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Aggregation operators in group decision making: Identifying citation classics via H-classics

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Abstract

To analyze the past, present and future of a particular research field, classic papers are usually studied because they identify the highly cited papers being a relevant reference point in that specific research area. As a result of the possible mapping between high quality research and high citation counts, highly cited papers are very interesting. The objective of this study is to use the H-classics method, which is based on the popular h-index, to identify and analyze the highly cited documents published about aggregation operators in the research area of group decision making. According to the H-classics method, this research area is represented by 87 citation classics, which have been published from 1988 to 2014. Authors, affiliations (universities/institutions and countries), journals, books and conferences, and the topics covered by these 87 highly cited papers are studied.

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Keywords: Citation classics, H-classics, h-index, aggregation operators, group decision making.

1. Introduction

Group decision making (GDM) is usually seen as the process of selecting the best option/s or alternative/s from a feasible set according to the evaluations given by a group of people, frequently called decision makers [1]. According to several known and respected authors in this research field, there are two main processes required to solve a GDM problem in a proper way [2,3]. The first one is the consensus process, whose main objective is to support decision makers until obtaining the highest agreement level among their evaluations [4]. The second one is the selection process, which deals with individual decision makers' evaluations to compute a collective ranking of alternatives according to the collective preference [5].

In both processes, an important step is that of the aggregation. In the consensus process, aggregation is used to calculate the consensus level that the decision makers have reached. On the other hand, in the selection process,

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aggregation is used to compute the collective opinion and to order the options or alternatives from best to worst. Therefore, many researchers have studied aggregation operators for GDM scenarios.

After many years of a productive research in the area of aggregation operators, it is necessary to look backward and review the research developed. A systematic evaluation of research is performed as it has been emphasized for optimizing research allocation, restricting research in particular fields, re-orientating research support, or augmenting research productivity [6]. To do so, the bibliometric concept of citation classics may be used. Eugene Garfield introduced this concept to denote the highly cited papers of a particular research field [7]. Citations classics are defined as documents that are highly cited as designated by the Arts and Humanities Citation Index, the Social Sciences Citation Index, or the Science Citations Index [8].

Important information for the development of a scientific field can be discovered by analyzing citation classics [9]. For instance, the major advances in the research area may be recognized and the hot topics to motivate other works may be discovered. Two main ways to identify citation classics were initially used [9]: (i) selecting several documents in the top of the list of highly cited documents [7], or (ii) setting citation thresholds [10]. However, the disadvantage of both methods is how to establish the specific threshold, which will change depending on the studied field. Martínez et. al. proposed in [9] a new method to identify the citation classics, which overcomes the above drawback. This new approach, called H-Classics, is based on the h-index [11], which is a robust bibliometric measure.

In this study, the publications considered as classic in the scientific area of aggregation operators are identified. In particular, the authors, affiliations (universities/institutions and countries), journals, books and conferences, which have more contributed to the citation classics, are shown. In addition, the topics covered by these citation classics are analyzed.

The rest of this study is organized as follows: Section 2 describes both the data used in this analysis and the approach employed to identify the citation classics. Section 3 shows the obtained results. Section 4 points out some conclusions.

2. Material and methods

To evaluate research performance, bibliometrics is principally used [8,9]. Its primary supposition is that the more often a document is cited, the greater its influence on the research area [12]. Based on this assumption, a higher citation rates means a higher quality [6]. In such a way, citation classics determine the documents that are highly cited, being a significant reference point in a particular scientific field. In a particular research area, the identification of the citation classics is beneficial to determine the authors publishing important findings in addition to the long- or short-term impact of their publications from the literary perspective [6].

Traditional methods identifying citation classics are based on a particular threshold as, for instance, the citation counts [10] or the number of papers [7]. Based on this, the documents that exceed the particular threshold are assumed to belong to the collection of citation classics. However, as the choice of the threshold is determined by the scientific field that is analyzed, there is not rigorous scientific argument to select it. To avoid this, Martínez et al. proposed a new approach based on the h-hindex [11], which was called H-Classics [9]: "H-Classics of a research area A could be defined as the H-core of A that is composed of the H highly cited papers with more than H citations received."

