Ordered Weighted Averaging Operators 1988–2014: A Citation-Based Literature Survey

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This study surveys the ordered weighted averaging (OWA) operator literature using a citation network analysis. The main goals are the historical reconstruction of scientific development of the OWA field, the identification of the dominant direction of knowledge accumulation that emerged since the publication of the first OWA paper, and to discover the most active lines of research. The results suggest, as expected, that Yager's paper[1] (*IEEE Trans. Systems Man Cybernet*, 18(1), 183–190, 1988) is the most influential paper and the starting point of all other research using OWA. Starting from his contribution, other lines of research developed and we describe them.

1. INTRODUCTION

The family of ordered weighted averaging (OWA) operators was first introduced by Yager[1] as a tool to deal with the problem of aggregating multicriteria to form an overall decision function. He described it as cumulative operators for membership aggregation. Following this conceptualization, the role of OWA weighting vector has been highlighted as a means for introducing the decision maker's attitude[2] and the OWA operator has received great attention and has been applied to different disciplinary contexts, for example, decision making under uncertainty,[3] fuzzy system and information retrieval system,[4,5] and data mining.[6] It is widely recognized that the OWA operators have been applied to different research fields, but the present study is the first work depicting the OWA development scenario and describing its development path. This paper is the first systematic review of the growing literature on the OWA operator; it aims to trace the development of OWA research using social network analysis (SNA) and presents a survey on the diffusion of the OWA in the literature over the past 26 years. Our main goals are

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- to identify the major publications/citations in the OWA field,
- to identify and illustrate the intellectual structure of this research domain, and
- to describe the subarea in which the OWA have been most applied.

To conduct this review, we employed the data of ISI Web of Knowledge and elaborated them first with the HistCite software[7,8] to obtain the corresponding historiograph. Second, we analyzed the data applying an algorithm widely used in the analysis of citation network, the critical path method (CPM).[9] The historiograph displays how each paper has influenced other papers included in the panel provided by ISI[10] and allows the chance to understand the role of key events (papers), people (authors), and journals in a field. This historiograph analysis is focused on the most influential contributions to the body of research on the OWA operators. Differently, the CPM aims to trace the dominant direction of knowledge accumulation. To identify the papers dealing with the OWA, we first used the keyword "ordered weighted averaging" and obtained 537[a] results that include published academic paper (394) and proceedings (143).

2. THE OWA OPERATORS: BACKGROUND

The formulation of OWA, as proposed originally by Yager,[1] refers to the issue of aggregating criteria functions to form an overall decision function.

DEFINITION 1. *A mapping F from*

$$I^n \rightarrow I \quad (\text{where} I = [0, 1])$$

is called an OWA operator of dimension n if associate with F, is a weighting vector W,

$$W = \begin{bmatrix} W_1 \\ W_2 \\ W_n \end{bmatrix}$$

such that

$$W_1 \in (0, 1)$$

$$\sum_i W_i = 1$$

$$F\,(a_1, a_2, \ldots, a_n) = W_1 b_1 + W_2 b_2 + \cdots + W_n b_n,$$

[a]The full list of papers can be found in a supplementary document provided in the online issue of the journal.

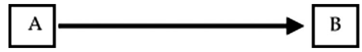

Figure 1. Example of citation network.

where b_1 is the largest element in the collection $a_1, a_2, \ldots, a_n$. And an n vector B can be the ordered argument vector if each element $b_i \in [0, 1]$ and $b_i \geq b_j$ if $j > i$. Given and OWA operator F with a weight vector W and an argument tuple $(a_1, a_2, \ldots, a_n)$, we can associate with this tuple an ordered input vector B is the vector consisting of the argument of F put in a descending order. Using this notation, then

$$F\,(a_1, a_2, \ldots, a_n.) = W'B,$$

the inner product of $W'$and$B$. It is also possible to denote $F\,(a_1, a_2, \ldots, a_n)$ as $F\,(B)$, where B is the highest associated ordered argument vector.

Furthermore, Yager[1] points to the fact that the weights, the W's, are associated with a particular ordered position rather than a particular element, that is, W_i is the weight associated with the *i*th largest vector *B*.

