Fuzzy Optimization and Decision Making (2019) 18:371–397
https://doi.org/10.1007/s10700-018-9301-8

A bibliometric analysis of Fuzzy Optimization and Decision Making (2002–2017)

Dejian Yu[1] · Zeshui Xu[2] · Wanru Wang[3]

Published online: 29 November 2018

Abstract

Fuzzy Optimization and Decision Making (FODM) is one of the influential journals in the research field of computer science and operation research, which was found in 2002. In this study, 370 publications published in FODM during 2002 and 2017 were retrieved from the Scopus database, and bibliometric methods are applied to analyze the structure of the FODM journal. First, general statistical analysis based on the number of publications and citations was implemented to find the annual publishing trends, citation structures, most cited publications, and productive authors/institutions/countries/territories. Second, the co-citation networks of cited authors/sources/references were generated; the nodes, links, and total link strengths based on the visualized networks are used to analyze citation connections. Next, to detect the development of the research topics, the co-occurrence networks of keywords of the different stages were illustrated, and the burst detection of keywords is used to identify the emerging topics. Finally, the future challenges of the FODM journal are discussed according to the process and findings of our study. This study provides a systematic and objective view of the FODM journal, which can be helpful for scholars to understand the development and the research structure of this journal.

Keywords Bibliometric analysis · Citation structure · Co-citation · Keywords co-occurrence · Burst detection

✉ Zeshui Xu
xuzeshui@263.net

Dejian Yu
yudejian62@126.com

Wanru Wang
wanruwang0401@163.com

[1] Business School, Nanjing Audit University, Nanjing 211815, Jiangsu, China

[2] Business School, Sichuan University, Chengdu 610064, China

[3] School of Information Management, Nanjing University, Nanjing 210023, China

1 Introduction

Fuzzy Optimization and Decision Making (FODM) focusing on the research related to optimization and decision making under fuzzy environment, is one of the most important journals in the research domain of computer science and operation research & management science. According to its journal homepage, FODM was found in 2002, and it publishes one volume with four issues per year. It first appeared in the 2009 edition of Journal Citation Reports (JCR), the latest JCR (2016 edition) indicates that the impact factor of FODM is 1.681. As FODM journal has been developed more than 15 years, a systematic analysis of the FODM publications is conducted using bibliometric methods in this study, so that some underlying information can be detected. This study can provide multiple views to understand the development of the FODM journal and find the evolution of the research directions that FODM concerned.

Bibliometrics was first named by Pritchard (1969), which aims to use mathematics and statistical methods to analyze bibliography. Generally, bibliographic elements, such as title, abstract, keywords, author names, institutions, journal titles, citations, and references, are extracted from retrieved dataset to make citation analysis (Garfield 1979). Bibliometric methods have been applied to various research fields, such as intuitionistic fuzzy set (Yu and Shi 2015), digital evaluation model (Peng et al. 2015), technology mining (Madani 2015), operations research and management science (He et al. 2017; Merigó and Yang 2017), product and process innovation (Marzi et al. 2017), and fuzzy set theory in China (Yu et al. 2018b).

In recent years, some scholars began to utilize bibliometric methods to analyze the publications of a specific journal to present the structure of the journal. For example, Calma and Davies (2015) used citation network analysis to present a retrospective analysis of the publications of *Studies in Higher Education* between 1976 and 2013, citation analysis and clustering analysis were applied to find the most productive authors, most cited authors, and most discussed research topics. Yu et al. (2017) and Merigó et al. (2018) both made a bibliometric analysis of the publications published in *Information Sciences* (IS) to celebrate its 50th anniversary, both of these two studies analyzed the publishing trend, most cited papers, and influential authors/institutions/countries/territories. However, Yu et al. (2017) also explored the collaborative pattern of the authors from the views of the cooperation of countries and institutions, respectively, and made co-citation analysis of documents to summarize the emerging trends of the IS journal according to the network visualized by CiteSpace; Merigó et al. (2018) utilized the visualized tool VOSviewer to generate different kinds of bibliographic networks to provide a deeper view, and five stages of the co-citation networks of journals were provided to find the citation evolution of the IS journal. Goyal (2017) showed a systematic overview of *Policy Sciences* by using bibliometric methods to analyze the 1072 publications during 1970 and 2017, the most influential authors, most important references, and the research topics were discussed. Zhang et al. (2017) analyzed the topic change of the *Knowledge-Based Systems* (KBS) using topic-based bibliometric methods, six main research topics of the KBS were detected, and it can provide important guidance for the submissions of the KBS. Yu et al. (2018a) presented a comprehensive bibliometric analysis of the publications in *IEEE Transactions on Fuzzy Systems* (TFS) during 1994–2015 from

the perspectives of citation structure, authorship, collaboration, global distribution, co-citation analysis, and clustering analysis, the result is contributed to understanding the influence and research focuses of the TFS.

In this study, to show a systematic and objective overview of the FODM journal, the publications in the FODM between 2002 and 2017 are analyzed using bibliometric methods. First, general analyses of the FODM publications and citations, including yearly output, citation structure, situation of being cited, high cited publications, productivity of the authors/institutions/countries/territories, are presented according to the total number of publications (TP), total number of citations (TC), citations per publication (TC/TP), and h-index (Hirsch 2005). Then, the co-citation networks of the cited authors/sources/references are illustrated based on the nodes, links, and link strengths in the networks. Finally, the co-occurrence networks of keywords of different stages are shown to analyze the development of the research topics of the FODM publications, and the burst detection of keywords is used to identify the emerging topics. As an influential journal in the field of fuzzy and decision making, FODM publications have made important contributions to the studies in the fields of management, business, economics, operation research and engineering, etc. Therefore, the findings of this study are helpful for researchers to understand the structure and development of the related research.

This paper consists of six sections. After the Introduction section, the general analysis of FODM publications is presented in Sect. 2, the co-citation networks analysis is shown in Sect. 3, and the co-occurrence network analysis of keywords is illustrated in Sect. 4. Section 5 discusses the future challenges of the FODM journal, and Sect. 6 concludes this study.

2 General analysis of FODM publications

In this section, basic statistical analysis of 370 publications that were published in the FODM between 2002 and 2017 are presented. The dataset was retrieved from Scopus database on February 20, 2018, all the related data statistics were exported on the same day to make further data processing. We choose Scopus database because it covers all the years' data of the FODM journal from 2002, whereas the Web of Science only includes the FODM publications from 2007. Scopus database is also one of the main sources for bibliometric study and has been used in some of the existing studies (Eito-Brun and Rodríguez 2016; Palomo et al. 2017; Cristino et al. 2018). The publication types of the dataset used in this study include articles (340), conference papers (14), editorials (9), reviews (4), and errata (3).

2.1 Publication and citation structure of FODM

FODM has published four issues with about 20 publications each year since its first volume started in 2002. Figure 1 shows the number of FODM publications and the h-index between 2002 and 2017, the h-index values of the most of the years is higher than 10, except for the latest 4 years. The annual distribution of citations is shown in

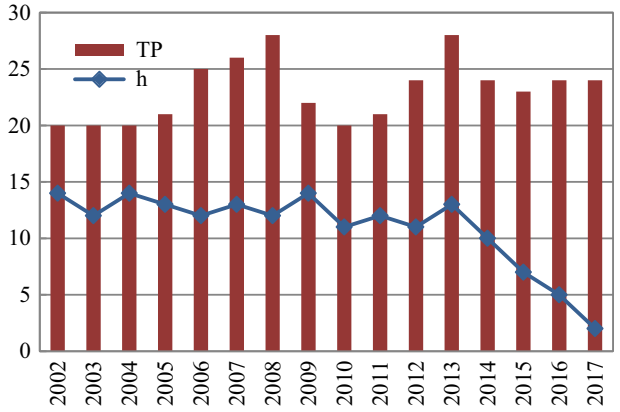

Fig. 1 Distribution of FODM publications by years, 2002–2017

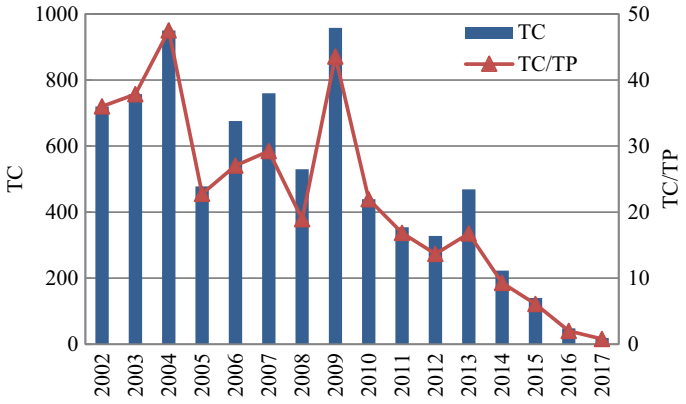

Fig. 2 Distribution of citations of FODM publications by years, 2002–2017

Fig. 2, it can be seen that the publications published in 2004 and 2009 received more than 900 citations, respectively, and both of the numbers of citations per publication (TC/TP) are higher than 40.

