternatives: $\tilde{X} = X^0$. In Fig. 2 markers highlight two solutions that make up the complete set of alternatives. It can be argued that, taking into account the positive practical experience of interaction of the participants, a number of better options for forming teams with given parameters have been built.

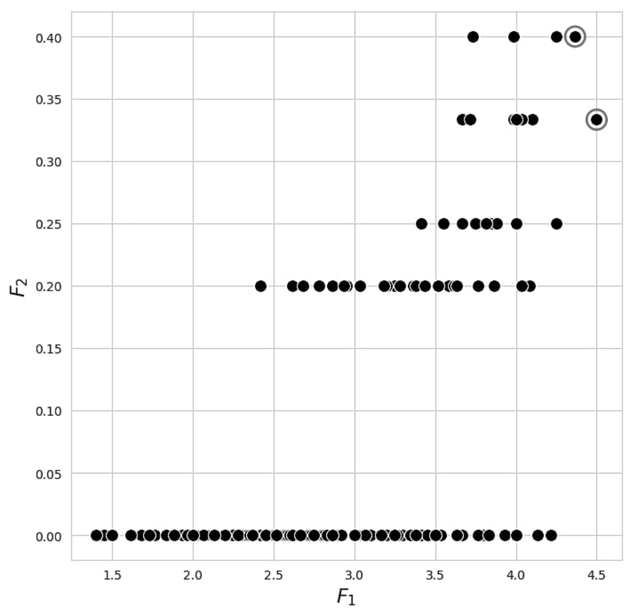

Fig. 2. The values of the vector objective function (2)–(4) ($n = 8$, $k = 3$)

The conditions of martial law in Ukraine led to the need to increase the productivity of teamwork to meet the needs of the front and restore Ukraine.

Restrictions on the practical use of the results of this research are determined by the time limits of the competition, which determines the direction of further research in this case.

The issue of mathematical justification of the choice of the number of team members, the number of teams for a certain number of participants requires further research.

This will make it possible to build methodological recommendations for practical application.

4. Conclusions

A graph-theoretic formalization of the team formation problem on a complete undirected weighted graph has been developed. The set of vertices of this graph corresponds to the set of potential participants. Each edge is weighted with a number that reflects the quality of the interaction between the two participants. A valid solution is to cover the graph with cliques, the size of which is determined by the number of team members. A mathematical model of a two-criterion problem with MAXSUM and MAXMIN criteria was built, where the first criterion evaluates the overall success of the created teams, the second criterion evaluates the «weakest link», allowing to choose the option that maximizes the minimum edge weights for each clique. An illustrative example is given as the implementation of the brute force, which requires exponential time for execution. When planning a series of competitions in practice, it is necessary to take into account the time resource – how many series of competitions can be held. Illustrative examples with introduced artificial restrictions on the number of occurrences of a pair in one team are given. Descriptive statistics of the conducted experiments are presented. Further research is planned to be devoted to distinguishing the classes of the described problem with certain parameters and algorithms for their solution, based on algorithmic approaches of graph theory, which will be acceptable for application in practice.

