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THE SCIENTIFIC COLLABORATION OF RESEARCHERS IN THE FIELD OF ENTREPRENEURSHIP MANAGEMENT USING VERTEX COLORING AND CO-AUTHORED POLYGRAPHS

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Abstract. The purpose of the current research is to study and compare graphs co-authored by Iranian researchers in Persian scientific research journals in the field of entrepreneurship management using vertex and edge coloring of graphs. In this research, the data related to the scientific-research documents of 308 Iranian researchers in 5 Persian scientific research journals in the field of entrepreneurship management from 2019 to 2023 by using the issues printed in these journals and the graphs related to the authors of these journals were extracted using they are drawn from mathematical software and then compared and analyzed using algebraic parameters such as the average degree of vertices, independence, chromatic and matching number. In the main results, it was checked that the average grade of Smart Business Management Studies Journal is 4.3 and higher than other journals. Also, the largest research group (clique number) is 6 people and the most research variety (independence number) is 25 and it is related to entrepreneurship development magazines. Among the discussed journals in the field of entrepreneurship management, according to the average grades, the amount of research cooperation of the Journal of Smart Business Management Studies is at a higher level than the other four journals. Also, according to the independence number, the variety of research fields in the journal of entrepreneurship development is more than other journals discussed in this field in the country.

Keywords: clique number, Color number, Independence number, Matching number, Scientific network of entrepreneurship management.

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1. Introduction

A graph consists of vertices connected by a family of 2-membered subsets of the set of vertices, which are edges (links), where each edge consists of two vertices like a and b is formed and displayed as $a-b$. The number of vertices and edges of a graph is called the order and size of the graph respectively. The co-authorship graph or in fact the graph that is used to draw co-authorship relationships is a graph in which one vertex corresponds to each researcher and two vertices (researcher) are linked by an edge if they have published at least one joint article. The neighborhood of a vertex is the set of vertices, each of which is directly connected to that vertex by an edge, and the number of members of this neighborhood is called the degree of that vertex. In the co-authorship graph, a researcher's neighborhood includes researchers who have published at least one joint research work with him. The higher the rank of a researcher, the more his research collaborations. If there are $(m-1)$ vertices between two verticees a and b, provided that they are connected consecutively from a to b, then we say that there is a path of length m between vertices a and b. The presence of a path of length one between two researchers in the co-authorship graph indicates their direct research collaboration, and the presence of a path longer than one between two researchers in the co-authorship graph indicates their indirect research collaboration. If the vertices at the beginning and end of the path are the same, then the path is called a round. The length of the shortest circle in the graph is called the waist of the graph, and the length of the shortest path between two vertices is called the distance between those two vertices. In the co-authorship graph, the smaller the distance between two vertices, the closer the research field of the two researchers corresponding to those two vertices is probably. A clique in a graph consists of a number of vertices that are connected in pairs. The number of vertices of the largest clique in the mentioned graph is called the clique number. A clique in the coauthorship graph can be interpreted and analyzed as a research subgroup. The higher the clique number of the co-authorship graph, the larger the research group is in the journal, see [5, 16, 17]. The co-authorship graph of this research, in fact, draws a precise mathematical model of the amount of research collaboration among researchers in a journal or a discipline, a university or a geographic region. Despite the fact that this graph is also used in the study of scientific metrics and methods, but in this research, attention is paid to this graph with a more detailed and broader view. In order to measure the research cooperation of researchers, in this research, precise mathematical criteria have been used, some of which are not considered in scientometric methods.

Until 2019, no researcher has used precise mathematical methods, including graph parameters such as independence, chromatic, and matching numbers, to check co-authored networks (graphs), except for one case and that was by Shaveisi and Amini in [16]. By using precise mathematical parameters (graph theory branch), co-authored (graph) networks and scientific cooperation of mathematics

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researchers have been investigated in the specialized trends of this field. Also, in 2022, the level of cooperation of educational science researchers using this method was investigated by Abdi and Amini in [1]. Therefore, in this research, an attempt is made to determine the level of cooperation of researchers in the field of entrepreneurship management in 5 Persian scientific research journals, such as smart business management studies journals, entrepreneurship development, business research journals, business management research, and international scientific business management. From 2019 to 2023, using accurate parameters of mathematical graphs such as average degrees, clique number, matching number, chromatic number and independence number with a broader and more accurate view compared to scientometric methods. Because some graph parameters such as independence, chromatic and matching numbers are not considered in scientometric methods. In this research, by attributing the co-authorship graph to the entrepreneurship management researchers in the aforementioned scientific research journals, research collaboration will be analyzed and compared using the above graph parameters. If in previous researches in which co-authorship networks have been studied, they have used scientometric criteria and network interpretation.

2. Main Results

In this part, we express the main results in the form of questions and answers.

According to graph parameters such as clique number and average degree or the ratio of size (number of edges) to order (number of vertices), in which journal have researchers collaborated the most? The number of group articles and also the largest research group was related to which of the journals?