Table 1 lists the statistics of citation structure of the FODM publications by years, five publications (1.35%) have been cited more than 200 times, 14 publications (3.78%) have been cited more than 100 times (including the number of publications that are cited more than 200 times), and 38 publications (10.27%) have received more than 50 citations. More than half publications received more than five citations so far, and ninety percent publications have been cited at least one time. In addition, the number of authors per publication per year (AN/TP) is also listed in Table 1. The values of AN/TP are all about two authors per publication each year, and the values of the latest 2 years are close to three authors, which imply the trend of the collaboration among multiple authors in the FODM publications.

Table 1 Statistics of citation structure in FODM by years according to Scopus

Year	TP	TC	≥ 200	≥ 100	≥ 50	≥ 20	≥ 10	≥ 5	≥ 1	TC/TP	AN/TP	h
2002	20	720	0	2	6	11	14	17	18	36.00	2.05	14
2003	20	757	1	1	5	10	13	16	20	37.85	2.15	12
2004	20	950	1	2	4	8	15	15	20	47.50	2.20	14
2005	21	478	0	0	3	10	13	17	20	22.76	2.29	13
2006	25	676	1	1	2	8	14	18	20	27.04	2.08	12
2007	26	760	1	2	4	8	14	18	26	29.23	1.88	13
2008	28	530	0	1	2	10	12	19	25	18.93	2.39	12
2009	22	958	1	3	5	9	16	21	22	43.55	2.14	14
2010	20	439	0	1	2	4	12	15	20	21.95	1.95	11
2011	21	354	0	0	2	7	14	18	21	16.86	2.10	12
2012	24	328	0	0	1	5	12	17	22	13.67	2.17	11
2013	28	469	0	1	2	7	15	25	26	16.75	2.36	13
2014	24	223	0	0	0	4	10	14	23	9.29	2.17	10
2015	23	140	0	0	0	0	6	14	22	6.09	2.30	7
2016	24	48	0	0	0	0	0	5	17	2.00	2.54	5
2017	24	19	0	0	0	0	0	0	11	0.79	2.71	2
Total	370	7849	5	14	38	101	180	249	333	–	–	–
Percentage	–	–	1.35%	3.78%	10.27%	27.30%	48.65%	67.30%	90.00%	–	–	–

2.2 Who is paying attention to FODM?

As one of the international journals in the field of computer science and operation research, FODM has attracted researchers from all over the world. To analyze the attention of the FODM journal, four aspects, including the number of publications of the source, country/territory, institution, and subject that cites the FODM publications, are shown in Table 2.

According to the top 20 sources that cite the FODM, *Journal of Intelligent and Fuzzy Systems* is ranked first with 249 papers citing the FODM publications, followed by *Information Sciences* and FODM itself with 211 and 201 papers citing the FODM publications, respectively. There are 143 papers in *Fuzzy Sets and Systems*, 123 papers in *Lecture Notes in Computer Science* (it mainly publishes conference proceedings papers in the field of computer science), 121 papers in *IEEE Transactions on Fuzzy Systems*, 120 papers in *Applied Soft Computing*, and 112 papers in *Expert Systems with Applications* citing the FODM publications according to the Scopus database.

In terms of country/territory, researches from China cite the most number of the FODM publications with 2654 papers. The other countries/territories have less than 500 papers that citing FODM publications respectively, such as Spain (439), India (437), Iran (391), United States (365), Taiwan (238), and Japan (200) from a high level to low level. Among the top 20 institutions, 14 of them are from China mainland, and Sichuan University is ranked the first with 167 papers that cite the FODM publications, followed by Tsinghua University with 152 papers. Two universities from Spain, including Universidad de Granada and Universitat de Barcelona, are ranked third and eighth with 137 papers and 86 papers, respectively. It should be noted that if a paper is finished by researchers from different countries/institutions, each country/institution would be counted as having one paper in this research.

To find papers from which subjects are concerning the FODM publications, the top 20 subjects with a high number of publications are also listed in Table 2. As we can expect, the papers in the fields of Computer Science (3933), Mathematics (2677), and Engineering (2287) account for a high percentage, followed by Decision Sciences (814), Business, Management and Accounting (427), Social Sciences (190), and Environmental Science (179). In addition, there are some papers from the subjects of Physics and Astronomy, Medicine, and Chemistry also paying attention to the FODM publications.

2.3 The most cited publications in FODM

The top 30 most cited publications in FODM are listed in Table 3, including their titles, authors, publication year, number of citations, and citations per year (TC/Year). Most of these publications were published before 2010, with only two publications were published after 2010, and no publication was published in recent 4 years. These 30 publications cover the researches of the theoretical developments, methods, modeling, and applications related to ordered weighted averaging operators, multiple attribute decision making, fuzzy optimization, and intuitionistic fuzzy information.

Table 2 Numbers of publications of the source/country/territory/institution/subject citing FODM

Rank	Source	TP	Country/territory	TP	Institution	TP	Subject	TP
1	Journal of Intelligent and Fuzzy Systems	249	China	2654	Sichuan University	167	Computer Science	3933
2	Information Sciences	211	Spain	439	Tsinghua University	152	Mathematics	2677
3	Fuzzy Optimization and Decision Making	201	India	437	Universidad de Granada	137	Engineering	2287
4	Fuzzy Sets and Systems	143	Iran	391	Southeast University	117	Decision Sciences	814
5	Lecture Notes in Computer Science	123	United States	365	Hebei University	117	Business, Management and Accounting	427
6	IEEE Transactions on Fuzzy Systems	121	Taiwan	238	Central South University China	100	Social Sciences	190
7	Applied Soft Computing	120	Japan	200	Tianjin University	99	Environmental Science	179
8	Expert Systems with Applications	112	United Kingdom	184	Universitat de Barcelona	86	Economics, Econometrics and Finance	137
9	Studies in Fuzziness and Soft Computing	100	Malaysia	156	PLA University of Science and Technology	77	Energy	114
10	International Journal of Uncertainty Fuzziness and Knowledge-Based Systems	96	Canada	145	Zhejiang University of Finance and Economics	71	Multidisciplinary	101
11	Soft Computing	94	Italy	144	Islamic Azad University	66	Physics and Astronomy	93
12	IEEE International Conference on Fuzzy Systems	93	Turkey	134	Iona College	63	Earth and Planetary Sciences	67

Table 2 continued

Rank	Source	TP	Country/territory	TP	Institution	TP	Subject	TP
13	Computers and Industrial Engineering	90	Poland	102	Waseda University	63	Materials Science	57
14	Knowledge-Based Systems	88	South Korea	99	Beijing Institute of Technology	61	Chemical Engineering	49
15	International Journal of Intelligent Systems	86	France	98	Dalian University of Technology	60	Medicine	49
16	Advances in Intelligent Systems and Computing	80	Australia	93	Beihang University	60	Biochemistry, Genetics and Molecular Biology	45
17	European Journal of Operational Research	56	Germany	81	Chinese Academy of Sciences	58	Agricultural and Biological Sciences	43
18	Mathematical Problems in Engineering	55	Czech Republic	74	Nanjing University of Science and Technology	54	Arts and Humanities	43
19	Communications in Computer and Information Science	49	Brazil	69	University of Tehran	54	Chemistry	28
20	Applied Mathematical Modelling	48	Saudi Arabia	67	Fuzhou University	53	Neuroscience	15