Acknowledgment

The work was performed as part of the research work «Making decisions based on intelligent technologies and open data», registration number 05014, in the Department of System Analysis and Computational Mathematics of National University «Zaporizhzhia Polytechnic», Ukraine.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The research was performed without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Kozlowski, S. W. J., Ilgen, D. R. (2006). Enhancing the Effectiveness of Work Groups and Teams. *Psychological Science in the Public Interest, 7 (3)*, 77–124. https://doi.org/10.1111/j.1529-1006.2006.00030.x
2. Acosta Mejía, C., Cambra Carrizo, G. I., Martinez-Carrasco, J., Cerda, M., Kang, M., Villalba, H., Yépez, C. (2024). Unveiling the IDB's Project Executing Units: Performance Indicators, Results-Based Management, and Demand for Knowledge. *Inter-American Development Bank*. https://doi.org/10.18235/0013040
3. Sa'diyah, K. (2024). Occupational Health and Safety, Training, and Teamwork for Hospital Medical Performance. *Safety and Health for Medical Workers, 1 (1),* 29–38. https://doi.org/10.69725/ehxp3d73
4. Poth, A., Kottke, M., Riel, A.; Yilmaz, M., Clarke, P., Messnarz, R., Reiner, M. (Eds.) (2021). Orchestrating Agile IT Quality Management for Complex Solution Development Through Topic-Specific Partnerships in Large Enterprises – An Example on the EFIS Framework. *Systems, Software and Services Process Improvement. EuroSPI 2021. Communications in Computer and Information Science*. Vol. 1442. Cham: Springer, 88–104. https://doi.org/10.1007/978-3-030-85521-5_7
5. Pasupa, T., Suzuki, S. (2022). Two-Stage Adaptive Large Neighbourhood Search for Team Formation and Worker Assignment Problems in Cellular Manufacturing Systems. *Applied Sciences, 12 (16)*, 8323. https://doi.org/10.3390/app12168323
6. Yang, W. Z. (2024). Teamwork triumphs: fostering student development through cooperative learning in university physical education. *International Journal of Current Educational Practice, 12 (2),* 114–120. https://doi.org/10.5281/zenodo.10954880
7. Hebles, M., Jara, M., Alvarez de E, C. Y. (2020). Teamwork competence and collaborative learning in entrepreneurship training. *European J. of International Management, 20 (2),* 238–255. https://doi.org/10.1504/ejim.2020.10022225
8. Sangadji, H. (2023). The Influence of Emotional Intelligence, Teamwork, And Organizational Citizenship Behavior on Performance Agricultural Extension Workers in Banten Province. *IJHCM (International Journal of Human Capital Management), 7 (1),* 141–157. https://doi.org/10.21009/ijhcm.07.01.11
9. Feitosa, J., Grossman, R., Kramer, W. S., Salas, E. (2020). Measuring team trust: A critical and meta-analytical review. *Journal of Organizational Behavior, 41 (5),* 479–501. https://doi.org/10.1002/job.2436
10. Delfgaauw, J., Dur, R., Onemu, O., Sol, J. (2022). Team Incentives, Social Cohesion, and Performance: A Natural Field Experiment. *Management Science, 68 (1),* 230–256. https://doi.org/10.1287/mnsc.2020.3901
11. Makanda, I. L. D., Jiang, P., Yang, M., Shi, H. (2023). Emergence of collective intelligence in industrial cyber-physical-social systems for collaborative task allocation and defect detection. *Computers in Industry, 152,* 104006. https://doi.org/10.1016/j.compind.2023.104006
12. Ai, W., Chen, Y., Mei, Q., Ye, J., Zhang, L. (2023). Putting Teams into the Gig Economy: A Field Experiment at a Ride-Sharing Platform. *Management Science, 69 (9),* 5336–5353. https://doi.org/10.1287/mnsc.2022.4624
13. Ertac, S., Gümren, M., Koçkesen, L. (2019). Strategic feedback in teams: Theory and experimental evidence. *Journal of Economic Behavior & Organization, 162,* 1–23. https://doi.org/10.1016/j.jebo.2019.04.005
14. Fischer, M., Rilke, R. M., Yurtoglu, B. B. (2023). When, and why, do teams benefit from self-selection? *Experimental Economics, 26 (4),* 749–774. https://doi.org/10.1007/s10683-023-09800-2
15. Zhao, M., Eadeh, F. R., Nguyen, T.-N., Gupta, P., Admoni, H., Gonzalez, C., Woolley, A. W. (2023). Teaching agents to understand teamwork: Evaluating and predicting collective intelligence as a latent variable via Hidden Markov Models. *Computers in Human Behavior, 139,* 107524. https://doi.org/10.1016/j.chb.2022.107524
16. Mansour, T. (2012). *Combinatorics of Set Partitions*. Chapman and Hall/CRC. https://doi.org/10.1201/b12691

ISSN 2664-9969

17. Perepelitsa, V. A., Tereschenko, E. V. (2018). On Complete and Quasi-Complete Two-Criteria Optimization Problems on Graphs. *Cybernetics and Systems Analysis, 54 (3),* 385–390. https://doi.org/10.1007/s10559-018-0040-1

18. Ohirko, O. I., Halayko, N. V. (2017). *Teoriya ymovirnostey ta matematychna statystyka.* Lviv: L'vDUVS, 292.

✉***Anton Riabenko,*** *PhD, Department of System Analysis and Computational Mathematics, National University «Zaporizhzhia Polytechnic», Zaporizhzhia, Ukraine, e-mail: rjabenkoae@gmail.com, ORCID: https://orcid.org/0000-0001-7738-7918*

✉***Elina Tereschenko,*** *PhD, Department of System Analysis and Computational Mathematics, National University «Zaporizhzhia Polytechnic», Zaporizhzhia, Ukraine, e-mail: elina_vt@ukr.net, ORCID: https://orcid.org/0000-0001-6207-8071*

Anna Bakurova, *Doctor of Economic Sciences, Department of System Analysis and Computational Mathematics, National University «Zaporizhzhia Polytechnic», Zaporizhzhia, Ukraine, ORCID: https://orcid.org/0000-0001-6986-3769*

Andrii Pyrozhok, *PhD, Department of Electric Drive and Commercial Plant Automation, National University «Zaporizhzhia Polytechnic», Zaporizhzhia, Ukraine, ORCID: https://orcid.org/0000-0001-5690-092X*

Olexiy Kuzkin, *Doctor of Technical Sciences, Department of Transportation Technologies, National University «Zaporizhzhia Polytechnic», Zaporizhzhia, Ukraine, ORCID: https://orcid.org/0000-0002-3160-1285*

✉*Corresponding author*