To identify the H-Classics in the scientific field of aggregation operators in GDM, the following steps are applied:

- *Selection of the bibliographic database to retrieve the scientific production and citations.* Due to the ISI Web of Science (ISIWos) contains the most accurate and reliable citation data, it was chosen as bibliographic database.
- *Set the research area under study by defining a query to retrieve the papers.* The following query was used to retrieve the documents: TS=("aggregation operator" OR "aggregation operators" OR "OWA"), which returned 4099 publications (in July 2017). After a manual manipulation of the documents that were returned, several papers were chosen in the scope of this study. However, a non-significant percentage of human errors in the results is possible because the manipulation of the data was manually developed.
- *Calculate the h-index in the research area.* To calculate the h-index in the research area of aggregation operators in GDM, the list of returned papers was ordered by citation count using the ISIWos capabilities. As a result, a h-index equal to 87 was obtained.

- *Recover the H highly cited document included in the H-Core*. 87 documents belonging to the H-Core were retrieved to study their authors, affiliations (universities/institutions and countries), journals, books, conferences, and the topics. In Appendix A, the list of full references is shown.

The retrieved raw data was imported into SciMAT [13], which is a science mapping analysis open source software, to build a knowledge base and perform a pre-processing step. Particularly, we applied a de-duplication step over keywords, affiliations, and authors to merge into one entity the items representing the same concept, affiliation, or author, respectively.

Finally, to represent the topics covered by the retrieved documents, tag clouds are used. A tag cloud (weighted list) is a very useful graphic representation to study smaller data sets. It is a visual depiction of content tags in a particular research area in such a way that more common tags are represented in an emphasize or larger font. Although tag clouds were introduced for website analysis and social networks [14], their use has been also extended to bibliometrics studies [15]. In particular, Wordle (`http://www.wordle.net/`) was used in this study to build the cloud tags.

3. Analysis and results

The H-Classics in the research field of aggregation operators used in GDM are analyzed in this section. In particular, the aspects studied are: (i) longitudinal, (ii) authors and affiliations (universities/institutions and countries), (iii) journals, conferences and books, and (iv) most used keywords or terms. In the following subsections, the results obtained in each one of these aspects are represented and analyzed in detail.

3.1. Longitudinal

In the research field of aggregation operators, the h-index is equal to 87. Therefore, the top 87 highly cited papers are identify as citation classics. In 1988 the first classic was published. In this manuscript, Ronald Robert Yager introduced the Ordered Weighted Aggregation (OWA) operator, which was a new type of operator for aggregation whose performance was found to be between those obtained using the OR operator requiring at least on criteria to be satisfied and the AND operator requiring all criteria to be satisfied [16]. In addition, the properties of this new operator were investigated.

Fig. 1 shows the distribution of citation classics per year. Since 2004, there is a great growth in the number of citation classics (59, 67.81%). In particular, 2010 and 2011 are the years where more citations classics were published (21, 24.14%). The last citation classics were published in 2014.

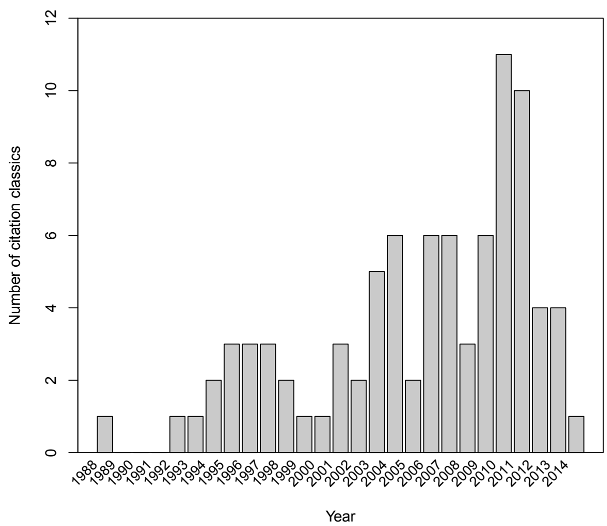

Fig. 1. Distribution of citation classics per year.

Table 1. Authors with three or more citation classics.

Rank	Author	#Citation classics
1	Yager RR	23
2	Xu ZS	21
3	Merigo JM	9
4	Wei GW	7
5	Casanovas M	4
6	Chiclana F	4
7	Herrera F	4
8	Herrera-Viedma	4
9	Filev DP	4
10	Alonso S	3
11	Calvo T	3
12	Gil-Lafuente AM	3
13	Grabish M	3

Table 2. Universities/Institutions with three or more citation classics.