3. METHODOLOGY

The study of papers citation network by means of SNA has become very popular in the past few years as it allows to understand different dynamics such as collaboration among researchers;[11,12] knowledge patterns and Calero–Medina and Noyons,[13] and emerging knowledge trends within disciplines.[14,15] Two major contributions characterized this growing methodological approach, the pioneering study by Garfield et al.[7] and the development of three algorithms proposed by Hummon and Doreian.[16] The former seeks to shed light on the chronological representation of the development of a discipline focusing on the most cited authors and works to infer about their impact on the discipline's progress, whereas the latter shifts the attention from nodes to links allowing the so-called connectivity analysis. More specifically,[16] algorithms, search path link count, search path node pairs, and node projection pairs count, capture the level of connectivity of each citation (a link between two nodes) and are based on sequences of links and nodes called "search path." Recently, Batagelj (2003) elaborated the search path count (SPC) algorithm, which is considered the best development of Hummon and Doreain algorithms and overcome some limitations.[17] In this work, citations are considered proxies for knowledge flows, thus if the author "A" cites author's "B" we assume there is a knowledge flows between them, more precisely, "A" work relies to some extent on "B" contribution (Figure 1).

In this study, we combine the two citations-based methodologies, to investigate the OWA literature. As outputs, we provide first the historiograph[7] of the related discipline to study the chronological development of the discipline, then we apply the CPM, which is based on the SPC that calculates traversal weights on arcs, and finally we analyze a cocitation network of most cited publications to highlight

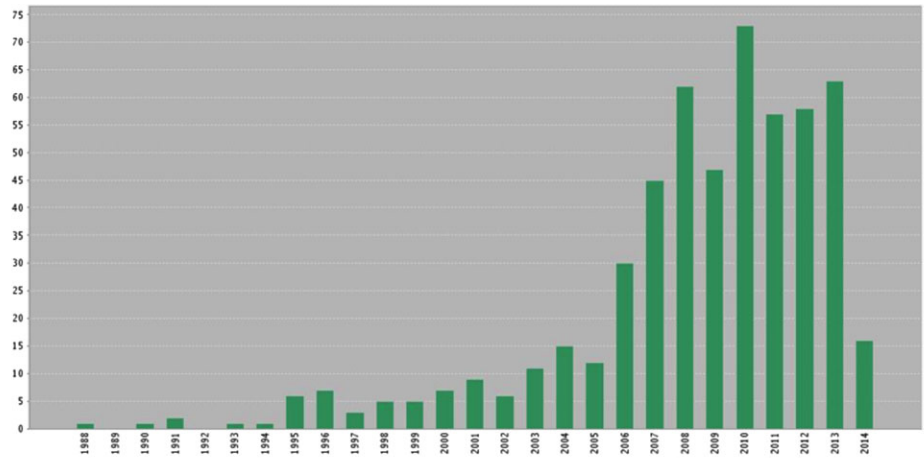

Figure 2. Published items in each year. Source Web of Science.

similarities between these works. Traversal weights measure the importance of path-linking entry vertices in a network to exit ones. Entry vertices are those not cited within the data set, whereas exit vertices do not cite others within the data set. The CPM algorithm determines the path from entry vertices to exit vertices with the largest total sum of weights on the arcs and provides a visual display of a broader longitudinal connectivity then the SPC output. We apply it to map the knowledge underlying the evolution of the main direction the field. We consider this as the backbone of the discipline.

The analysis of the historiography was first introduced by Garfield and colleagues,[7] which described the historiography as a chronological map allowing the historical reconstruction of scientific development of a field and its chronological representation. Typically, it shows only a portion of the most cited works within the field. Thus, it is a genealogical approach to the study of a discipline, showing when it starts and what its descendants are. We choose to provide the historiograph of the OWA field (Figure 3) as output as this paper is the first review of the scientific development of this discipline.

CPM captures the dominant direction of knowledge accumulation that emerged over the whole-time period covered by this analysis, namely the backbone of the field of interest. By computing the total number of paths linking the oldest vertices in a citation network to the most recent ones, the algorithm maps all possible streams of cumulative growth of knowledge and selects the most important one. CPM determines the source–sink path(s) with the largest total sum of weights and identifies the path from entry vertices to exit vertices with the largest total sum of weights on the arcs. We conduct the CPM to highlight the intellectual structure underpinning the scientific development of the field of interest and complement this analysis with insights from a cocitation perspective. In fact, the analysis of references of published articles allows to highlight whether any two references are commonly

