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Research article

A Bibliometric Analysis of Metaheuristic Research and Its Applications

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ABSTRACT

Metaheuristic algorithms are generic optimization tools to solve complex problems with extensive search spaces. This algorithm minimizes the size of the search space by using effective search strategies. Research on metaheuristic algorithms continues to grow and is widely applied to solve big data problems. This study aims to provide an analysis of the performance of metaheuristic research and to map a description of the themes of the metaheuristic research method. Using bibliometric analysis, we examined the performance of scientific articles and described the available opportunities for metaheuristic research methods. This study presents the performance analysis and bibliometric review of metaheuristic research documents indexed in the Scopus database between the period of 2016-2021. The overall number of papers published at the global level was 3846. At global optimization, heuristic methods, scheduling, genetic algorithms, evolutionary algorithms, and benchmarking dominate metaheuristic research. Meanwhile, the discussion on adaptive neuro-fuzzy inference, forecasting, feature selection, biomimetics, exploration, and exploitation, are growing hot issues for research in this field. The current research reveals a unique overview of metaheuristic research at the global level from 2016-2021, and this could be valuable for conducting future research.

1. Introduction

Systems are faced with competition at every stage due to limited resources. It has induced the process referred to as an optimization process. Most optimization problems with practical implications in industries, engineering, science, economics, and business are complex and challenging to resolve. Optimization techniques are used to find the best results depending on the problem. Optimization occurs to minimize the cost of production of goods, the time spent on a task, the risk in an investment or the maximization of profits, the quality of goods, and the efficiency of a device [1]. Optimization requires a good strategy in making decisions to obtain optimum results. Those problems cannot be solved accurately by using classical methods. In this case, metaheuristic methods have emerged as an alternative.

Metaheuristic methods are generic optimization tools to solve difficult problems with huge search spaces. These methods minimize the size of the search space by using effective search strategies. Metaheuristic methods can use search expertise smartly to explore and exploit the search space in a randomized way, and the answer is inexact and near-optimal [2]. Metaheuristic methods have become popular in science, industry, and many disciplines during the last ten years. There is much research on developing metaheuristic methods and their applications in various fields. However, no study has discussed metaheuristics research trends, clustering, and performance analysis. Ezugwu in [3] has addressed the co-authorship and author analysis based on articles published in WoS-indexed journals

ISSN 2502-3357 (online) | ISSN 2503-0477 (print)
9 (1) January 2023 1-17

and discussed a taxonomic classification of metaheuristic algorithms. However, He has not presented research trends and grouped research themes in metaheuristics. This research aims to provide the performance analysis of metaheuristic research and map out an overview of the research themes of metaheuristic methods. Using the bibliometric analysis, this research aims to look at the performance of scientific articles and describe research opportunities for metaheuristic methods. This bibliometric study uses a database of articles published in Scopus-indexed journals.

2. Materials and Methods

Some mathematicians are interested in solving analytic problems and proving theorems, but some are trying to explore applications of mathematics itself. Graph theory is a branch of mathematics with many applications in various fields. Research on solving graph problems using metaheuristic methods has been done previously. For example, Kratica (2008) conducted a study to determine the strong metric dimension of families of graphs using a genetic algorithm [4]. In addition, Kratica also investigated the application of genetic algorithms to obtain the metric dimension of more general graphs [5]. Hertz (2020) conducted a study to ensure the metric dimension and minimum cardinality of the doubly resolving set in n-cubes using an IP-based Swapping Algorithm [6]. In addition, Hertz et al.'s study determined the resolving set in 2021 [7]. Research on applying heuristic methods to graph theory, mainly metric dimensions, can continue to be developed in line with research on metric dimensions. For example, Bong [8] and Ismail [9] developed a study on the metric dimension.

In Applied Mathematics, metaheuristic methods have developed rapidly as they are reliable and easy to implement. Engineers face increasingly complex problems across several fields daily, such as operations research, mechanical system design, image processing, scheduling problems, and so on. Several studies have been carried out previously. For example, Izquerdo et al. implemented PSO to solve water distribution and wastewater system design problems, network calibration, identification, and detection of leaks in the water industry [10]. Elaziz's (2017) study explained how to improve Sine Cosine Algorithms (SCA) by applying opposition-based learning (OBL) as a method for the preferable exploration [11]. Siavash (2018) conducted a comparison test on GA and PSO and a hybrid algorithm in optimizing Water flooding [12]. In the same year, Cheraghalipour presented a new mechanism with a distinct approach to tackle optimization jobs. This method is generated from a tree's event for light and food. The distinction and intensification of stages and their trade-offs are specified in this study [13]. Sulianto examined the potency of several metaheuristic algorithms to investigate hydraulic parameters in drinking water network problems [14]. Bekdas (2017) used the Harmony Search method and the Bat Algorithm to obtain the optimization step for the mass damper set under earthquake excitation by allowing the soil-structure relation [15]. In [16], Koczy et al. proved the efficiency of an algorithm in solving classic TSP problems. In addition, Talatahari et al. (2020) showed that Chaos Game Optimization could provide good results and outperform other metaheuristics in most issues [17].