Table 3 Top 30 most cited publications in FODM according to Scopus

Rank	Title	Author(s)	Year	TC	TC/year
1	Generalized OWA aggregation operators	Yager RR	2004	391	30.08
2	A survey of credibility theory	Liu B	2006	309	28.09
3	Computing with words in decision making: foundations, trends and prospects	Herrera F, Alonso S, Chiclana F, Herrera-Viedma E	2009	287	35.88
4	Fuzzy random variables: a scalar expected value operator	Liu YK, Liu B	2003	252	18.00
5	Some similarity measures of intuitionistic fuzzy sets and their applications to multiple attribute decision making	Xu ZS	2007	218	21.80
6	Intuitionistic and interval-valued intuitionistic fuzzy preference relations and their measures of similarity for the evaluation of agreement within a group	Xu ZS, Yager RR	2009	170	21.25
7	Existence and uniqueness theorem for uncertain differential equations	Chen X, Liu B	2010	156	22.29
8	On compatibility of interval fuzzy preference relations	Xu ZS	2004	142	10.92
9	Toward fuzzy optimization without mathematical ambiguity	Liu B	2002	119	7.93
10	Prioritized OWA aggregation	Yager RR	2009	113	14.13
11	Efficiency analysis and ranking of DMUs with fuzzy data	Saati MS, Memariani A, Jahanshahloo GR	2002	113	7.53
12	Multi-person multi-attribute decision making models under intuitionistic fuzzy environment	Xu ZS	2007	109	10.90
13	Extension of the LINMAP for multiattribute decision making under Atanassov's intuitionistic fuzzy environment	Li DF	2008	108	12.00
14	A VIKOR-based method for hesitant fuzzy multi-criteria decision making	Liao HC, Xu ZS	2013	103	25.75
15	Project selection by constrained fuzzy AHP	Enea M, Piazza T	2004	93	7.15
16	Recent advances in intuitionistic fuzzy information aggregation	Xu ZS, Cai X	2010	91	13.00
17	Performance analysis of adaptive genetic algorithms with fuzzy logic and heuristics	Yun Y, Gen M	2003	84	6.00

Table 3 continued

Rank	Title	Author(s)	Year	TC	TC/year
18	On fuzzy portfolio selection problems	Wang S, Zhu S	2002	83	5.53
19	Application of fuzzy linear programming in production planning	Vasant PM	2003	80	5.71
20	Some aspects of intuitionistic fuzzy sets	Yager RR	2009	72	9.00
21	Learning weights in the generalized OWA operators	Beliakov G	2005	68	5.67
22	Heavy OWA operators	Yager RR	2002	63	4.20
23	Interactive fuzzy linear programming and an application sample at a textile firm	Ertuğrul I, Tuş A	2007	62	6.20
24	An approach to improving consistency of fuzzy preference matrix	Xu ZS, Da Q	2003	62	4.43
25	On method for uncertain multiple attribute decision making problems with uncertain multiplicative preference information on alternatives	Xu ZS	2005	59	4.92
26	A new method for ranking intuitionistic fuzzy values and its application in multi-attribute decision making	Zhang X, Xu ZS	2012	56	11.20
27	Fuzzy BCC model for data envelopment analysis	Lertworasirikul S, Fang SC, Nuttle HLW, Joines JA	2003	56	4.00
28	Fuzzy Markov chains and decision-making	Avrachenkov KE, Sanchez E	2002	56	3.73
29	Minimizing a linear objective function with fuzzy relation equation constraints	Guu SM, Wu YK	2002	55	3.67
30	A survey on fuzzy relational equations, part I: classification and solvability	Li P, Fang SC	2009	54	6.75

As we stated in Sect. 2.1, there are five publications that have been cited more than 200 times, i.e. Yager (2004), Liu (2006), Herrera et al. (2009), Liu and Liu (2003) and Xu (2007). According to the TC/Year, seven publications are cited more than 20 times per year since they were published, respectively, including the four of the top five publications, Xu and Yager (2009), Chen and Liu (2010) and Liao and Xu (2013). Liao and Xu (2013) is the youngest publication in the top 30 most cited publications, which introduced a VIKOR-based method to solve multi-criteria decision making problems under the hesitant fuzzy circumstance. In these 30 publications listed in

Table 3, nine publications are authored/co-authored by Xu ZS (Sichuan University, China), five publications are authored/co-authored by Yager RR (Iona College, United States), and four publications are authored/co-authored by Liu B (Tsinghua University, China). To further analyze the influential authors, the statistics of authors of the FODM publications are listed in the next subsection.

2.4 The most productive authors/institutions/countries/territories

Table 4 lists the top 20 most productive authors with at least five publications in FODM, it can be seen that five authors have published more than 10 papers in FODM. Xu ZS from Sichuan University (China) is ranked the first with publishing 23 publications in FODM and has been cited for 1219 times, followed by Yager RR from Iona College (United States) with 19 publications and 1012 citations. Both of these two scholars have received more than 50 citations per publication, and their h-index is higher than ten. According to the total number of citations, Liu B from Tsinghua University (China) is ranked third with 955 citations, and he is ranked first according to the value of TC/TP, which means each of his publication is cited on an average of 86.82 times.

In Table 4, the total number of publications that have been cited more than 200, 100, 50, 20, and 10 of the most productive authors are also listed. Liu B has the most publications (two publications) are cited more than 200 times. Both of Xu ZS and Yager RR have one publication with more than 200 citations, and 13 publications of them have been cited more than 10 times, respectively. Among these 20 productive authors, there are nine authors from China, three from the United States and Germany, respectively. Table 5 lists the most productive countries/territories with more than five FODM publications, China is ranked first, which has published 149 publications in FODM with 3712 citations, it is followed by the United States that has published 55 publications in FODM and has been cited 1519 times. The next four countries/territories are Taiwan, Spain, Japan, and India with at least 20 publications.

The most productive institutions with at least five publications in FODM are listed in Table 6. There are 13 institutions from China, Tsinghua University, one of the famous universities in China, is ranked first with 29 publications and has been cited 1643 times. Two universities from the United States are followed by Tsinghua University, i.e., Iona College and North Carolina State University. Southeast University from China is ranked first according to the value of TC/TP, there are nine publications that have received 569 citations in total, and each publication received 63.22 citations. In addition, the h-index, and the total number of publications that have been cited more than 200, 100, 50, 20, and 10 of the most productive countries/territories and institutions are also provided in Tables 5 and 6, respectively.

3 Co-citation network analysis

In this section, the co-citation (Small 1973) networks of the cited authors/sources/references by FODM publications are illustrated and analyzed. A bibliometric tool

Table 4 Most productive authors in FODM

Rank	Name	Institution	Country/territory	TP	TC	TC/TP	h	≥ 200	≥ 100	≥ 50	≥ 20	≥ 10
1	Xu ZS	Sichuan University	China	23	1219	53.00	14	1	5	11	13	13
2	Yager RR	Iona College	United States	19	1012	53.26	11	1	3	5	9	13
3	Wu HC	National Kaohsiung Normal University	Taiwan	13	125	9.62	7	0	0	0	1	4
4	Fang SC	North Carolina State University	United States	12	229	19.08	7	0	0	3	4	5
5	Liu B	Tsinghua University	China	11	955	86.82	9	2	4	4	6	9
6	Inuiguchi M	Osaka University	Japan	6	36	6.00	2	0	0	0	0	2
7	Ke H	Tongji University	China	6	53	8.83	4	0	0	0	0	3
8	Tang WS	Tianjin University	China	6	76	12.67	5	0	0	0	1	3
9	Verdegay JL	University of Granada	Spain	6	72	12.00	5	0	0	0	1	4
10	Yao K	Tsinghua University	China	6	123	20.50	5	0	0	1	2	4
12	Cao BY	Guangzhou University	China	6	18	3.00	1	0	0	0	0	1
11	Bector CR	University of Manitoba	Canada	5	161	32.20	5	0	0	1	4	5
13	Chandra S	Indian Institute of Technology Delhi	India	5	151	30.20	5	0	0	1	3	5
14	Kumar M	Institute of Preventive Medicine	Germany	5	67	13.40	5	0	0	0	0	5
15	Li DF	Fuzhou University	China	5	214	42.80	5	0	1	1	3	4
16	Li PK	Tsinghua University	China	5	132	26.40	5	0	0	2	2	3
17	Nuttle HLW	North Carolina State University	United States	5	87	17.40	3	0	0	1	2	2
18	Stoll N	Institute of Automation	Germany	5	67	13.40	5	0	0	0	0	5
19	Stoll R	Institute of Preventive Medicine	Germany	5	67	13.40	5	0	0	0	0	5
20	Zhao RQ	Tianjin University	China	5	59	11.80	4	0	0	0	1	2