Rank	University/Institution	#Citation classics
1	Iona College	23
2	Southeast University (Nanjing)	16
3	University of Barcelona	8
4	Chongqing University Arts & Sciences	8
5	De Montfort University	4
6	University of Granada	4
7	Eötvös Loránd University	3
8	Tsinghua University	3

Table 3. Countries with two or more citation classics.

Rank	Country	#Citation classics
1	Peoples R China	36
2	USA	26
3	Spain	19
4	England	6
5	France	3
6	Hungary	4
7	Belgium	3
8	Australia	2
9	Canada	2

3.2. Authors and affiliations

Tables 1–3 show the quantitative measures of authors and their affiliations (universities/institutions and countries). In particular, only authors with three or more citation classics, universities or institutions with three or more citation classics, and countries with two or more citation classics are shown.

According to Tables 1–3, both USA and Peoples R China and their universities and researchers are ranked in the first positions. Concerning the authors, Ronald Robert Yager (USA) and Zeshui Xu (Peoples R China) are those that more have contributed in this research field (see Table 1). Regarding the universities or institutions, the US Iona College has almost three times more citation classics than the third and fourth universities in the rank (University of Barcelona and Chongqing University Arts & Sciences). In addition, the Southeast University (Nanjing) has two times more citation classics than the third and fourth universities in the rank (see Table 2). Finally, Peoples Republic of China and USA are the countries that have published a high number of citation classics (see Table 3). They together with Spain are the three countries that more have contributed to this research area.

3.3. Journals, conferences, books

The journals, conferences and books, with two or more citation classics are shown in Table 4. In fact, except a book chapter, all the citation classics are published in journals. The journal Fuzzy Sets and Sytems and the journal

Table 4. Journals/conferences/books in which two or more citation classics have been published.

Rank	Journal/Conference/Book	#Citation classics
1	Fuzzy Sets and Systems	12
2	Information Sciences	11
3	International Journal of Intelligent Systems	9
4	IEEE Transactions on Fuzzy Systems	8
5	Knowledge-Based Systems	6
6	Experts Systems With Applications	5
7	IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans	4
8	IEEE Transactions on Systems, Man, and Cybernetics - Part B: Cybernetics	4
9	International Journal of Uncertainty, Fuzziness, and Knowledge-Based Systems	4
10	Applied Soft Computing	2
11	European Journal of Operational Research	3
12	International Journal of Approximate Reasoning	3
13	Computers & Industrial Engineering	2
14	International Journal of General Systems	2

Information Sciences are the most important journals in the research area of aggregation operators as 23 of the citation classics have been published here. Furthermore, the journals: (i) International Journal of Intelligent Systems, (ii) IEEE Transactions on Fuzzy Systems, and (iii) Knowledge-Based Systems, with 9, 8 and 6 citation classics, respectively, have significantly contributed to the development of this research area. In addition, we should point out that the "Aggregation Functions: A Guide for Practitioners" (Studies in Fuzziness and Soft Computing), is the only book in which a citation classic has been published as a book chapter.

3.4. Most used keywords or terms

Finally, to discover the topics covered by the 87 citation classics published in the scientific area of aggregation operators, a tag cloud was built. To do so, both the keywords given by the researchers and those given by the bibliographic database (ISI Keywords Plus) were used. In bibliometric analysis, analyzing keywords is a common approach to discover main trends in a particular scientific area. Here, the occurrence of the terms that appears in the keywords are described. Before, SciMAT [13] was used to perform a stemming analysis with the purpose of identifying similar keywords and count them together. The tag cloud in which the size of the terms are proportional to its frequency is represented in Fig. 2. It is observed that, naturally, "aggregation" and "owa-operators" are the most important keywords. However, it is notable how other connected terms also have a strong importance. Some of them are mainly related to the structure in which the decision makers provide their opinions ("fuzzy-sets", "intuitionistic-fuzzy-set", "hesitant-fuzzy-set", "vague-sets") and others are related with the type of decision problem ("group-decision-making", "multicriteria-decision-making") . Furthermore, other concepts as, for instance, "consensus" and "weights", are also important in this research field.