In addition, Balochian [18] presented a metaheuristic method inspired by imitating behavior, Social Mimic Optimization (SMO). He compared the method with fourteen other metaheuristic methods. The results obtained indicate that SMO has a high ability to solve high-dimensional decision variables. Shadravan et al. in [19] compared a sailfish-inspired metaheuristic method, the SailFish Optimizer (SFO), with six other existing metaheuristic algorithms. Kaveh et al. [20] introduced a new metaheuristic method, which was used to tackle the finite optimization issue. Agbaje studied automatic data grouping using a specific algorithm. Meanwhile, Shabani (2019) reviewed an algorithm for solving specific problems with a single goal. This algorithm was inspired by human exploration during search and rescue operations [22]. Farshi (2020) introduced a new metaheuristic called battle royale optimization (BRO). This method was inspired by the digital game genre known as "battle royale". This method was compared with the PSO and six other optimization algorithms. The results show that BRO is efficient and provides excellent results [23]. Last. Hashim (2021) introduced a new method called Archimedes Optimization Algorithm (AOA). This algorithm was inspired by the laws of physics, namely Archimedes [24].

2.1. Method

There are several methods to conduct a literature review. Evi in [25] used specific diagram techniques to perform their analysis. However, in the current study, we first conducted a performance analysis that

ISSN 2502-3357 (online) | ISSN 2503-0477 (print)
9 (1) January 2023 1-17

adapts the steps taken by Goodell [26]. We then completed a bibliometric study of scientific articles about metaheuristic research using VOSviewer. Based on Table 1, we worked on an article selection in this performance analysis.

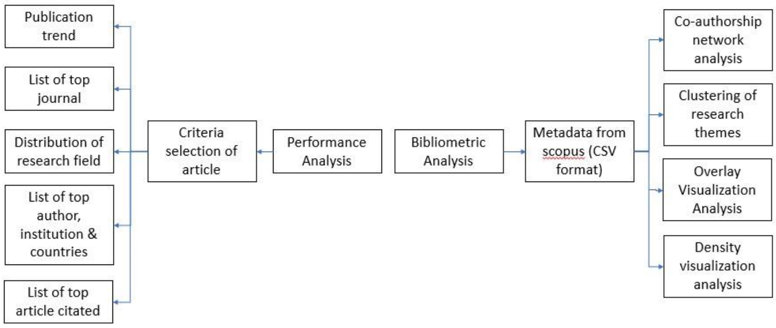

Fig. 1. Systematic literature review phases for this study

Table 1. Selection Criteria of articles

Filtering criteria	Reject	Accept
Search Criteria		
Search engine: Scopus Search date: 06 December 2021 Search term: (“metaheuristic”) AND (“method”)		
Content screening: Include articles if “Titles, abstract, and keywords” indicate relevance to the scope of the study (i.e., metaheuristic and method) only		10.035
Subject area: ”Computer Science,” “Mathematics,” “Engineering,” “Decision Science,” “Business, Management, and Accounting,” “Energy,” “Physics and Astronomy,” “Materials Science,” “Social Sciences,” “Environmental Science,” “Biochemistry, Genetics, Molecular Biology,” Chemical Engineering,” “Medicine,” Earth and Planetary Sciences,” “Economics, Econometrics, and Finance,” “Chemistry,” “Agricultural and Biological Sciences,” “Neuroscience,” “Multidisciplinary,” “Art and Humanities,” “Immunology and Microbiology,” “Psychology,” “Pharmacology, Toxicology and, Pharmaceutics,” “Nursing.”		10.035
Document type: “Articles”	3812	6223
Publication Stage: “Final”	276	5947
Source Type: “Journal”	122	5825
Article selection		
Language screening: Include documents in English only	113	5712

Next, we conducted a bibliometric analysis. The method used in this bibliometric analysis was adapted from van Eck et al. [27] and Ranjbar-Sahraei & Negenborn [28]. Bibliometric studies were carried out by utilizing a database of articles published in Scopus-indexed journals. Article metadata was downloaded on 8th December 2021. Documents categorized as review, editorial, and articles in press did not include downloaded metadata. The metadata was then exported to a CSV file format so that all recorded information from each article was downloaded, as described in Table 2.

Table 2. CSV Document Export Settings downloaded from Scopus Database

Item	Recorded information
Citation	author, Scopus ID, article title, year of publication, journal name, volume, edition, page, number of citations, source and document type, DOI, access type
Bibliography	affiliation, ISSN, PubMed ID, publisher, editor, original language of the document, correspondence address, journal abbreviation
Abstract & Keywords	abstract, author's keywords, index
Funding	amount, acronym, sponsor, funding text
Other information	trade and manufacture names, conference information, bibliography

We used the information in Table 2 to explore which researchers are influential, the author's affiliation or institution, co-authorship, the most cited articles, and the most widely used keywords. This information was used to build data visualization. The downloaded metadata was then processed using VOSviewer software version 1.6.16. This tool is needed to create a visualization of the metadata that has been previously downloaded and processed in such a way based on the algorithm that has been embedded in the device. Keywords or terms that appear as research themes were extracted from the title and abstract of a scientific article.

The steps taken were as follows. First, we run the VOSviewer program. Second, we pressed the Create button on the File tab until a dialogue box appeared. Third, we selected the data type, created a map based on text data, and then pressed the Next button. Fourth, we chose the data source, read data to form a bibliographic database file, and selected the Next button. Subsequently, we selected the Scopus tab, selected the previous CSV file, and pressed the Next button. Fifth, we chose the title and abstract

ISSN 2502-3357 (online) | ISSN 2503-0477 (print)
9 (1) January 2023 1-17

field options to be extracted, ticked both options, and waited for some time. Sixth, we specified the full counting method and pressed the Next button. Then we filled in the threshold with 15 so that from 20931 terms, 494 keywords that often appear were found. Then, we selected the Next button, and by default, it was filled with numbers obtained from 60% of keywords, and then we selected the Next button. Last, keywords were sorted alphabetically during the term verification stage, and less specific terms related to the study of metaheuristic methods were ignored [29].