Table 5 Most productive countries/territories in FODM

Rank	Country/territory	TP	TC	TC/TP	h	≥ 200	≥ 100	≥ 50	≥ 20	≥ 10
1	China	149	3712	24.91	30	3	10	22	41	75
2	United States	55	1519	27.62	19	1	3	8	19	27
3	Taiwan	38	425	11.18	11	0	0	1	6	12
4	Spain	24	475	19.79	10	1	1	1	4	10
5	Japan	21	348	16.57	11	0	0	1	5	12
6	India	20	396	19.80	13	0	0	1	8	14
7	Iran	15	215	14.33	5	0	1	1	2	4
8	Italy	15	222	14.80	7	0	0	1	5	5
9	Canada	9	199	22.11	8	0	0	1	4	6
10	Czech Republic	9	169	18.78	6	0	0	0	5	5
11	Germany	9	122	13.56	7	0	0	0	1	6
12	South Korea	9	170	18.89	4	0	0	2	2	4
13	Poland	8	65	8.13	4	0	0	0	1	1
14	United Kingdom	8	321	40.13	4	1	1	1	1	2
15	Australia	7	139	19.86	5	0	0	1	3	3
16	France	6	150	25.00	5	0	0	1	4	4
17	Belgium	5	68	13.60	4	0	0	0	2	2
18	Malaysia	5	180	36.00	4	0	0	1	3	4

VOSviewer is used to generate the networks in this section, which was developed by Van Eck and Waltman (2010).

3.1 Co-citation network of cited authors

To find the most cited authors by FODM, the co-citation network of the cited authors by FODM publications is shown in Fig. 3. Only those authors have been cited at least eight times are chosen to be displayed in this network, 315 authors meet the threshold among the 5956 authors. In Fig. 3, one node represents one author, the total number of citations of authors is used to indicate the weight of nodes, the edges between two nodes mean that these two authors are co-cited, and different thicknesses of the edges mean different weights of the links.

As shown in Fig. 3, the first three largest nodes are Liu B, Zadeh LA, and Yager RR. Based on the co-citation network of cited authors, the top ten most cited authors by FODM publications are listed in Table 7, the numbers of citations, links, and total link strength (TLS) of the most cited authors are also provided. Due to the problem of different formats representing the same name, for example, both the node 'Xu, Z.S.' and the node 'Xu, Z.' in Fig. 3 represent the author 'Xu Zeshui', we merged the values of those different formats of the same author in Table 7. Liu B was cited the most by FODM for 545 times, and he is co-cited with 202 authors for 13,311 times. Zadeh

Table 6 Most productive institutions in FODM

Rank	Institution	Country/territory	TP	TC	TC/TP	h	≥ 200	≥ 100	≥ 50	≥ 20	≥ 10
1	Tsinghua University	China	29	1643	56.66	17	3	6	9	15	21
2	Iona College	United States	18	1011	56.17	11	1	3	5	9	13
3	North Carolina State University	United States	12	229	19.08	7	0	0	3	4	5
4	Sichuan University	China	11	63	5.73	4	0	0	0	0	3
5	National Kaohsiung Normal University	Taiwan	10	76	7.60	5	0	0	0	0	3
6	Southeast University	China	9	569	63.22	7	0	2	6	7	7
7	Osaka University	Japan	8	92	11.50	5	0	0	0	1	5
8	University of Granada	Spain	8	355	44.38	6	1	1	1	2	4
9	PLA University of Science and Technology China	China	8	216	27.00	5	0	1	2	3	4
10	Hebei University	China	7	338	48.29	6	1	1	1	2	5
11	Chinese Academy of Sciences	China	7	124	17.71	5	0	0	1	1	3
12	Guangzhou University	China	7	23	3.29	2	0	0	0	0	1
13	Tongji University	China	7	54	7.71	4	0	0	0	0	3
14	Dalian University of Technology	China	6	184	30.67	5	0	0	2	5	5
15	Renmin University of China	China	6	80	13.33	3	0	0	1	2	2
16	Tianjin University	China	6	76	12.67	5	0	0	0	1	3
17	University of Manitoba	Canada	5	161	32.20	5	0	0	1	4	5
18	Fuzhou University	China	5	65	13.00	4	0	0	0	1	2
19	University of Science and Technology Beijing	China	5	101	20.20	3	0	0	1	3	3
20	Wrocław University of Science and Technology	Poland	5	23	4.60	3	0	0	0	0	0
21	I-Shou University	Taiwan	5	74	14.80	4	0	0	0	1	2
22	Indian Institute of Technology Delhi	India	5	151	30.20	5	0	0	1	3	5

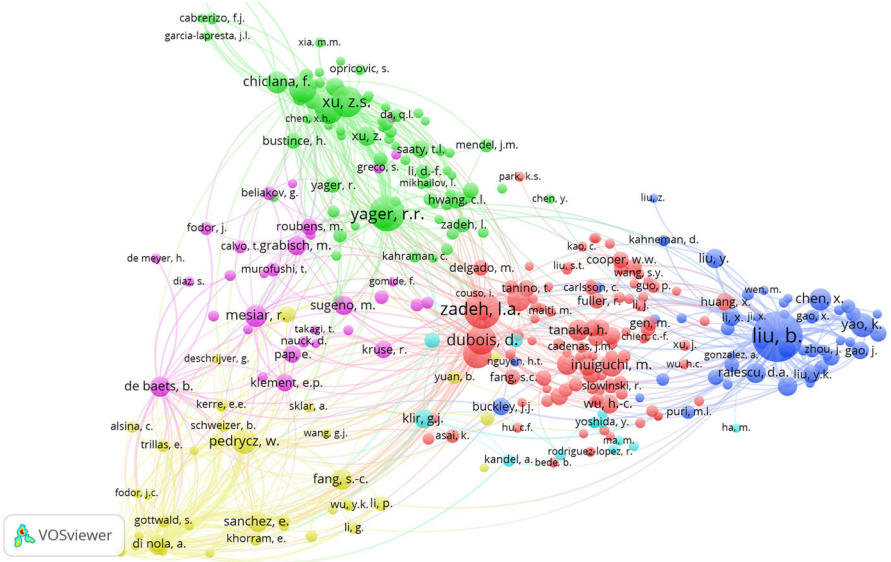

Fig. 3 Co-citation network of cited authors

LA is ranked second according to the number of citations, and he is co-cited with 441 authors. The followed are Yager RR, Xu ZS, and Dubois D.

3.2 Co-citation network of cited sources

Similarly, Fig. 4 shows the co-citation network of the cited sources by FODM, the threshold of the minimum number of citations of a source is set as five, and 183 sources meet the threshold among the 2730 sources. Table 7 also lists the top ten most cited sources by FODM with the number of citations, the number of co-cited links, and TLS.

It is well-marked in Fig. 4 that the biggest node is *Fuzzy Sets and Systems* in the center, which indicates that it is the most popular journal cited by FODM for 1275 times. There are 178 links connected with *Fuzzy Sets and Systems*, which means that it is co-cited with 178 sources for a total of 23,650 times. FODM is cited by itself for 463 times, followed by *European Journal of Operational Research*, *Information Sciences*, *IEEE Transactions on Fuzzy Systems*, and *Journal of Uncertain Systems*.