Fig. 2. Main topics cited in keywords.

4. Conclusions

A bibliometric study with the purpose of identifying the citation classics in the research area of aggregation operators has been performed here. To do so, the concept of H-Classics [9] has been used to perform the characterization of the citation classics. In the study, 87 citations classics have been identified and analyzed to show their their authors, affiliations (universities/institutions and countries), journals, books, conferences, and topics covered. Ronald Robert Yager, the Iona College, and Peoples Republic of China, are the author, institution and country, respectively, that more have contributed to development of this scientific field. In addition, Fuzzy Sets and Systems and Information Sciences are the journals in which more citation classics have been published.

Acknowledgements

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References

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Appendix A. H-core research documents list

Table A.5: H-Core: list with the 87 highly cited papers in the research field of aggregation operators

Rank	Paper	#Citations
1	Yager RR (1988) On ordered weighted averaging aggregation operators in multicriteria decisionmaking. IEEE Transactions on Systems, Man, and Cybernetics 18(1):183–190	3065
2	Yager RR (1993) Families of OWA operators. Fuzzy Sets and Systems 59(2):125–148	649
3	Xu ZS (2007) Intuitionistic fuzzy aggregation operators. IEEE Transactions on Fuzzy Systems 15(6):1179–1187	604
4	Xu ZS, Yager RR (2006) Some geometric aggregation operators based on intuitionistic fuzzy sets. International Journal of General Sytems 35(4):417–433	581
5	Yager RR (1996) Quantified guided aggregation using OWA operators. International Journal of Intelligent Systems 11(1):49–73	527

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Table A.5: Continued from previous page