3. Results and Discussions

3.1. Performance analysis

The number of publications in Scopus-indexed journals employing metaheuristic methods has increased, as shown in Figure 2 below.

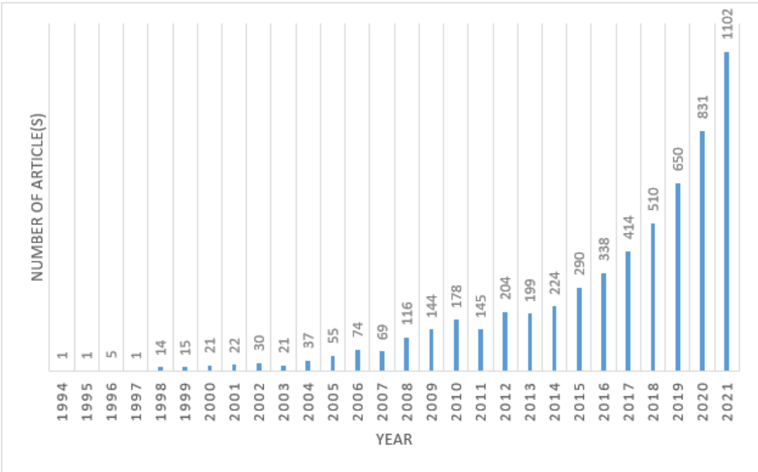

Fig. 2. Publication trend of Metaheuristic research

Meanwhile, the top journals contain scientific articles on Metaheuristic research from 1991-2021, as shown in Table 2. The paper with the high number of citations, as many as 272 citations, in the European Journal of Operation Researchwas was co-authored by Devika et al. in 2014. This article presents a comparison of metaheuristics hybridization methods in planning a specific supply chain problem [30]. Another article with a high number of citations, as many as 180 citations, was co-authored by Liu et al. (2013). Liu and his colleagues presented heuristic methods for a specific vehicle routing problem in-home health care. They used two mixed-integer programming models in their research and applied GA and a taboo search (TS) algorithm [31]. Another article with a high number of citations, as many as 120 citations, is the article by Nickel et al. (2012). In their paper, Nickel et al. used different meta-heuristics combined with constraint programming methods to solve specific routing and scheduling problems [32].

Another article published by the European Journal of Operation Research was co-authored by Herran et al [33]. They discussed an efficient searching algorithm for the space-free multi-row facility layout problem [33]. The latest article published in the Journal of Expert Systems with Applications is co-authored by Oliva et al. (2021). In the paper, the Moth Swarm Algorithm (MSA) was developed by combining some mechanisms to obtain more accurate solutions [34]. Another recent article published in the Journal of Expert Systems with Applications is co-authored by Li et al. In their paper, Li and his collegues introduced a new problem, a novel discrete cuckoo search (DCS) algorithm, which was used and improved to solve the problem [35].

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9 (1) January 2023 1-17

Table 3. Top Journals in Metaheuristic research

Journal	TC	TP	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2021
European Journal of Operational Research	11455	148		10	15	46	32	45
Computers and Operation Research	9398	170	1	1	12	62	34	60
Expert Systems with Applications	6494	165				19	37	109
Applied Soft Computing Journal	5179	152				3	42	107
Knowledge-Based Systems	3626	48				1	7	40
Computers and Industrial Engineering	2631	99		3	4	8	12	73
Information Sciences	2465	59			1	2	22	34
Journal of Heuristics	1971	66		9	14	16	11	16
Annals of Operation Research	1831	40	1	1	5	5	12	16
Neural Computing and Applications	1526	68		1		1	6	60
Soft Computing	1485	109				1	16	92
Engineering Applications of Artificial Intelligence	1401	49			2	4	12	31
International Journal of Production Research	1397	54		3	2	16	17	16
International Journal of Advanced Manufacturing Technology	1250	53			2	21	21	9
IEEE Access	1213	144						144
Journal of The Operation Research Society	1039	38		1	7	13	7	10
Swarm And Evolutionary Computation	886	42					9	33
Energies	682	50					1	49
Applied Soft Computing	602	52					4	48
Mathematical Problems in Engineering	570	56				1	24	31
Engineering optimization	439	33					4	29
Applied Sciences Switzerland	319	53						53
Sustainability Switzerland	204	34						34
Mathematics	187	38						38

The latest article published in the Applied Soft Computing Journal was authored by Chakraborty and Mali. They discussed an algorithm and its application in biomedical image segmentation [36]. The article on the metaheuristics method with the most citations was published in the Applied Soft Computing Journal, co-authored by Yu et al. The paper discusses a new algorithm for global optimization [37]. The article with the second-highest number of citations was published in the Applied Soft Computing Journal, co-authored by Sadollah et al. The article discusses a modified version of an algorithm, which is obtained based on the observation of the water cycle process and how rivers and streams flow to the sea [38]. Meanwhile, the article with the third-highest number of citations was published in the Applied Soft Computing Journal, co-authored by Yapici et al. (2019). The paper discusses a new metaheuristic algorithm, namely the Pathfinder. The swarm-inspired algorithm, which is different from a mathematical model, was applied to a real engineering problem and provides competitive results [39].