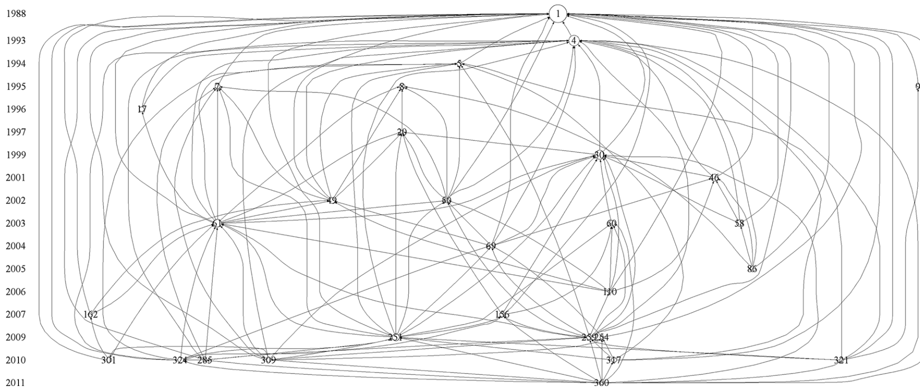

Figure 3. The historiograph showing the top 30 most cited OWA papers.

cocited, that is referenced together. Is a set of references commonly cocited; it can be argued that they constitute the intellectual structure of the field.[18] Data have been analyzed with two major software: HistCite and Pajek.[b]

3.1. Data and Basic Statistics

We adopt ISI Web of Science as the data source of this study. OWA papers have been searched and retrieved through the use of the keyword "ordered weighted averaging." We first obtained 540 results, 3 of these were not imported as they do not belong to the "Core Collection within ISI Web Science[c]", thus the procedure ended up with 537 results, 674 authors, and 249 journals. A main issue to handle when searching for OWA papers is the right "search key," we opt to use "ordered weighted averaging" instead of the abbreviation OWA to avoid potential misunderstanding. As first goal, we identify the major publications and authors in the OWA field. The growing attention received by this topic is shown in Figure 2, which depicts the trend of publications since Yager's first OWA paper in 1988.

We ranked authors and journals using the total local score (TLC), which refers to how many times the author's papers included in this collection have been cited by other papers also in the collection and the total global citation score (TGCS), which refers to how many times the author's papers included in this collection have been cited. This score is calculated from the times cited score retrieved from the Web of Science. Thus, considering TGCS means accounting also for the influence that authors' publication has outside the discipline's borders. However, it is based only

[b]These two software are available free: http://interest.science.thomsonreuters.com/forms/HistCite/; http://pajek.imfm.si/doku.php?id=download.

[c]The data to be analyzed with HistCite software should belong to the Web of Science Core Collection. The three results not included are papers published in the *Journal of Environmental Systems* by P. N Smith.

Table I. First 30 most cited papers ranked according to global citation score

ID	Author	Local Citation Score (LCS)	Global citation score
1	Yager, R. R., 1988, *IEEE Transactions on Systems*	451	2029
4	Yager, R. R., 1993, *Fuzzy Sets and Systems*	171	485
5	Yager, R. R., 1994, *International Journal of General Systems*	40	85
7	Fodor, J., 1995, *IEEE Transactions on Fuzzy Systems*	41	108
8	Filev, D., 1995, *Information Sciences*	50	92
9	Herrera, F., 1995, *Information Sciences*	36	213
17	Herrera, F., 1996, *Fuzzy Sets and Systems*	43	264
20	Mitchell, H. B., 1997, *International Journal of Uncertainty Fuzziness and Knowledge-Based Systems*	24	40
30	Yager, R. R., 1999, *IEEE Transactions on Systems*	130	284
46	Fuller, R., 2001, *Fuzzy Sets and Systems*	78	127
49	Xu, Z. S., 2002, *International Journal of Intelligent Systems*	55	144
50	Xu, Z. S., 2002, *International Journal of Intelligent Systems*	33	95
45	Fuller, R., 2003, *Fuzzy Sets and Systems*	65	106
60	Yager, R. R., 2003, *Fuzzy Sets and Systems*	56	117
61	Xu, Z. S., 2003, *International Journal of Intelligent Systems*	99	268
69	Chiclana, F., 2004, *International Journal of Intelligent Systems*	26	69
86	Wang, Y. M., 2005, *Information Sciences*	48	73
110	Xu, Z. S., 2006, *Information Fusion*	28	112
156	Chiclana, F., 2007, *European Journal of Operational Research*	38	92
162	Xu, Z. S., 2007, *IEEE Transactions on Fuzzy Systems*	34	219
251	Merigó, J. M., 2009, *Information Sciences*	75	144
254	Wu, J., 2009, *Computers & Industrial Engineering*	26	49
259	Merigó, J. M., 2009, *International Journal of Intelligent Systems*	44	75
285	Merigó, J. M., 2010, *Cybernetics and Systems*	27	47
301	Zhao, H., 2010, *International Journal of Intelligent Systems*	39	104
309	Merigó, J. M., 2010, *International Journal of Fuzzy Systems*	34	60
317	Merigó, J. M., 2010, *Computers & Industrial Engineering*	41	69
321	Merigó, J. M., 2010, *International Journal of Uncertainty Fuzziness and Knowledge-Based Systems*	25	52
324	Merigó, J. M., 2010, *Information Sciences*	50	87
360	Merigó, J. M., 2011, *Computers & Industrial Engineering*	28	53