The waist values for the co-authored graphs of 5 researchers are from 3 journals, so the mentioned parameters cannot be suitable parameters for comparing the graphs. But the column related to the clique number also shows that the largest research group (published two by two joint articles) in the journals of intelligent business management studies and exploration of business management is 6 people, and in this sense, these journals are different from the other three journals in question. The largest research group (with a published joint article) they are 5 people are better. It also shows the average degree of research cooperation of these journals, that the highest value of this parameter is assigned to the co-authorship graph of the authors of the Smart Business Management Studies Quarterly is equal to 4.3. It indicates that the amount of research cooperation in this journal is at a higher level than the other four journals under discussion, and after this journal, the amount of research cooperation is in entrepreneurship development quarterly, business research journal, exploration of business management and management respectively. International scientific business, whose average grades are 4.02, 3.8, 3.6, and 3.56, respectively. Of course, the comparison of this amount of research cooperation can be seen from the values of the ratio of the sizes (number of edges) to the orders (number of vertices) of the graphs, the higher the value of this ratio, the greater the amount of

research cooperation. Therefore, in general, the amount of research cooperation of researchers in the quarterly journals of smart business management studies and entrepreneurship development is at a favorable level; However, in other discussed journals, the overall level of research cooperation is at a lower level.

According to graph parameters such as vertex chromatic number and independence number of co-authored graphs, which of the Persian scientific research journals in the field of entrepreneurship management has the most discontinuity and diversity of research fields?

The chromatic number of the vertices of the graph co-authored by the researchers of two journals of intelligent business management studies and the exploration of business management is equal to 6, and the chromatic number of the vertices of the graph co-authored by the researchers of three other journals of entrepreneurship development, business research paper and international scientific business management is equal to 5 is Therefore, the number of vertical chromatic classes of the first magazine and the fourth magazine is more, and this results that the research discontinuity in the two magazines of smart business management and exploration of business management is better than the other three magazines. In addition, as it is evident in the column related to the independence number of the above table, there is a big difference between the independence numbers of the co-authored graphs of journal authors at the country level. The highest number of independence (25) is related to Entrepreneur Development Magazine and the lowest number of independence (10) is related to Journal of Business Research. This issue states that the variety of research fields in Entrepreneurship Development Journal is more than other journals discussed in this field in the country. After Entrepreneurship Development Magazine, Smart Business Management Magazine has the most variety of research fields in the field of management and entrepreneurship. International scientific business management journals, business management exploration and business research journal have a lower index in the variety of research fields.

According to graph parameters such as vertex chromatic number and independence number of co-authored graphs, which one of the Persian scientific research journals in the field of educational sciences has the most discontinuity and diversity of research fields?

The column related to the maximum degree shows which researcher had the most research cooperation compared to other researchers. The highest maximum degree among the graphs of the journals is related to the graph of the journal of intelligent business management studies and is equal to 16. Therefore, in this journal, there is a researcher who directly published a joint article with 16 other people in this journal, and this researcher's name is Fatemeh Thaghafi. But these 16 people or other researchers may not have so many articles in common with each other in this journal, in this same journal Abbas Toloui Ashlaghi has had a very good collaboration with 15 other researchers. The next researcher who has had the most research cooperation compared to other researchers belongs to the

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Journal of Entrepreneurship Development, and his name is Kambiz Talebi, who has directly published a joint article in this journal with 13 (the maximum degree of the graph of Entrepreneurship Development) people. Of course, in this same journal, Seyed Mojtabi Sajjadi had a significant joint scientific collaboration with other researchers. Because the chromatic number of the Yali graph co-authored by the researchers of smart business management studies and entrepreneurship development magazines is equal to 16 and 13, respectively, and the highest amount of these numbers is related to these magazines. In other words, there are 16 and 13 articles in these magazines, respectively, and one author (Fateme Thaqfi and Kambiz Talebi) played a role in publishing all of them. From this point of view, Kaush magazines of business management, international scientific business management and business research journal are in the next ranks.

Which of the Persian scientific research journals in the field of entrepreneurship management has the highest number of parallel and distinct research groups in the country?

The co-authorship graph of the researchers of Smart Business Management Studies Journal has the highest number of matches and indicates that the number of articles that no two of them have a common author is more in Smart Business Management Studies Journal than other journals. In other words, the number of parallel and distinct research groups in the journal of intelligent business management studies is more than other Persian scientific research journals in the field of entrepreneurship management in the country. Therefore, there are 38 articles in the Journal of Smart Business Management Studies, where each researcher has the role of author in at most one of the articles.Also, Entrepreneurship Development Magazine is in the next rank with 35 articles, and the Journal of Business Journalism has the last rank.