The two most cited articles in the Journal of Computers and Operations Research are the ones co-authored by Govindan et al. (2015) and Peng et al. (2015) [40],[41]. The latest article in the journal Computers and Operations Research was co-authored by Hughes et al. Hughes and colleagues developed algorithms capable of solving optimization problems [42]. The description of research fields related to metaheuristic research is presented in Figure 3 below. From the table, it can be seen that computer science, engineering, and mathematics dominate the study of metaheuristic methods.

In Computer Science journal, it was noted that Mirjalili was the author whose publications were cited the most. Mirjalili's Gray Wolf Optimizer (2014) is cited the most by ither authors. The paper describes a new meta-heuristic that is inspired by grey wolves (Canis lupus) [43]. In 2017, Mafarja collaborated with Mirjalili to produce a hybrid whole optimization algorithm with SA for feature selection [44]. The paper is the second most cited article in Computer Science journal. The flower pollination algorithm and Slime mould algorithm have the most citations in this field [45],[46]. The metaheuristic research themes in Computer Science journal are presented in Table 3, while the top authors, institutions, and countries related to metaheuristic research and its application are presented in Table 4.

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ISSN 2502-3357 (online) | ISSN 2503-0477 (print)
9 (1) January 2023 1-17

Fig. 3. Distribution of research fields related to the metaheuristic method

Table 3. The themes of metaheuristic research in computer science

Author(s)	Algorithm or Subject	The Problem	TC
Li et al. [46]	Slime mould algorithm	Stochastic optimization	384
Arora and Singh [47]	Butterfly Optimization Algorithm	Global optimization	333
Faramarzi et al. [48]	Equilibrium Optimizer	Optimization	331
Abualigah and Khader [49]	Improvement of PSO	Document clustering	306
Chen et al. [50]	Harris hawks Optimization	Framework and case studies	152
Wang and Jiao-Hong [51]	Krill herd and Artificial bee colony	Improvement Algorithm	55
Wang [52]	Moth search algorithm	Global optimization	279
Wang et al. [53]	Earthworm optimization algorithm	Global optimization	145
Heidari et al. [54]	Efficient boosted grey wolf Optimization and kernel extreme learning machine	Global search	55
Mafarja et al. [55]	Evolutionary population dynamics and Grasshopper optimization	Feature selection	235
Mafarja et al. [56]	The binary grasshopper optimization algorithm	Feature selection	184
Sayed et al. [57]	Chaotic dragonfly algorithm	Feature selection	86
Dokeroglu et al. [58]	New generation metaheuristic algorithm	A survey	154
Li and Yao [59]	Quality evaluation	Survey of multi-objective optimization problems	94
Wang et al. [60]	Krill herd algorithm	A review	77
Zhao et al. [61]	Atom search optimization	The hydrogeologic parameter estimation problem	133
Shadravan et al. [19]	The Sailfish Optimizer	Constrained engineering optimization problems	118
Khalilpourazari and Khalilpourazary [62]	A hybrid algorithm based on Water Cycle and Moth-Flame Optimization algorithms	Numerical and constrained Engineering optimization problems	87
Houssein et al. [63]	Hybrid Harris hawks optimization and support vector machines	Drug design and discovery	66

Table 4. Top authors (a), institutions (b), and countries (c) of Metaheuristic research

(a)

TC	Author	TP
7247	Gandomi, A.H	30
6274	Yang, X.S	21
3922	Mirjalili, S	24
3571	Mladenovic, N	23
1606	Heidari, A.A	18
1529	Kaveh, A	60
1514	Glover, F	30
1473	Talatahari, S	22
1429	Sadollah, A	19
1296	Marti, R	18
1290	Tarantilis, C.D	23
1174	Kiranoudis, C.T	22
1173	Chen, H	17
880	Zandieh, M	25
486	Oliva, D	19
485	Al-Betar, M.A	19
456	Hoang, N.D	23
417	Chou, J.S	19
404	Elaziz, M.A	20
378	Bekdas, G	17
372	Abd Elaziz, M	17
286	Cuevas, E	29
240	Duarte, A	17
215	Moayedi, H	18

(b)

TC	Institution	TP
6264	Iran University of Science and Technology	133
3844	University of Tehran	105
2385	Amirkabir University of Technology	75
2358	National Taiwan University of Science and Technology	52
2120	Duy Tan University	77
1991	University of Tabriz	46
1803	Islamic Azad University	66
1672	Huazhong University of Science and Technology	67
1622	University Malaya	40
1586	Shahid Beheshti University	53
1414	Zagazig University	63
1337	National Technical University of Athens	36
1210	Universiti Sains Malaysia	46
859	Ton-Duc-Thang University	57
787	Universidad de Guadalajara	56
701	Sharif University of Technology	35
695	CNRS Centre National de la Recherche Scientifique	32
686	Ministry of Education China	50
655	K. N. Toosi University of Technology	32
654	Universiti Teknologi Malaysia	32
584	Universiti Kebangsaan Malaysia	39
509	University of Belgrade	40
484	Islamic Azad University, Qazvin Branch	34
301	Islamic Azad University, Science and Research Branch	33

(c)

TC	Country	TP
27133	Iran	908
17934	United States	472
14518	United Kingdom	267
14168	China	675
12939	Spain	368
11502	Canada	214
11392	India	623
7338	Australia	152
7289	France	226
6772	Brazil	292
5784	Turkey	363
5263	Malaysia	255
4964	Taiwan	158
3688	Germany	125
3468	Italy	156
3148	Vietnam	151
3099	Greece	91
2725	Egypt	166
2634	Mexico	190
2401	Saudi Arabia	157
2372	Poland	111
1908	South Korea	124
1815	Algeria	132
1591	Japan	94

The top-cited publications in Scopus-indexed journals related to metaheuristic research and their applications are presented in Table 5. Mirjalili in [64] is the most impactful and influential paper with the highest number of citations in Scopus (1606), followed by Dorigo in [65], Hansen, and Gandomi in [66].