on the materials included in the ISI Web of Science database, which constitute the main limitation of this kind of study.

The first visual representation of our analysis is the historiograph depicted in Figure 3 that provides a citation-based graphical representation of how core papers have influenced one another. The figure depicts only the top 30 most cited papers as shown in Table I. The decision to set a threshold of 30 papers is arbitrary, however is usually suggested as reasonable to get first information about most influential works. A key indicator of influence is a relative circle size, which reflects the extent of an article's influence over the development of the core body of knowledge concerning the OWA research domain. As expected, Yager's paper[1] shows the biggest shape as it is recognized as the starting and most influential contribution.

Table II. Most cited authors ranked by TLCSx (total citations score excluding self-citation)

S. No.	Author	Number of record	TLCS	TLCS/t	TLCSx	TGCS	TGCS/t
1	Yager, R. R.	40	1078	57.21	995	3669	185.11
2	Xu, Z. S.	27	431	48.85	364	1572	180.39
3	Merigó, J. M.	62	524	112.27	191	958	206.92
4	Filev, D. P.	3	193	11.24	180	412	24.06
5	Herrera, F.	10	191	14.68	161	1110	88.39
6	Herrera-Viedma, E.	14	191	14.68	161	1246	103.17
7	Majlender, P.	3	166	13.29	161	266	21.20
8	Fuller, R.	3	145	11.24	140	240	18.78
9	Da, Q. L.	5	163	14.11	129	428	36.27
10	Casanovas, M.	22	245	51.65	89	441	93.18
11	Verdegay, J. L.	4	99	5.20	88	618	32.39
12	Ahn, B. S.	14	116	16.94	84	162	23.60
13	Wang, Y. M.	4	85	9.68	80	145	17.93
14	Chiclana, F.	11	99	11.08	79	522	63.48
15	Gil-Lafuente, A. M.	18	183	37.83	73	338	70.73
16	Liu, X. W.	17	88	12.27	64	182	27.13
17	Alonso, S.	5	64	7.11	53	432	51.65
18	Filev, D.	1	50	2.50	49	92	4.60
19	Emrouznejad, A.	5	55	8.55	46	91	14.42
20	Malczewski, J.	4	52	5.92	46	156	19.30

3.2 Researcher Statistics

The 20 most cited authors have been ranked in Table II according to the number of total citation score excluding self-citations, which are less indicative of influence on others. As expected, Yager is the most cited author, followed by Xu, Merigó, and Filev in the top five positions.

3.3. Journal Statistics

Table III shows the top 20 most active journals that have published OWA papers. The top five journals in this area are *International Journal of Intelligent Systems*, *Information Science*, *Fuzzy Sets Systems, Expert Systems with Applications*, and *Computers & Industrial Engineering*. Journals are ranked considering the TGCS and considering time (TGCS/t).

4. OWA KNOWLEDGE ACCUMULATION USING CRITICAL PATH METHOD

Figure 4 shows the result of CPM, which captures the evolution and direction of knowledge accumulation. The graph aims at showing the sequence of knowledge contributions and differently from the historiograph here we do not have differences in shapes dimension to mean a different influence played by one on another. Here the emphasis is on the evolution of the discipline and its direction.