3.3 Co-citation network of cited references

The co-citation network of the cited references is shown in Fig. 5, the threshold of the minimum number of citations of a cited reference is set as two, 602 references meet the threshold among the 7556 cited references, and the top 500 cited references based on the value of TLS is selected. Because there are some slight differences in the formats of some references, when we exported the data of the co-citation network

Table 7 Most cited authors and sources by FODM

Rank	Author	Citations	Links	TLS	Source	Citations	Links	TLS
1	Liu B	545	202	13,311	Fuzzy Sets and Systems	1275	178	23,650
2	Zadeh LA	291	441	8332	Fuzzy Optimization and Decision Making	463	172	8182
3	Yager RR	262	359	7163	European Journal of Operational Research	371	159	7130
4	Xu ZS	220	297	6773	Information Sciences	320	163	9113
5	Dubois D	146	265	5072	IEEE Transactions on Fuzzy Systems	226	161	5533
6	Herrera F	137	188	5755	Journal of Uncertain Systems	159	77	2136
7	Prade H	131	262	4926	International Journal of Intelligent Systems	115	126	2820
8	Herrera-Viedma E	121	166	5549	Information and Control	109	154	2326
9	Kacprzyk J	97	219	3479	Management Science	79	119	1420
10	Fang SC	96	229	3052	Applied Mathematics and Computation	78	106	2678

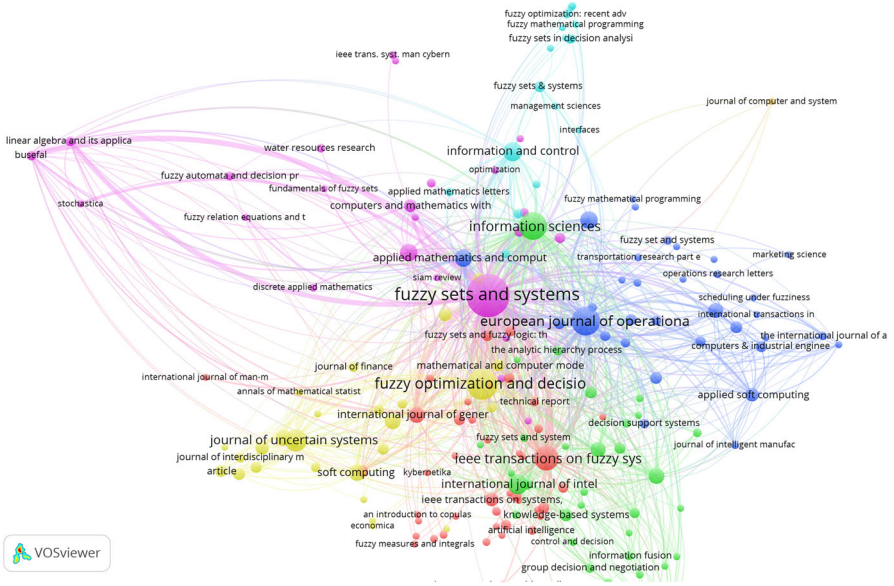

Fig. 4 Co-citation network of cited sources

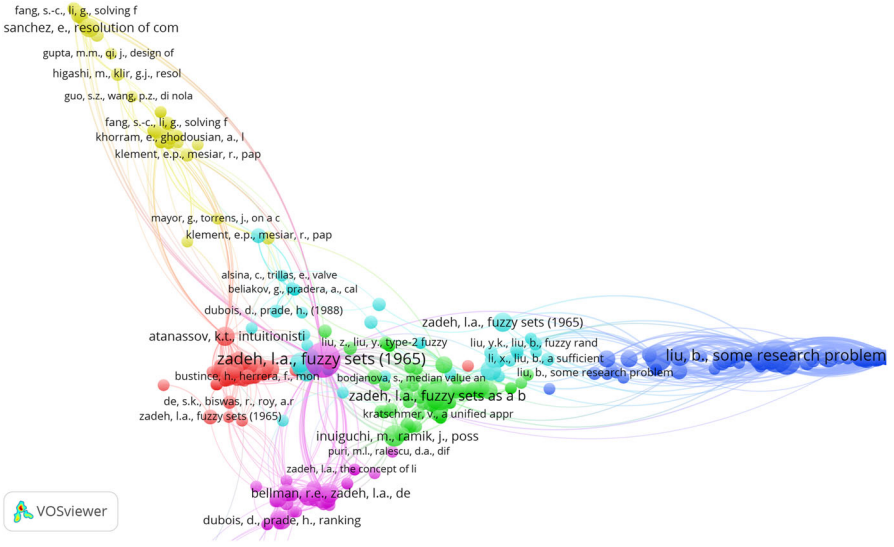

Fig. 5 Co-citation network of cited references

of cited references, we merged the values of those references representing the same one, and the top ten most cited references by FODM publications are listed in Table 8, including their titles, authors, sources, publish year, number of citations, number of co-cited links, and TLS.

Table 8 Most cited references by FODM publications

Rank	Title	Author(s)	Source	Year	Citations	Links	TLS
1	Fuzzy sets	Zadeh LA	Information and Control	1965	75	331	456
2	Some research problems in uncertainty theory	Liu B	Journal of Uncertain Systems	2009	39	111	364
3	Uncertainty theory (2nd ed.)	Liu B	Berlin: Springer	2007	38	145	341
4	Uncertainty theory: a branch of mathematics for modeling human uncertainty	Liu B	Berlin: Springer	2010	38	190	357
5	Fuzzy sets as a basis for a theory of possibility	Zadeh LA	Fuzzy Sets and Systems	1978	31	162	217
6	Fuzzy process, hybrid process and uncertain process	Liu B	Journal of Uncertain Systems	2008	23	87	242
7	Why is there a need for uncertainty theory?	Liu B	Journal of Uncertain Systems	2012	21	85	187
8	Expected value of fuzzy variable and fuzzy expected value models	Liu B, Liu YK	IEEE Transactions on Fuzzy Systems	2002	18	105	149
9	Existence and uniqueness theorem for uncertain differential equations	Chen X, Liu B	Fuzzy Optimization and Decision Making	2010	13	65	155
10	Theory and practice of uncertain programming	Liu B	Berlin: Springer	2009	13	74	111

It can be seen that Zadeh (1965) is the most cited reference in the FODM publications, it has been cited by 75 FODM publications and there are 331 co-citation links in the co-citation network of cited reference, i.e., it is co-cited with 331 references by FODM publication for 456 times based on our dataset. Among these ten most cited references, eight references are authored/co-authored by Liu B, including two books published by Springer; and two papers are authored by Zaden LA. In addition, the youngest reference is Liu (2012) and it was published in the *Journal of Uncertain Systems* in 2012.

4 Co-occurrence analysis of keywords

To summarize the research topics of FODM publications, the co-occurrence networks of keywords (including author keywords and index keyword provided by Scopus) are analyzed in this section. According to Chen et al. (2008), when using the keywords to identify thematic topics, its conceptual level is higher than the terms extracted from

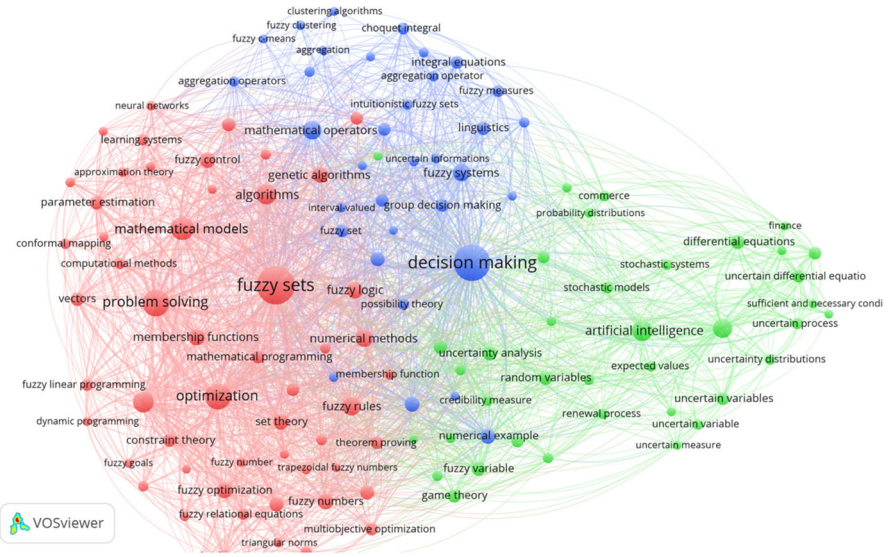

Fig. 6 Co-occurrence network of keywords of FODM publications, 2002–2017

titles and abstracts generally. To further analyze the development of research topics, the period between 2002 and 2017 is divided into three stages: 2002–2006, 2007–2011, and 2012–2017, and three keywords co-occurrence networks corresponding to the three stages are also illustrated. The co-occurrence networks of keywords in this section are also generated using VOSviewer (Van Eck and Waltman 2010).