ISSN 2502-3357 (online) | ISSN 2503-0477 (print)
9 (1) January 2023 1-17

Table 5. Top Articles on Metaheuristic Research

Author(s)	Source	Algorithm applied or Subject	Problems	TC
Mirjalili [64]	Knowledge-Based Systems	Moth-flame optimization algorithm	Constrained-stochastic optimization	1606
Dorigo and Blum [65]	Theoretical Computer Science	Ant colony optimization	A survey of ACO	1577
Hansen and Mladenovic [67]	European Journal of Operational Research	Variable neighborhood search	Principles and applications in graph theory	1380
Gandomi and Alavi [66]	Communications in Nonlinear Science and Numerical Simulation	Krill herd	Benchmarking	1183
Gandomi et al. [68]	Engineering with Computers	Cuckoo search algorithm	Structural optimization problems	1146
Yang and Gandomi [69]	Engineering Computations	Bat algorithm	Global engineering optimization	981
Socha and Dorigo [70]	European Journal of Operational Research	Ant colony optimization	Continuous optimization	920
Askarzadeh [71]	Computers and Structures	Crow search algorithm	Constrained engineering optimization	916
Cheng and Prayogo [72]	Computers and Structures	Symbiotic organisms search	Structural design problems	785
Braysy and Gendreau [73]	Transportation Science	Route construction and local search algorithms	Vehicle routing problem with time windows	739
Eskandar et al. [74]	Computers and Structures	Water cycle algorithm	constrained engineering optimization problems	719
Lodi et al [75]	European Journal of Operational Research	A Survey	Two-dimensional packing problems	603
Yang and Deb [76]	Computers and Operations Research	Multi-objective cuckoo search	Design optimization	584
Gandomi et al. [77]	Communications in Nonlinear Science and Numerical Simulation	Firefly algorithm with chaos	Global optimization	566
Mirjalili et al. [78]	Expert Systems with Applications	Multi-objective grey wolf optimizer	Multi-criterion optimization	564
Glover et al. [79]	Control and Cybernetics	Scatter search, path relinking	Optimization	564
Hansen et al. [80]	Annals and Operations Research	Variable neighborhood search	Any particular problem	563
Chatterjee and Siarry [81]	Computers and Operations Research	Particle swarm optimization	Combinatorial	555
Harman and Jones [82]	Information and Software Technology	Search-based software	Reformulation and evaluation criteria	553
Gandomi et al. [83]	Computers and Structures	Firefly Algorithm	Mixed variable structural optimization	552
Czyzzak and Jaszkiewicz [84]	Journal of Multi-Criteria Decision Analysis	Pareto simulated annealing	Multiple-objective combinatorial optimization	541
Abu-Mouti and El-Hawary [85]	IEEE Transactions on Power Delivery	Artificial bee colony algorithm	Optimal distributed generation allocation, sizing in distribution systems	534
Kuo and Prasad [86]	IEEE Transactions on Reliability	Heuristic and metaheuristic algorithm	An overview of system-reliability optimization	514
Yang et al. [87]	Applied Soft Computing Journal	Firefly Algorithm	Non-convex economic dispatch problems	513
Schneider et al. [88]	Transportation Science	Variable neighborhood search + Tabu Search	The electric vehicle routing problem	470

3.2. Bibliometric analysis

In this step, bibliometric analysis was conducted by making network, overlay, and density visualizations using VOSviewer to determine the bibliometric network between articles from the downloaded metadata. The bibliometric network consists of nodes and edges. The nodes represented by circles can be publications, journals, researchers, or keywords, while the edge indicates the relationship between pairs of nodes. In addition, the edge indicates the existence of a relationship between two nodes and the strength of the relationship, which is shown by distance. The closer the distance between one node and another, the higher the relationship between the nodes [29].

Collaboration networks are a symbol of contemporary research. Scientists are no longer independent players. Co-authorship networks are powerful tools to see collaboration trends and identify leading scientists. The analysis reveals the social structure of the network by identifying the researcher and their connections. In Figure 4, we describe the co-authorship network in metaheuristic research. Each circle represents a researcher, and the circle sizes show the number of his/her publications. The researcher in metaheuristic research could be grouped into 15 clusters, and each cluster can be recognized based on its color.