Table III. Top 20 most influential journals in the OWA field ranked according to their TLCS/t

S. No.	Journals	Number of record	TLCS	TLCS/t	TGCS	TGCS/t
1	*International Journal of Intelligent Systems*	42	429	51.27	1086	124.59
2	*Information Sciences*	19	371	46.31	1105	120.16
3	*Fuzzy Sets and Systems*	20	517	37.77	1476	107.65
4	*Expert Systems with Applications*	27	157	37.73	366	87.87
5	*Computers & Industrial Engineering*	12	167	32.06	308	60.66
6	*IEEE Transactions on Systems, Man and Cybernetics*	1	451	16.70	2029	75.15
7	*IEEE Transactions on Fuzzy Systems*	18	154	16.06	669	77.44
8	*International Journal on Fuzzy Systems*	6	66	13.42	136	27.23
9	*IEEE Transactions on Systems, Man and Cybernetics Part B-Cybernetics*	9	157	12.22	488	43.71
10	*International Journal of Approximate Reasoning*	10	88	11.59	234	27.07
11	*European Journal of Operational Research*	12	96	11.05	370	42.72
12	*International Journal of Uncertainty Fuzziness and Knowledge-Based Systems*	17	97	10.54	262	29.25
13	*Group Decision and Negotiation*	8	32	7.19	185	28.86
14	*International Journal of Computational Intelligence Systems*	3	33	7.15	80	16.95
15	*Journal of Systems Engineering and Electronics*	7	35	6.75	61	11.80
16	*Information Fusion*	5	48	6.68	162	24.02
17	*Cybernetics and Systems*	4	35	6.33	65	11.46
18	*International Journal of General Systems*	9	87	5.93	203	15.33
19	*Knowledge-Based Systems*	10	22	4.96	71	16.50
20	*Economic Computation and Economic Cybernetics Studies and Research*	4	15	4.25	30	8.25

After examining the title, abstract, and keywords[d] of these papers (Table IV), we describe the development of this discipline and its major areas of research. The analysis of the content reveals the efforts of researchers focused on two major directions.

The first works by Yager,[1,19,20] and Yager and Filev[21] constitute the knowledge base over which future works developed and further applied the OWA method. They lay out the foundation of this research topic. Yager[1] deals with the problem of aggregating multiple criteria to form an overall decision function and introduces the "orness," which refers to the "and-like" or "or-like" aggregation result of an OWA operator. Thus the operator lies between two extremes, 1 ("and-like") and 0 ("or-like"), the former relates to the situation in which all criteria are satisfied. Differently, the latter refers to the situation in which at least one of the criteria has to be satisfied. The 11 values between 0 and 1 depend on the decision maker's

[d]Some journals such as *International Journal of Intelligent Systems* and *IEEE Transactions on Systems Man and Cybernetics* do not provide keywords. In these cases, we propose keywords as recurrent words along the papers and use Italic fonts to highlight them.

Table IV. Papers on the CPM

ID	Authors	Title	Journal	Keywords	Year of publication
1	Yager, R.R.	On ordered weighted averaging operators in multicriteria decision making	*IEEE Transactions on Systems, Man and Cybernetics*	Ordered weighted averaging operators, decision making	1988
4	Yager, R. R.	Families of OWA operators	*Fuzzy Sets and Systems*	Aggregation; fuzzy sets; averaging operators; linguistic quantifiers; logical operators	1993
5	Yager, R. R.; Filev, D R.	Parameterized and-like and or-like OWA operators	*International Journal of General Systems*	Aggregation operators; decision making; averaging operators; fuzzy set theory; fuzzy logic control	1994
6	Yager, R.R.	Measures of entropy and fuzziness related to aggregation operators	*Information Sciences*	Entropy measures	1995
18	Yager, R. R.	Constrained OWA aggregation	*Fuzzy Sets and Systems*	*Fuzzy mathematical programming*; linguistic quantifiers; constrained optimization; OWA operators	1996
21	Yager, R. R.	On the analytic representation of the Leximin ordering and its application to flexible constraint propagation	*European Journal of Operational Research*	Aggregation; constraint propagation; fuzzy sets; OWA operators; Leximin; mathematical programming	1997
24	Mitchell, H B.; Estrakh, D. D.	An OWA operator with fuzzy ranks	*International Journal of Intelligent Systems*	*Fuzzy ranks*	1998
35	Mitchell, H B.; Schaefer, P. A.	Multiple priorities in an induced ordered weighted averaging operator	*International Journal of Intelligent Systems*	*Multiple fuzzy priorities*	2000
49	Xu, Z.S.; Da, Q. L.	The uncertain OWA operator	*International Journal of Intelligent Systems*	*Internal numbers; uncertain OWA operator*	2002
50	Xu, Z.S.; Da, Q. L.	The ordered weighted geometric averaging operators	*International Journal of Intelligent Systems*	*Ordered weighted geometric averaging operators*	2002
51	Yager, R. R.	Using fuzzy methods to model nearest neighbour rules	*IEEE Transactions on Systems, Man and Cybernetics part B-Cybernetics*	Nearest-neighbour models	2002
57	Herrera, F., Herrera-Viedma, E., Chiclana, F.	A study of the origin and uses of the ordered weighted geometric operator in multicriteria decision making	*International Journal of Intelligent Systems*	*Ordered weighted geometric operator; multicriteria decision making*	2003