4.1 Co-occurred networks of the keywords in different stages

Figures 6, 7, 8 and 9 show the four co-occurrence networks of keywords in the four different stages, respectively, keywords occurred at least three times are selected to create the co-occurrence networks in Figs. 6, 7 and 8 and the threshold is set five in Fig. 9. The nodes represent the keywords, the number of occurrence is used to represent the weight of the nodes; the link between two nodes means that these two keywords occurred together in the FODM publications, and the thicker line is, the more co-occurred times they have. The top 30 keywords used in the FODM publications in four stages are also provided with the frequency (Freq) in Table 9, and the single and plural forms of the keywords are merged together.

As shown in Fig. 6, the top two biggest nodes are ‘fuzzy sets’ and ‘decision making’, which have been respectively used 163 and 142 times during 2002 and 2017 according to Table 9. The following used keywords are ‘problem solving’, ‘optimization’, and ‘mathematical models’. The node ‘fuzzy sets’ has strong link strength with the nodes ‘decision making’ (62), ‘problem solving’ (49), ‘optimization’ (39), and ‘mathematical models’ (34). All these keywords are highly correlated to fuzzy optimization and decision making research. It should be noted that the link strength of the link between nodes ‘decision making’ and ‘artificial intelligence’ is also strong (37), and the key-

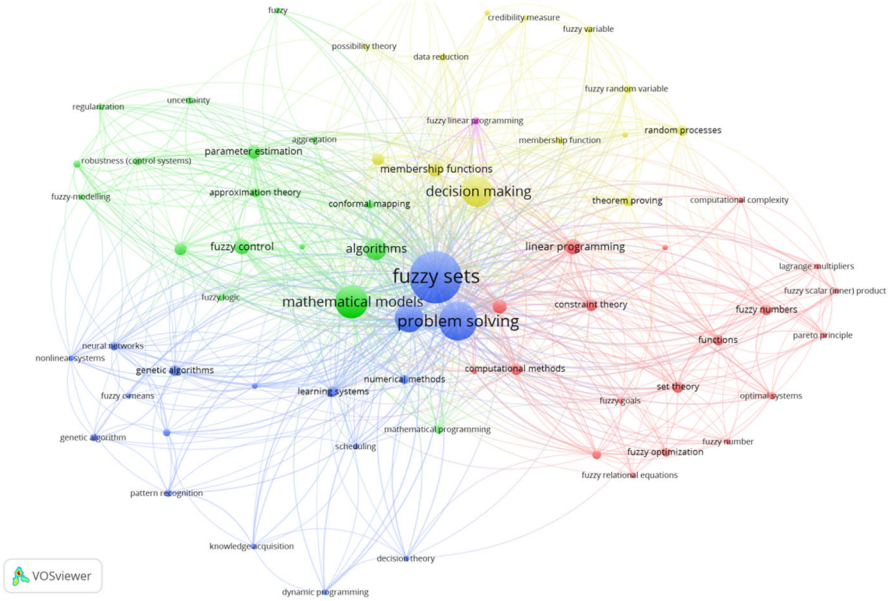

Fig. 7 Co-occurrence network of keywords of FODM publications, 2002–2006

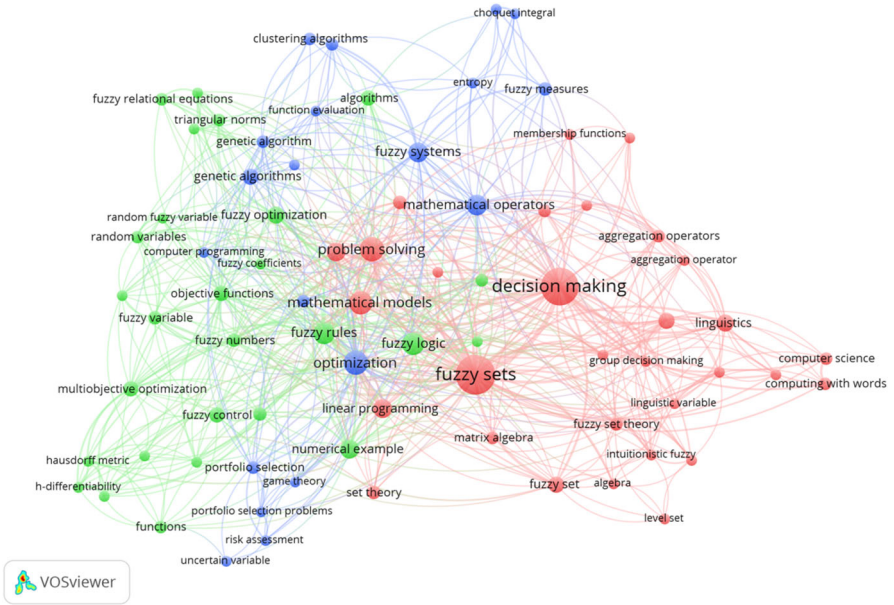

Fig. 8 Co-occurrence network of keywords of FODM publications, 2007–2011

words ‘artificial intelligence’ belongs to index keywords provided by Scopus, which implies that there are some decision making problems related to the field of artificial intelligence.

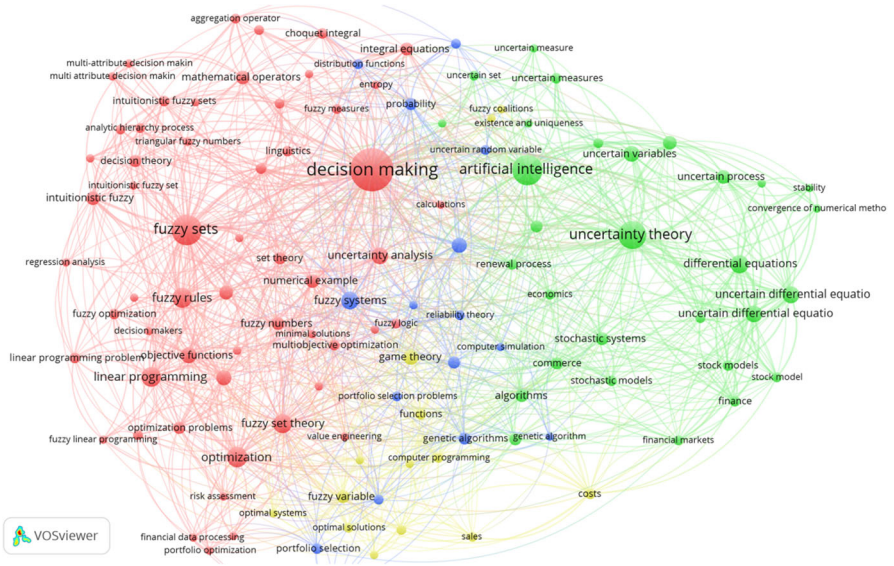

Fig. 9 Co-occurrence network of keywords of FODM publications, 2012–2017

As listed in Table 9, the most used keyword is 'fuzzy sets' in both the first 5 years (2002–2006) and the second 5 years (2007–2011). During 2002 and 2006, Fig. 7 indicates that the links with strong link strengths between nodes are mainly concentrated on the top six nodes listed in Table 9, the research topics focus on optimization problems in decision making and fuzzy sets in this stage. In the second 5 years, the occurrence of the keywords 'fuzzy logic', 'fuzzy rules', and 'fuzzy systems' is increased, but Fig. 8 indicates that the link strengths of the links between the top five nodes are weaken. Except the research focuses of the fuzzy sets and decision making, some studies also involved in fuzzy rules and fuzzy logic. In the recent 6 years (2012–2017), the keywords 'artificial intelligence', 'uncertainty theory', and 'uncertain differential equations' are appeared frequently. In the co-occurrence network of keywords shown in Fig. 9, the link strength of the link between the nodes 'decision making' and 'artificial intelligence' is stronger than the link between the nodes 'decision making' and 'fuzzy sets', which indicates the developing trend of the connection between decision making and artificial intelligence.