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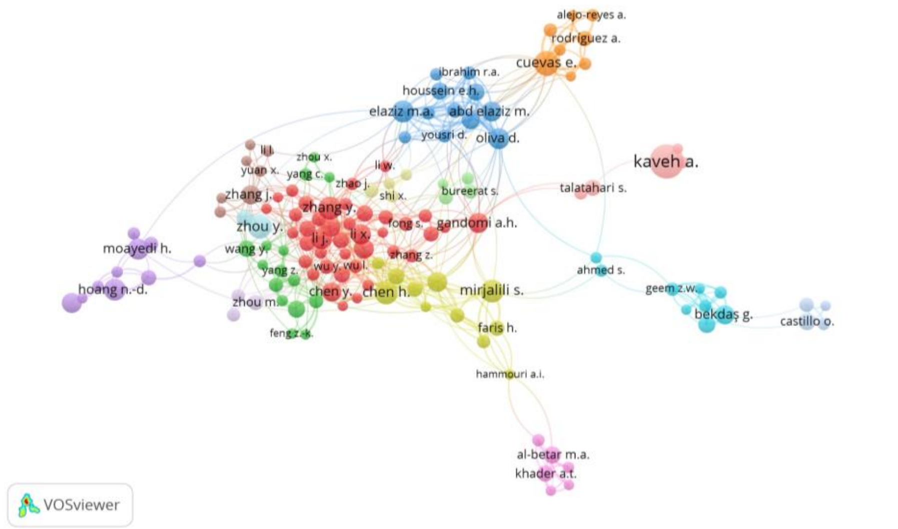
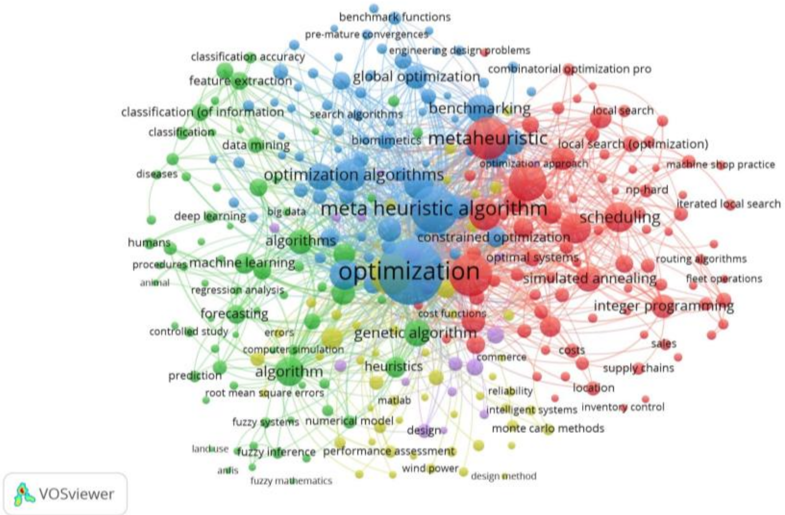
9 (1) January 2023 1-17



Description: Labels indicate authors or researchers. The color indicates cluster. Source [29]

Fig. 4. Co-authorship network in metaheuristic research

Duarte and Martí are listed as two prolific authors in metaheuristic research. Duarte and his colleagues in [89],[33],[90],[91],[92],[93] and Martí and her colleagues in [94],[90],[95],[96],[97],[93],[92] have offered their contribution to solving various operations and research problems using the metaheuristic method. In addition, Martí in [98],[99],[100],[101],[102] has also applied the metaheuristics method in solving several problems in graph theory. In another place, Hajiaghaei-Keshteli, an Iranian researcher, is a prominent researcher. He has collaborated with many other researchers to solve supply chain design problems, such as in [103],[104],[105],[106],[107],[108],[109],[110],[111],[112] Hajiaghaei-Keshteli and his associates have contributed to solving transportation, distribution, and scheduling problems, such as in [113],[114],[115],[116],[117].



Description: The labels indicate frequently appearing keywords or terms. The colors indicate clusters. Source [29]

Fig. 5. Mapping and clustering of 3846 articles in Scopus-Indexed Journals from 2016-2021, with the keyword metaheuristic method

Meanwhile, Figure 5 shows that each circle represents a keyword or term that frequently appears, and these were obtained from the title and abstract of the articles. The circle size indicates the number of publications related to the word, both in the title and abstract of the article, i.e. the larger the circle size, the greater the number of articles relevant to that keyword or phrase. Adjacent terms are often in a position close to each other in visualization. Table 5 presents the clustering of research themes based on frequently appearing words. The analysis found that the metadata of 3846 scientific articles with the theme of metaheuristic method, which came from Scopus-indexed journals in 2016-2021, could be grouped into five clusters, each of which can be identified based on its colour. The terms in each cluster can be seen in detail in Table 5.

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ISSN 2502-3357 (online) | ISSN 2503-0477 (print)
9 (1) January 2023 1-17