(*Continued*)

Table IV. Continued

ID	Authors	Title	Journal	Keywords	Year of publication
59	Ogryczak, W.; Sliwinski, T.	On solving linear programs with the ordered weighted averaging objective	*European Journal of Operational Research*	Equity; lexicographic maximin; *linear programming*; multiple criteria; ordered weighted averaging	2003
60	Yager, R. R.	Induced aggregation operators	*Fuzzy Sets and Systems*	IOWA operator; OWA aggregation operators; best yesterday models	2003
61	Xu, Z. S.; Da, Q. L.	An overview of operators for aggregating information	*International Journal of Intelligent Systems*	*Survey; aggregation operators*	2003
68	Liu, X. W.; Chen, L. H.	On the properties of the parametric geometric OWA operator	*International Journal of Approximate Reasoning*	OWA operator; geometric OWA operator; maximum entropy OWA operator	2004
76	Xu, Z. S.	EOWA and EOWG operators for aggregating linguistic labels based on linguistic preference relations	*International Journal of Uncertainty Fuzziness and Knowledge-Based Systems*	Group decision making; multiplicative linguistic preference relations; additive linguistic preference relations; extended ordered weighted averaging (EOWA) operator	2004
77	Xu, Z. S.	Uncertain linguistic aggregation operators based approach to multiple attribute group decision making under uncertain linguistic environment	*Information Sciences*	Aggregation; multiple attribute group decision making; uncertain linguistic ordered weighted averaging (ULOWA) operator; uncertain linguistic hybrid aggregation (ULHA) operator	2004
86	Wang, Y. M.; Parkan, C.	A mini-max disparity approach for obtaining OWA operator weights	*Information Sciences*	OWA operator; Operator weights; Degree of orness; mini-max	2005
104	Xu, Z. S.	On generalized induced linguistic aggregation operators	*International Journal of General Systems*	Generalized induced linguistic aggregation operators, linguistic variable, uncertain linguistic variable, operational laws	2006
111	Amin, G. R., Emrouznejad, A.	An extended mini-max disparity to determine the OWA operator weights	*Computers & Industrial Engineering*	OWA operator weights; *duality of linear programming*	2006
152	Wang, Y. M.; Luo, Y.; Hua, Z.	Aggregating preference rankings using OWA operator weights	*Information Sciences*	Preference ranking; preference aggregation; OWA operator weights; orness degree	2007
159	Llamazares, B.	Choosing OWA operator weights in the field of social choice	*Information Sciences*	Ordered weighted averaging operators; aggregation operator weights; majority rules	2007

(*Continued*)