4.2 Bursting keywords detection

CiteSpace software, which was developed by Chen (2006), provides a function of burst detection to identify bursting keywords. The bursting detection of keywords can be used to detect the emerging trends (Chen et al. 2014; Kim and Chen 2015). Based on the co-occurrence network of keywords used in the FODM publications during 2002 and 2017, the top 23 bursting keywords are listed in Table 10. The strongest bursting keyword is 'problem solving' with 19.86 strength, followed by 'mathematical models',

Table 9 Top 30 keywords used in FODM in four different stages

2002–2006		2007–2011		2012–2017		2002–2017	
Keywords	Freq	Keywords	Freq	Keywords	Freq	Keywords	Freq
Fuzzy sets	78	Fuzzy sets	48	Decision making	70	Fuzzy sets	163
Problem solving	48	Decision making	38	Fuzzy sets	36	Decision making	142
Mathematical models	35	Optimization	16	Artificial intelligence	35	Problem solving	68
Decision making	34	Problem solving	16	Uncertainty theory	31	Optimization	64
Optimization	31	Mathematical models	14	Uncertain differential equations	22	Mathematical models	49
Algorithms	21	Fuzzy logic	13	Optimization	17	Artificial intelligence	38
Membership functions	17	Fuzzy rules	12	Linear programming	16	Linear programming	38
Fuzzy control	13	Genetic algorithm	11	Fuzzy rules	15	Algorithm	34
Linear programming	13	Mathematical operator	11	Fuzzy set theory	14	Uncertainty theory	32
Genetic algorithms	11	Fuzzy systems	10	Uncertain variables	14	Genetic algorithm	31
Parameter estimation	11	Linear programming	9	Differential equations	13	Membership function	29
Vectors	11	Numerical example	9	Fuzzy systems	12	Fuzzy rules	28
Fuzzy numbers	10	Numerical method	9	Uncertainty analysis	11	Mathematical operators	28
Computer simulation	9	Fuzzy optimization	8	Objective functions	10	Fuzzy numbers	25
Mathematical operators	9	Linguistics	8	Fuzzy random variable	9	Fuzzy systems	24
Computational methods	8	Aggregation operators	7	Game theory	9	Numerical methods	24

Table 9 continued

2002–2006		2007–2011		2012–2017		2002–2017	
Keywords	Freq	Keywords	Freq	Keywords	Freq	Keywords	Freq
Constraint theory	8	Decision theory	7	Genetic algorithms	9	Fuzzy logics	21
Fuzzy random variable	8	Algorithms	6	Membership functions	9	Fuzzy random variable	21
Set theory	8	Fuzzy control	6	Numerical methods	9	Fuzzy control	19
Functions	7	Intuitionistic fuzzy sets	6	Random variables	9	Fuzzy optimization	19
Learning systems	7	Multi-objective optimization	6	Stock models	9	Set theory	19
Random processes	7	Objective functions	6	Group decision making	8	Uncertain variables	19
Theorem proving	7	Fuzzy measures	5	Intuitionistic fuzzy	8	Fuzzy set theory	18
Approximation theory	6	Fuzzy numbers	5	Intuitionistic fuzzy sets	8	Numerical example	17
Conformal mapping	6	Fuzzy variable	5	Mathematical operators	8	Decision theory	16
Fuzzy optimization	6	Mathematical programming	5	Numerical example	8	Differential equation	16
Matrix algebra	6	Set theory	5	Uncertain measures	8	Function	16
Numerical method	6	Uncertainty analysis	5	Uncertain processes	8	Fuzzy variable	16
Mathematical programming	5	Clustering algorithms	4	Uncertainty distribution	8	Objective functions	16
Neural networks	5	Computer science	4	Algorithms	7	Uncertainty analysis	16

Table 10 Top 23 bursting keywords occurred in FODM publications

Keywords	Strength	Begin	End	2002-2017
membership function	4.33	2002	2006	
fuzzy sets	13.04	2003	2006	
problem solving	19.86	2003	2007	
learning systems	3.50	2003	2007	
fuzzy control	6.72	2003	2007	
random processes	2.87	2003	2006	
optimization	5.64	2003	2006	
mathematical models	17.19	2003	2007	
parameter estimation	4.40	2003	2006	
vectors	4.15	2003	2006	
theorem proving	2.89	2003	2007	
computational methods	4.12	2003	2005	
algorithms	6.15	2003	2006	
mathematical programming	3.35	2005	2007	
fuzzy logic	2.92	2006	2007	
numerical examples	6.83	2009	2013	
uncertain variables	4.92	2011	2014	
fuzzy set theory	2.89	2012	2017	
artificial intelligence	9.33	2012	2017	
uncertainty analysis	3.23	2013	2017	
uncertain differential equations	3.55	2013	2017	
uncertainty distribution	3.24	2013	2015	
uncertainty theory	9.55	2013	2015	

and ‘fuzzy sets’, all the top three keywords with high strength were burst began in 2003, and ended in 2006 or 2007.

In recent 5 years, there are six bursting keywords, which indicate the emerging trends of the FODM publications, including ‘fuzzy set theory’, ‘artificial intelligence’, ‘uncertainty analysis’, ‘uncertain differential equations’, ‘uncertainty distribution’, and ‘uncertainty theory’. Both of the last two keywords began in 2013 and ended in 2015. Among the other four bursting keywords, the strength of the keyword ‘artificial intelligence’ is the strongest, which began in 2012. According to the frequently occurred keywords listed in Table 9 and the bursting keywords listed in Table 10 during the period from 2012 to 2017, it can be concluded that the recent research themes of the FODM publications focus on studying the theories, methods, models, systems of uncertainty, and applying those theories and models to solve the optimization and decision-making problems.

5 Discussion about the future challenges of FODM

In the process of our study, the direct citation network of papers and co-authorship network are also analyzed. However, we found that these two kinds of networks are quite sparse. In terms of direct citation network of papers, it is mainly due to the fact

that the self-citation rate of the FODM is low with only about 3.51% based on our dataset. Respecting the co-authorship network, the collaboration between authors in the FODM publications is not obvious, in other words, there are several links in the co-authorship network, and the links are dispersed.

As we aforementioned in Sect. 2.1, FODM publishes about 20 publications each year since its first publishing year, the total number of 370 publications has been cited for 7894 times. The total number of citations is usually considered as the indicator of popularity (Yan et al. 2011), and the popularity can be used to indicate the influence of the journal (Merigó et al. 2018). Therefore, it can be concluded that FODM has created its influence in the related fields, although the number of the annual publications of this journal is not high. In this case, the quality of the articles is guaranteed when the editors decide to accept articles, thus, the quality of the journal can be guaranteed at the same time.

With the development of the scientific researches and academic journals, the FODM journal may face some potential future challenges. On the one hand, how to maintain or increase the attention of the FODM journal is worth considering since it publishes a relatively less publications each year but the number of publications in the whole retrieval database is increasing substantially recent years. On the other hand, how to guarantee the quality of the future publications in the FODM journal and to further spread its scientific influence in the future is another challenge.

6 Conclusion

This study shows a bibliometric analysis of the FODM publications between 2002 and 2017 based on the Scopus database. The analysis mainly covers three perspectives: a general statistical analysis based on the total number of publications and citations, co-citation networks analysis, and co-occurrence networks of keywords.