3. **Conclusions**

The researchers of Persian scientific research journals of intelligent business management studies and entrepreneurship development have higher research cooperation than the researchers of other journals with average grades of 4.3 and 4.02 respectively. From the findings of this research, it can be concluded that the largest research group in the journals of smart business management studies and the exploration of business management has 6 members, and in other discussed journals, it has 5 members. In comparison with the research conducted in other fields, especially educational sciences and mathematics, it is observed that the amount of research cooperation of researchers in Persian scientific research journals in the field of entrepreneurship management is less than the amount of research cooperation of researchers in the field of educational sciences. For example (Abdi and Amini 2022) showed that the highest average grades related to the co-authored graph of the researchers of the Journal of Educational Measurement and Evaluation Studies is equal to 4.4 and they also showed that the largest research group is 6 people and it is related to the co-authored graph of the researchers

of teaching research journals, educational measurement and evaluation studies, and the research paper on the basics of education and training. However, compared to researchers in the field of mathematics, the amount of research cooperation of researchers in the field of entrepreneurship management is more than that of mathematics.

In general, it is expected that researchers in the field of entrepreneurship management have higher research cooperation than all other fields in order to generate more employment and production in the country. The values of Yali chromatic numbers and maximum degree, both indicate the maximum number of research collaborators of a researcher or researchers of that journal. From this point of view, the two journals of intelligent business management studies and entrepreneurship development are better than the other journals discussed. In fact, in the first journal, researcher Fatemeh Thaqfi, Abbas Toloui Ashlaghi, and in the second journal, researcher Cambyz Talebi, have published joint articles with 15, 16, and 13 people, respectively. The number of articles in which no two have a common author is more in the research teaching journal than in other journals. In other words, the number of parallel and distinct research groups in the journal of intelligent business management studies is more than other Persian scientific research journals. In fact, there are 38 articles in the Journal of Smart Business Management Studies, where each researcher has the role of author in at most one of the articles. From this point of view, entrepreneurship development magazine is in the next rank with 35 articles, and business research journal is in the last rank with 7 articles.

References

[1] A. Abdi and M. Amini, Discontinuity and diversity of Persian scientific research journals in the field of educational sciences by using coloring and mathematical algebraic parameters, *Mathematics and Society*, **7** no. 2 (1401) 69–94. [In Persian]

[2] D. de B. Beaver and R. Rosan, Studies in Scientific Collaboration 1, *Scientometrics*, **1** no. 1 (1978) 65–84.

[3] D de B. Beaver and R. Rosan, Studies in scientific collaboration 1, *Scientometrics*, **2** no. 1 (1979a) 133–149.

[4] D de B. Beaver and R. Rosan, Studies in scientific collaboration 1, *Scientometrics*, **3** no. 1 (1979b) 231–245.

[5] J. A. Bondy and U. S. R. Murty, *Graph Theory with Applications*, American Elsevier, New York, 1976.

[6] J. Bashiri and A. Gilvari, Co-author in the scientific publications of the agricultural research, education and promotion organization, *Scientometries Research Journal*, **4** no. 2 (1397) 56–69. [In Persian]

[7] N. Hariri and M. Nikzad, Co-authored articles in iranian articles in the fields of librarianship and information, management psychology and economics in the ISI database. between 2000 and 2009, *Iranian Journal of Information Processing and Management*, **26** no. 4 (1390) 825–844. [In Persian]

[8] P. Hasanzadeh, A. Esfandyari moghdam, F. Soheili and A. Mosavei Chelk, Co-authorship and the relationship between social influence and the efficiency and productivity of researchers in the field of chronic cardiovascular failure, *Scientometries Research Journal*, **4** no. 2 (1397) 143–160. [In Persian]

http://dx.doi.org/10.22108/msci.2024.141644.1666

[9] M. Hasanzadeh and S. Baghaei, Scientific society, scientific relations and co-authorship, *Rahyaft*, **44** (1388) 37–41. [In Persian]

[10] R. L. Hard, Co-authorship in the Academic Library Literature: A Survey of Attitudes and Behaviours, *The Journal of Academic Librarianship*, **26** no. 50 (2000) 339–345.

[11] S. Lijun, *Co-authorship Network in Transformation research*, The Media Laboratory, Massachusett of Technology, Cambridge. M. A, in Press, 2017.

[12] H. Noche Nasar, G. R. S. Murkani and M. A. Qaneei Rad, Analysis of the social network of co-authoring foreign articles by members of the board of educational sciences, *Scientometries Research Journal*, **4** no. 2 (1397) 33–56. [In Persian]

[13] M. E. J. Newman, Co-authorship networks and patterns of scientific collaboration, *Proceeding of National Academic Society*, **2** no. 101 (2004) 5200–5205.

[14] M. Rahimi and R. Fatahi, Scientific co-operation and information production, a look at common concepts and patterns in joint scientific production, *Book Quarterly*, **18** no. 3 (1386) 235–248. [In Persian]

[15] M. Rahimi and R. Fatahi, Investigating the scientific co-operation of faculty members in four subject areas at Ferdowsi University of Mashhad, *Library and Information Sciences*, **11** no. 2 (1387) 235–248. [In Persian]

[16] F. Shaveisi and M. Amini, The analysis of the co-authorship graph of Iranian researchers in mathematics by graph parameters, *Scientometries Research Journal*, **6** no. 1 (1399) 237–260. [In Persian]

[17] D. B. West, *Introduction to Graph Theory, 2nd ed*, Prentice Hall, Upper Saddle River, 2001.

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