Table IV. Continued

ID	Authors	Title	Journal	Keywords	Year of publication
162	Xu, S. Z.	Intuitionistic fuzzy aggregation operators	*IEEE Transactions on Fuzzy Systems*	Intuitionistic fuzzy hybrid aggregation, intuitionistic fuzzy ordered weighted averaging (IFOWA)	2007
250	Merigó, J. M.; Gil-Lafuente, A. M.	The induced generalized OWA operator	*Information Sciences*	Aggregation operators; OWA operators; generalized mean; quasi-arithmetic mean; decision-making	2009
284	Merigó, J. M.; Casanovas, M.	The fuzzy-generalized OWA operator and its application in strategic decision making	*Cybernetics and Systems*	Aggregation operators; decision making; fuzzy OWA operator; selection of strategies	2010
300	Zhao, H.; Xu, Z.; Ni, M.; Liu, S.	Generalized aggregation operators for intuitionistic fuzzy sets	*International Journal of Intelligent Systems*	*Generalized intuitionistic fuzzy weighted averaging operator*	2010
308	Merigó, J. M.; Casanovas, M.	Fuzzy-generalized hybrid aggregation operators and its application in fuzzy decision making	*International Journal of Fuzzy Systems*	Aggregation operators; fuzzy numbers; hybrid averaging; OWA operator; decision making	2010
316	Merigó, J. M.	Fuzzy decision making with immediate probabilities	*Computers & Industrial Engineering*	Decision-making; immediate probabilities; OWA operator; fuzzy numbers; strategic selection	2010
321	Merigó, J. M.; Casanovas, M.	Induced and heavy aggregation operators with distance measures	*Journal of Systems Engineering and Electronics*	It is called the induced heavy ordered weighted averaging (OWA) distance (IHOWAD) operator.	2010
323	Merigó, J. M.; Gil-Lafuente, A. M.	New decision-making techniques and their application in the selection of financial products	*Information Sciences*	Decision making; OWA operator; selection of financial products; hamming distance	2010
327	Merigó, J. M.; Casanovas, M.	Decision making with distance measures and linguistic aggregation operators	*International Journal of Fuzzy Systems*	Linguistic ordered weighted averaging distance (LOWAD) operator	2010
359	Merigó, J. M.; Casanovas, M.	Decision making with distance measures and induced aggregation operators	*Computers & Industrial Engineering*	Decision-making; OWA operator; distance measures; induced aggregation operators	2011

(*Continued*)

Table IV. Continued

ID	Authors	Title	Journal	Keywords	Year of publication
369	Merigó, J. M.; Casanovas, M.	Induced aggregation operators in the Euclidean distance and their application in financial decision making	*Expert Systems with Applications*	Induced aggregation operators; Euclidean distance; decision making; selection of investment	2011
375	Merigó, J. M.; Gil-Lafuente, A. M.; Gil-Aluja, J.	Soft computing techniques for decision making with induced aggregation operators	*Information-An International International Journal*	*Induced aggregation operators; induced ordered weighted averaging; induced ordered weighted averaging adequacy coefficient operator*	2011
379	Merigó, J. M.; Gil-Lafuente, A. M.	Fuzzy-induced generalized aggregation operators and its application in multiperson decision making	*Expert Systems with Applications*	Aggregation operator; OWA operator; fuzzy numbers;multi-person decision making	2011
386	Merigó, J. M.	A unified model between the weighted average and the induced OWA operator	*Expert Systems with Applications*	Weighted average; OWA operator; aggregation operators; multi-person decision making	2011
389	Merigó, J. M.	Fuzzy multi-person decision making with fuzzy probabilistic aggregation operators	*International Journal of Fuzzy Systems*	Multi-person decision making; Fuzzy probabilistic OWA	2011
403	Zeng, S. Z.; Su, W.	Linguistic induced generalized aggregation distance operators and their application to decision making	*Economic Computation and Economic Cybernetics Studies and Research*	Linguistic variables; OWA operator; distance measure; decision making; human resource management	2012
446	Zeng, S.; Su, W.; Le, A.	Fuzzy-generalized ordered weighted averaging distance operator and its application to decision making	*International Journal of Fuzzy Systems*	FGOWADO; Hamming distance, fuzzy Euclidean OWA distance	2012
488	Merigó, J. M.; Xu, Y.; Zeng, S.	Group decision making with distance measures and probabilistic information	*Knowledge-Based Systems*	Decision making; selection of policies; probability; Hamming distance; aggregating operators	2013
504	Zeng, S.; Merigó, J. M.; Su, W.	The uncertain probabilistic OWA distance operator and its application in group decision making	*Applied Mathematical Modelling*	Probability; OWA operator; distance measures; uncertainty; group decision-making	2013
527	Su, W.; Li, W.; Zeng, S.	Atanassov's intuitionistic linguistic ordered weighted averaging distance operator and its application to decision making	*Journal of Intelligent & Fuzzy Systems*	Distance measures, OWA operator, Atanassov's intuitionistic linguistic variables, multi-person decision making	2014