According to the general statistical analysis, *Journal of Intelligent and Fuzzy Systems*, *Information Sciences* and FODM itself cited the most FODM publications. Except that the papers in the fields of Computer Science, Mathematics, and Engineering cited the FODM publications, some papers in the fields of Physics and Astronomy, Medicine, and Chemistry also cited the FODM publications. The most productive authors are Xu ZS from Sichuan University and Yager RR from Iona College; China, United States, Taiwan, and Spain are the most productive countries/territories, and Tsinghua University, Iona College, and North Carolina State University are the top three most productive institutions.

The most cited author by FODM publications is Liu B, and he is co-cited with other 202 authors for more than ten thousand times by FODM publications. *Fuzzy Sets and Systems* is the most cited journal by FODM publications, and Zadeh (1965) is the most cited reference. In the top ten most cited references, most of them are authored by Liu B. The keywords ‘fuzzy sets’, and ‘decision making’ are the two most occurred in FODM publications, and the keywords ‘artificial intelligence’, ‘uncertainty analysis’, and ‘uncertain differential equations’ are the emerging keywords in recent years.

Overall, the citation structure, co-citation analysis, and research topics of FODM publications are explored in this study, which provide an objective view of the FODM

journal. It is hopefully contributed to the research fields related to computer science and management science. It also helps more scholars to know this journal and attract more excellent researchers from related fields to contribute to the development of scientific research themes involved in the FODM journal.

Acknowledgements This work was supported by the Project of Philosophy and Social Science in Zhejiang (No. 16NDJC159YB), the China National Natural Science Foundation (Nos. 71771155, 71571123), the Zhejiang Science and Technology Plan of China (No. 2015C33024), and the Zhejiang Provincial Natural Science Foundation of China (No. LY17G010007).

References

Calma, A., & Davies, M. (2015). Studies in higher education 1976–2013: A retrospective using citation network analysis. *Studies in Higher Education, 40*(1), 4–21.

Chen, C. (2006). CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *Journal of the Association for Information Science and Technology, 57*(3), 359–377.

Chen, C., Dubin, R., & Kim, M. C. (2014). Orphan drugs and rare diseases: A scientometric review (2000–2014). *Expert Opinion on Orphan Drugs, 2*(7), 709–724.

Chen, X., & Liu, B. (2010). Existence and uniqueness theorem for uncertain differential equations. *Fuzzy Optimization and Decision Making, 9*(1), 69–81.

Chen, C., Song, I. Y., Yuan, X., & Zhang, J. (2008). The thematic and citation landscape of data and knowledge engineering (1985–2007). *Data & Knowledge Engineering, 67*(2), 234–259.

Cristino, T. M., Neto, A. F., & Costa, A. F. B. (2018). Energy efficiency in buildings: Analysis of scientific literature and identification of data analysis techniques from a bibliometric study. *Scientometrics, 114*(3), 1275–1326.

Eito-Brun, R., & Rodríguez, M. L. (2016). 50 years of space research in Europe: A bibliometric profile of the European Space Agency (ESA). *Scientometrics, 109*(1), 551–576.

Garfield, E. (1979). *Citation indexing: Its theory and application in science, technology, and humanities*. New York: Wiley.

Goyal, N. (2017). A "review" of policy sciences: Bibliometric analysis of authors, references, and topics during 1970–2017. *Policy Sciences, 50*(4), 527–537.

He, X., Wu, Y., Yu, D. J., & Merigó, J. M. (2017). Exploring the ordered weighted averaging operator knowledge domain: A bibliometric analysis. *International Journal of Intelligent Systems, 32*(11), 1151–1166.

Herrera, F., Alonso, S., Chiclana, F., & Herrera-Viedma, E. (2009). Computing with words in decision making: Foundations, trends and prospects. *Fuzzy Optimization and Decision Making, 8*(4), 337–364.

Hirsch, J. E. (2005). An index to quantify an individual's scientific research output. *Proceedings of the National Academy of Sciences of the United States of America, 102*(46), 16569–16572.

Kim, M. C., & Chen, C. (2015). A scientometric review of emerging trends and new developments in recommendation systems. *Scientometrics, 104*(1), 239–263.

Liao, H. C., & Xu, Z. S. (2013). A VIKOR-based method for hesitant fuzzy multi-criteria decision making. *Fuzzy Optimization and Decision Making, 12*(4), 373–392.

Liu, B. (2006). A survey of credibility theory. *Fuzzy Optimization and Decision Making, 5*(4), 387–408.

Liu, B. (2012). Why is there a need for uncertainty theory? *Journal of Uncertain Systems, 6,* 3–10.

Liu, Y. K., & Liu, B. (2003). Fuzzy random variables: A scalar expected value operator. *Fuzzy Optimization and Decision Making, 2*(2), 143–160.

Madani, F. (2015). 'Technology Mining' bibliometrics analysis: applying network analysis and cluster analysis. *Scientometrics, 105*(1), 323–335.

Marzi, G., Dabić, M., Daim, T., & Garces, E. (2017). Product and process innovation in manufacturing firms: A 30-year bibliometric analysis. *Scientometrics, 113*(2), 673–704.

Merigó, J. M., Pedrycz, W., Weber, R., & De la Sotta, C. (2018). Fifty years of information sciences: A bibliometric overview. *Information Sciences, 432,* 245–268.

Merigó, J. M., & Yang, J. B. (2017). A bibliometric analysis of operations research and management science. *Omega, 73,* 37–48.

Palomo, J., Figueroa-Domecq, C., & Laguna, P. (2017). Women, peace and security state-of-art: A bibliometric analysis in social sciences based on SCOPUS database. *Scientometrics, 113*(1), 123–148.

Peng, Y., Lin, A., Wang, K., Liu, F., Zeng, F., & Yang, L. (2015). Global trends in DEM-related research from 1994 to 2013: A bibliometric analysis. *Scientometrics, 105*(1), 347–366.

Pritchard, A. (1969). Statistical bibliography or bibliometrics? *Journal of Documentation, 25*(4), 348–349.

Small, H. (1973). Co-citation in the scientific literature: A new measure of the relationship between two documents. *Journal of the Association for Information Science and Technology, 24*(4), 265–269.

Van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, A computer program for bibliometric mapping. *Scientometrics, 84*(2), 523–538.

Xu, Z. S. (2007). Some similarity measures of intuitionistic fuzzy sets and their applications to multiple attribute decision making. *Fuzzy Optimization and Decision Making, 6*(2), 109–121.

Xu, Z. S., & Yager, R. R. (2009). Intuitionistic and interval-valued intuitionistic fuzzy preference relations and their measures of similarity for the evaluation of agreement within a group. *Fuzzy Optimization and Decision Making, 8*(2), 123–139.

Yager, R. R. (2004). Generalized OWA aggregation operators. *Fuzzy Optimization and Decision Making, 3*(1), 93–107.

Yan, E., Ding, Y., & Sugimoto, C. R. (2011). P-Rank: An indicator measuring prestige in heterogeneous scholarly networks. *Journal of the Association for Information Science and Technology, 62*(3), 467–477.

Yu, D. J., & Shi, S. S. (2015). Researching the development of Atanassov intuitionistic fuzzy set: Using a citation network analysis. *Applied Soft Computing, 32,* 189–198.

Yu, D. J., Xu, Z. S., Kao, Y., & Lin, C. T. (2018a). The structure and citation landscape of IEEE transactions on fuzzy systems (1994–2015). *IEEE Transactions on Fuzzy Systems, 26*(2), 430–442.

Yu, D. J., Xu, Z. S., Pedrycz, W., & Wang, W. R. (2017). Information sciences 1968–2016: A retrospective analysis with text mining and bibliometric. *Information Sciences, 418,* 619–634.

Yu, D. J., Xu, Z. S., & Wang, W. R. (2018b). Bibliometric analysis of fuzzy theory research in China: A 30-year perspective. *Knowledge-Based Systems, 141,* 188–199.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control, 8*(3), 338–353.

Zhang, Y., Chen, H., Lu, J., & Zhang, G. (2017). Detecting and predicting the topic change of knowledge-based systems: A topic-based bibliometric analysis from 1991 to 2016. *Knowledge-Based Systems, 133,* 255–268.