Table 5. Clustering Based on Frequently Appearing Words Sorted Alphabetically

Cluster	Words that appear frequently
Cluster 1 (87 items)	ant colony optimization, ant colony optimization (aco), approximation algorithms, branch and bound method, cloud computing, combinatorial optimization, combinatorial optimization problems, complex networks, computational complexity, computational efficiency, computational experiment, computational results, computational time, cost reduction, costs, decision making, economic and social effects, efficiency, energy efficiency, energy utilization, fleet operations, genetic algorithms, graph theory, graphic methods, heuristic algorithms, heuristic methods, high-quality solutions, hybrid algorithms, hybrid meta-heuristic, integer programming, inventory control, iterated local search, job shop scheduling, linear programming, local search, local search (optimization), location, machine shop practice, machinery, manufacture, mathematical programming, meta heuristics, meta-heuristic, meta-heuristic approach, metaheuristic, metaheuristics, multi objective, multi-objective optimization, multi-objective optimization problem, multiobjective optimization, multitasking, near-optimal solutions, network routing, nonlinear programming, np-hard, numerical experiments, optimal solutions, optimal solutions, optimal systems, pareto principle, polynomial approximation, problem solving, production control, quality of service, routing algorithms, sales, scheduling, scheduling algorithms, scheduling problem, simulated annealing, simulated annealing algorithms, state of the art, stochastic models, stochastic systems, supply chain management, supply chains, tabu search, taguchi methods, task scheduling, travel time, traveling salesman problem, uncertainty, variable neighborhood search, vehicle routing, vehicle routing problem, vehicle routing problems, vehicle
Cluster 2 (72 items)	accuracy assessment, adaptive neuro-fuzzy inference system, algorithm, algorithms, anfis, animal, animals, artificial intelligence, artificial neural network, artificial neural networks, big data, birds, classification, classification (of information), classification accuracy, comparative study, computer simulation, controlled study, data mining, decision trees, deep learning, diagnosis, diseases, evolutionary algorithm, extreme learning machine, feature extraction, feature selection, feedforward neural networks, forecasting, fuzzy inference, fuzzy logic, fuzzy mathematics, fuzzy neural networks, fuzzy systems, genetic algorithm, heuristics, human, humans, image processing, inference engines, iran, knowledge acquisition, land use, large dataset, learning systems, machine learning, mathematical model, metaheuristic optimization, multilayer neural networks, nearest neighboor search, neural networks, nonhuman, numerical model, particle swarm optimisation, particle swarm optimization, prediction, predictive analytics, priority journal, procedures, process optimization, pso, quality control, regression analysis, reinforced concrete, remote sensing, soft computing, state-of-the-art methods, statistical analysis, statistical tests, support vector machine, trees (mathematics)
Cluster 3 (71 items)	bat algorithm, bat algorithms, bench-mark problems, benchmark functions, benchmarking, bioluminescense, biomimetics, chaos theory, chaotic systems, cluster analysis, clustering, clustering algorithms, competitive performance, complex optimization problems, computation theory, constrained optimization problems, constrained optimization, covariance matrix, cuckoo search, cuckoo search algorithm, cuckoo search algorithms, cuckoo searches, differential evolution, differential evolution algorithms, economic dispatch, electric load dispatching, engineering design problems, engineering problems, entropy, evolutionary algorithms, evolutionary computation, exploration and exploitation, firefly algorithm, firefly algorithms, function evaluation function, global optimization, global optimization problems, gravitational search algorithm (gsa), gravitational search algorithms, grey wolf optimizer, image enhancement, image segmentation, iterative methods, k-means clustering, learning algorithms, meta heuristic algorithm, meta-heuristic methods, meta-heuristic optimizations, meta-heuristic search, meta-heuristics, metaheuristic algorithm, metaheuristic algorithms, multilevel thresholding, natured inspired algorithms, opposition-based learning, optimisations, optimization, optimization algorithms, optimization method, optimization problems, optimization techniques, optimizers, performance, population statistics, pre-mature convergences, real-world problem, search algorithms, signal to noise ratio, swarm intelligence, whale optimization algorithm
Cluster 4 (51 items)	artificial bee colonies, artificial bee colonies (ABC), artificial bee colony, artificial bee colony algorithms, commerce, controllers, cost-benefit analysis, cost-effectiveness, cost functions, curve fitting, design method, detection method, digital storage, electric load flow, electric power transmission network, electric utilities, errors, extraction, flower pollination algorithm, hybrid metaheuristic algorithms, intelligent systems, investments, Matlab, mean square error, meta-heuristic optimization techniques, meta-heuristics techniques, meta-heuristic algorithms, monte Carlo methods, numerical method, parameter estimation, particle swarm optimization (PSO), particle swarm optimization algorithm, performance assessment, photovoltaic system, proportional control systems, reliability, reliability analysis, renewable energy resources, root mean square errors, sensitivity analysis, simulation, solar energy, solar power generation, state-of-the-art algorithms, teaching-learning-based optimizations, three-term control systems, uncertainty analysis, wind, wind power, wind turbines
Cluster 5 (18 items)	bioinformatics, biology, design, ecology, finite element method, harmony search, harmony search algorithms, inverse problems, numerical methods, objective functions, optimization approach, shape optimization, structural analysis, structural design, structural optimization, systems engineering, topology, trusses

After conducting the mapping and clustering of metaheuristic research, the next step was to map research trends based on the year of the article publication. The information obtained from the overlay visualization results can be used to detect and identify the state-of-the-art research using the metaheuristic method conducted in the last four decades. An overlay visualization was also obtained from the analysis of the metadata imported into VOSviewer. In this visualization, the colour of a node represents the keyword, while the node's colour indicates the year the article was published containing that keyword. The darker the colour of the node, the longer the topic is discussed in the research. The visualization in Figure 6 shows that topics related to combinatorial optimization, scheduling, routing algorithm, vehicle routing problem, and global optimization were the topics discussed during 2016—2017. The topics covering constrained optimization, cluster analysis, artificial intelligence, heuristic algorithm, search algorithm, and integer programming were extensively discussed during the period of 2018-2019. Then, between the period of 2019-2021, the topics of task scheduling, decision-making, learning algorithm, exploration and exploitation, forecasting, feature selection, biomimetics, deep learning, and big data were the research topic trends in the studies using the metaheuristic methods.