Rank	Paper	#Citations
6	Yager RR, Filev DP (1999) Induced ordered weighted averaging operators. IEEE Transactions on Systems, Man, and Cybernetics - Part B: Cybernetics 29(2):141–150	455
7	Xu ZS, Da QL (2003) An overview of operators for aggregating information. International Journal of Intelligent Systems 18(9):953–969	446
8	Grabisch M (1996) The application of fuzzy integrals in multicriteria decision making. European Journal of Operational Research 89(3):445:456	386
9	Xu ZS (2004) A method based on linguistic aggregation operators for group decision making with linguistic preference relations. Information Sciences 166(1–4):19–30	375
10	Xia M, Xu ZS (2011) Hesitant fuzzy information aggregation in decision making. International Journal of Approximate Reasoning 52(3):395–407	368
11	Yager RR, Rybalov A (1996) Uninorm aggregation operators. Fuzzy Sets and Systems 80(1):111–120	367
12	Xu ZS (2005) An overview of methods for determining OWA weights. International Journal of Intelligent Systems 20(8):843–865	355
13	Torra V (1997) The weighted OWA operator. International Journal of Intelligent Systems 12(2):153–166	330
14	Grabisch M (1995) Fuzzy integral in multicriteria decision-making. Fuzzy Sets and Systems 69(3):279–298	314
15	Xu ZS (2004) Uncertain linguistic aggregation operators based approach to multiple attribute group decision making under uncertain linguistic environment. Information Sciences 168(1–4):171–184	312
16	Bordogna G, Fedrizzi M, Pasi G (1997) A linguistic modeling of consensus in group decision making based on OWA operators. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans 27(1):126–132	309
17	Wei G (2010) Some induced geometric aggregation operators with intuitionistic fuzzy information and their application to group decision making. Applied Soft Computing 10(2):423–431	299
18	Files DP, Yager RR (1998) On the issue of obtaining OWA operator weights. Fuzzy Sets and Systems 94(2):157–169	288
19	Merigo JM, Gil-Lafuente AM (2009) The induced generalized OWA operator. Information Sciences 179(6):729–741	262
20	Herrera-Viedma E, Chiclana F, Herrera F, Alonso S (2007) Group decision-making model with incomplete fuzzy preference relations based on additive consistency. IEEE Transactions on Systems, Man, and Cybernetics - Part B: Cybernetics 37(1):176–189	254
21	Xu ZS, Da QL (2002) The uncertain OWA operator. International Journal of Intelligent Systems 17(6):569–575	242
22	Herrera F, Herrera-Viedma E (1997) Aggregation operators for linguistic weighted information. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans 27(5):646–656	242
23	Xu ZS (2010) Choquet integrals of weighted intuitionistic fuzzy information. Information Sciences 180(5):726–736	234
24	Xu ZS (2006) Induced uncertain linguistic OWA operators applied to group decision making. Information Sciences 7(2):231–238	231
25	Zhao H, Xu ZS, Ni M, Liu S (2010) Generalized aggregation operators for intuitionistic fuzzy sets. International Journal of Intelligent Systems 25(1):1–30	221
26	Wei G (2012) Hesitant fuzzy prioritized operators and their application to multiple attribute decision making. Knowledge-Based Systems 31:176–182	218
27	Yager RR (2004) OWA aggregation over a continuous interval argument with applications to decision making. IEEE Transactions on Systems, Man, and Cybernetics - Part B: Cybernetics 34(5):1952–1963	192
28	Yager RR (2003) Induced aggregation operators. Fuzzy Sets and Systems 137(1):59–69	190
29	Fuller R, Majlender P (2001) An analytic approach for obtaining maximal entropy OWA operator weights. Fuzzy Sets and Systems 124(1):53–57	190
30	Xu ZS (2006) An approach based on the uncertain LOWG and induced uncertain LOWG operators to group decision making with uncertain multiplicative linguistic preference relations. Decision Support Systems 41(2):488–499	189
31	Zhu B, Xu ZS, Xia M (2012) Hesitant fuzzy geometric Bonferroni means. Information Sciences 205:72–85	186
32	Chiclana F, Herrera-Viedma E, Herrera F, Alonso S (2007) Some induced ordered weighted averaging operators and their use for solving group decision-making problems based on fuzzy preference relations. European Journal of Operational Research 182(1):383–399	183
33	Xu ZS (2011) Approaches to multiple attribute group decision making based on intuitionistic fuzzy power aggregation operators. Knowledge-Based Systems 24(6):749–760	170
34	Tan C, Chen X (2010) Intuitionistic fuzzy Choquet integral operator for multi-criteria decision making. Expert Systems With Applications 37(1):149–157	170
35	Xu ZS, Da WL (2002) The ordered weighted geometric averaging operators. International Journal of Intelligent Systems 17(7):709–716	168
36	Fodor J, Marichal JL, Roubens M (1995) Characterization of the ordered weighted averaging operators. IEEE Transactions on Fuzzy Systems 3(2):236–240	159
37	Fuller R, Majlender P (2003) On obtaining minimal variability OWA operator weights. Fuzzy Sets and Systems 136(2):203–215	155
38	Merigo JM, Gil-Lafuente AM (2010) New decision-making techniques and their application in the selection of financial products. Information Sciences 180(11):2085–2094	152
39	Marichal JL (2000) An axiomatic approach of the discrete Choquet integral as a tool to aggregate interacting criteria. IEEE Transactions on Fuzzy Systems 8(6):800–807	151
40	Xia M, Xu ZS, Chen N (2013) Some hesitant fuzzy aggregation operators with their application in group decision making. Group Decision and Negotiation 22(2):259–279	147
41	Wei G (2010) A method for multiple attribute group decision making based on the ET-WG and ET-OWG operators with 2-tuple linguistic information. Expert Systems With Applications 37(12):7895–7900	147
42	Mas M, Monserrat M, Torrens J, Trillas E (2007) A survey on fuzzy implication functions. IEEE Transactions on Fuzzy Systems 15(6):1107–1121	147
43	Xu ZS, Xia M (2011) Induced generalized intuitionistic fuzzy operators. Knowledge-Based Systems 24(2):197–209	146
44	Wei G (2009) Uncertain linguistic hybrid geometric mean operator and its application to group decision making under uncertain linguistic environment. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems 17(2):251–267	145
45	Malczewski J (2006) Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis. International Journal of Applied Earth Observation and Geoinformation 8(4):270–277	142
46	Yager RR (2001) The power average operator. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans 31(6):724–731	135
47	Ben-Arieh D, Chen ZF (2006) Linguistic-labels aggregation and consensus measure for autocratic decision making using group recommendations. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans 36(3):558–568	128

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Table A.5: Continued from previous page

Rank	Paper	#Citations
48	Xu ZS (2004) EOWA and EOWG operators for aggregating linguistic labels based on linguistic preference relations. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems 12(6):791–810	127
49	Yager RR (2008) Prioritized aggregation operators. International Journal of Approximate Reasoning 48(1):263–274	126
50	Merigo JM, Casanovas M (2011) Decision-making with distance measures and induced aggregation operators. Computers & Industrial Engineering 60(1):66–76	124
51	Wang YM, Parkan C (2005) A minimax disparity approach for obtaining OWA operator weights. Information Sciences 175(1–2):20–29	124
52	Calvo T, De Baets B, Fodor J (2001) The functional equations on Frank and Alsina for uninorms and nullnorms. Fuzzy Sets and Systems 120(3):385–394	124
53	Wei G (2009) Some geometric aggregation functions and their application to dynamic multiple attribute decision making in the intuitionistic fuzzy setting. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems 17(2):179–196	123
54	Yager RR (2007) Centered OWA operators. Soft Computing 11(7):631–639	123
55	Filev DP, Yager RR (1995) Analytic properties of maximum-entropy OWA operators. Information Sciences 85(1–3):11–27	122
56	Yager RR (1994) Aggregation operators and fuzzy-systems modeling. Fuzzy Sets and Systems 67(2):129–145	122
57	Beliakov G, Bustince H, Goswami DP, Mukherjee UK, Pal NR (2011) On averaging operators for Atanassov's intuitionistic fuzzy sets. Information Sciences 181(6):1116–1124	121
58	Zhang Z (2013) Hesitant fuzzy power aggregation operators and their application to multiple attribute group decision making. Information Sciences 234:150–181	120
59	Boroushaki S, Malczewski J (2008) Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS. Computers & Geosciences 34(4):399–410	119
60	Yager RR (1992) Applications and extensions of OWA aggregations. International Journal of Man-Machine Studies 37(1):103–132	119
61	Tan C (2011) A multi-criteria interval-valued intuitionistic fuzzy group decision making with Choquet integral-based TOPSIS. Expert Systems With Applications 38(4):3023–3033	118
62	Chen SJ, Chen SM (2003) A new method for handling multicriteria fuzzy decision-making problems using FN-IOWA operators. Cybernetics and Systems 34(2):109–137	118
63	Xu ZS, Yager RR (2011) Intuitionistic fuzzy Bonferroni means. IEEE Transactions on Systems, Man, and Cybernetics - Part B: Cybernetics 41(2):568–578	117
64	Merigo JM, Casanovas M (2009) Induced aggregation operators in decision making with the Dempster-Shafer belief structure. International Journal of Intelligent Systems 24(8):934–954	117
65	Beliakov G, Pradera A, Calvo T (2007) Aggregation functions: a guide for practitioners. Introduction. Studies in Fuzziness and Soft Computing 221	115
66	Dong Y, Xu Y, Li H, Feng B (2010) The OWA-based consensus operator under linguistic representation models using position indexes. European Journal of Operational Research 203(2):455–463	107
67	Yager RR, Filev DP (1994) Parametrized and-like and or-like OWA operators. International Journal of General Systems 22(3):297–316	107
68	Merigo JM (2010) Fuzzy decision making with immediate probabilities. Computers & Industrial Engineering 58(4):651–657	105
69	Yu D, Wu Y, Lu T (2012) Interval-valued intuitionistic fuzzy prioritized operators and their application in group decision making. Knowledge-Based Systems 30:57–66	102
70	Zeng S, Su W (2011) Intuitionistic fuzzy ordered weighted distance operator. Knowledge-Bases Systems 24(8):1224–1232	101
71	Merigo JM, Casanovas M (2010) Fuzzy generalized hybrid aggregation operators and its application in fuzzy decision making. International Journal of Fuzzy Systems 12(1):15–24	101
72	Xu ZS, Yager RR (2010) Power-geometric operators and their use in group decision making. IEEE Transactions on Fuzzy Systems 18(1):94–105	101
73	Chiclana F, Herrera-Viedma E, Herrera F, Alonso S (2004) Induced ordered weighted geometric operators and their use in the aggregation of multiplicative preference relations. International Journal of Intelligent Systems 19(3):233–255	100
74	Merigo JM, Casanovas M, Martinez L (2010) Linguistic aggregation operators for linguistic decision making based on the Dempster-Shafer theory of evidence. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems 18(3):287–304	99
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