VOSviewer uses the basic red-green-blue (RGB) colour of each visualization it produces. From the results of density visualization, as shown in Figure 7, it can be identified that dense areas are shown from the number of nodes that are adjacent to one node to another.

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9 (1) January 2023 1-17

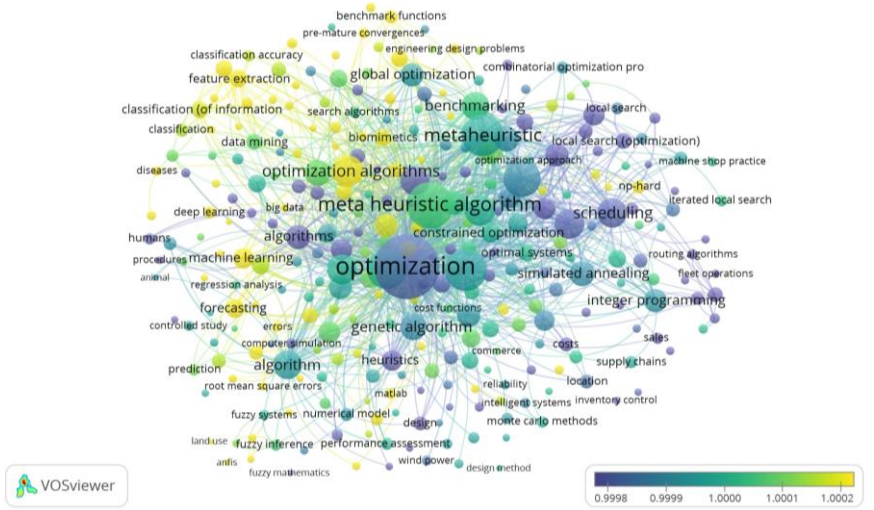

Fig. 6. Overlay Visualization of 3846 articles in Scopus-Indexed Journals from 2016-2021, with the keywords metaheuristic method

In addition, the rank of quantities shown by the number of keywords that frequently appear can be characterized by the yellow color around optimization, metaheuristic, and scheduling. In other words, this area is a theme that has been extensively researched. The issues indicated in blue/green color include graph theory, hybrid metaheuristic, design method, and detection method. This means that the last-mentioned topics have not been researched much, which indicates that a research gap in current metaheuristic research methods, so there is still a broad opportunity to conduct research in this topic.

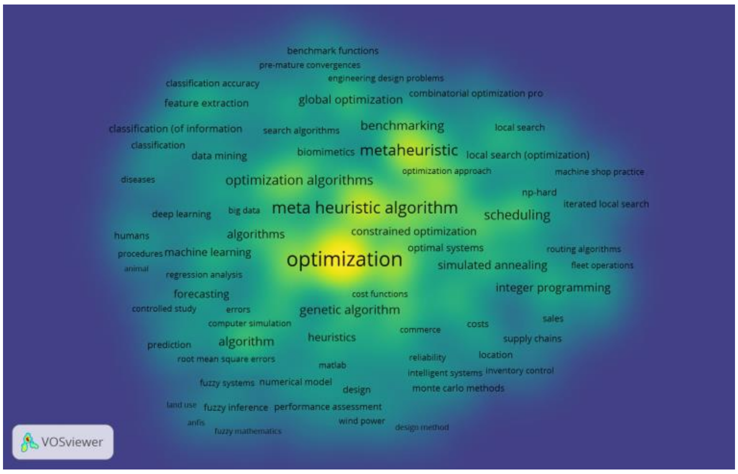

Fig. 7. Visualization of Density of 3846 articles in Scopus Indexed Journals in 2016-2021, with the keywords metaheuristic method.

4. Conclusion

This study comprehensively reviews metaheuristic research in the last five years of global literature output. Based on our findings, The top journals that contain scientific articles on metaheuristic research from 1991-2021 are the European Journal of Operational Research, Computers and Operation Research, and Expert Systems with Applications. Mirjalili is the most impactful and influential article with the highest number of citations in Scopus, followed by Dorigo, Hansen, and Gandomi. Optimization, heuristic methods, scheduling, genetic algorithms, evolutionary algorithm, and benchmarking are dominant topics in metaheuristic research. Meanwhile, the discussion on adaptive neuro-fuzzy inference, forecasting, feature selection, biomimetics, exploration, and exploitation is a growing hot issue for research in this field. The subjects indicated in blue/green, such as graph theory, hybrid metaheuristic, design method, and detection method, have not been extensively studied, which indicates a research gap in the current metaheuristic research methods. Therefore, a broad opportunity to research this topic is available. By involving studies from various disciplines, metaheuristic methods have become an exciting and promising topic. The current study suggests future research in systematic literature or bibliometric analysis to highlight each research field that uses metaheuristic methods.

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9 (1) January 2023 1-17

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Author Contributions

Hendy: Data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, visualization, writing – original draft, writing – review & editing. Mohammad Isa Irawan: Conceptualization, data curation, formal analysis, funding acquisition, investigation, supervision, methodology, resources, software, validation, visualization, writing – original draft, writing – review & editing. Imam Mukhlash: Data curation, formal analysis, funding acquisition, investigation, methodology, resources, software, supervision, validation, visualization, writing – original draft, writing – review & editing. Samsul Setumin: Data curation, writing-review & editing, validation.

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