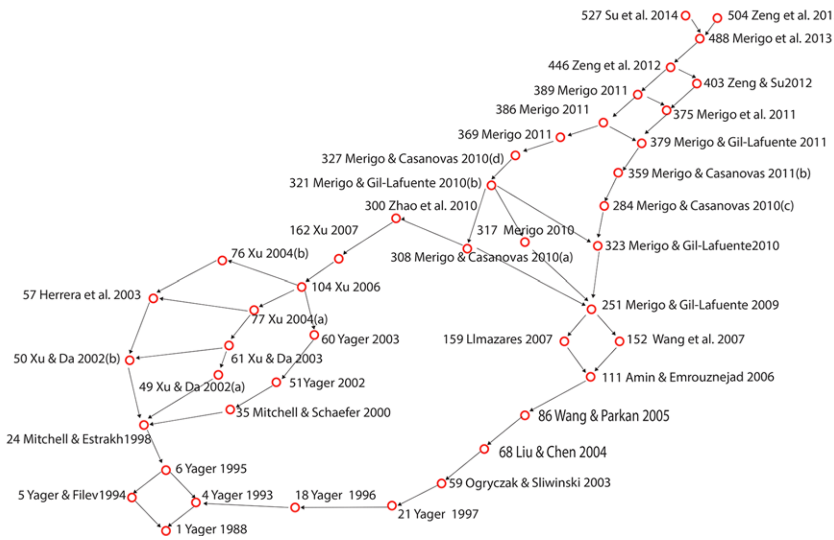

Figure 4. Critical path method of OWA development.

expertise and are supposed to reflect his degree of optimism. The "orness" concept itself received great attention and further specification.[22–24] Two lines of research depart from this knowledge base, mainly dealing with different approaches to obtain the associated weights.

On the one hand, we identify a branch of literature including a group of works that generalize the OWA operator to include the case of real-number and fuzzy ranks,[25] use a multiple priority induced OWA operator,[26] propose new classes of aggregation operators such as the ordered weighted geometric averaging operators,[27] investigate the uncertain OWA operator in which the associated weighting parameters cannot be specified, but value ranges can be obtained and each input argument is given in the form of an interval of numerical values,[28] and investigate the ordered weighted geometric operator and its relationship with the OWA operator in multicriteria decision making.[29] Within this area, we can find two other works of Yager. A paper dealing with fuzzy methods to model nearest neighbor rules[30] and a second one about induced OWA operators (IOWA)[31] that receive further attention in this subarea identified and great development later as we will show. Xu and Da proposed the induced ordered weighted geometric averaging operator (2003) as a new aggregator and the generalized induced linguistic aggregation operators.[32] Other two papers of Xu and Da (2003) extend the OWA proposing the (EOWA) operator and the uncertain linguistic ordered weighted averaging (ULOWA) operator and the uncertain linguistic hybrid aggregation (ULHA) operator.

The subsequent line focuses on fuzzy aggregation and fuzzy set theory. Within this group, the CPM highlights the following as the most significant contributions: Xu[33] propose an intuitionistic fuzzy version of the OWA operator (IFOWA);[34] the paper extends the generalized OWA operators introduced by Yager[24] to the intuitionistic fuzzy information. Merigó and Casanovas[35] present a series of operators, the fuzzy-generalized hybrid averaging operator, the fuzzy-induced generalized hybrid averaging operator, the quasi-Fuzzy Hybrid Averaging (FHA) operator and the quasi-Fuzzy Induced Hybrid Averaging (FIHA) operator, with the advantage of generalizing a wide range of fuzzy aggregation operators so that they can be used in different applications such as decision-making problems.

On the other hand, Ref. 36 deals with the problem of maximizing an OWA aggregation of a group of variables interrelated and constrained by a collection of linear inequality. In this paper, Yager proposes to model this problem as a linear programming (LP) problem. Subsequently, the OWA operator is proposed to as analytic formulation for the Leximin method, overcoming its lack of analytic formulation.[37] Following these conceptualizations, researchers worked on the LP formulations with the OWA objective functions.[38–41] However, there are differences among various approaches using the LP. According to Ogryczak and Śliwiński,[38] the LP problem with the OWA objective can be performed as a standard linear problem and two alternative LP formulations are introduced the max–min and the deviation model. Liu and Chen[39] propose the concept of parametric geometric OWA operator (PGOWA) and parametric maximum entropy OWA operator (PMEOWA), showing the consistence of the orness level and the aggregation value for an aggregated elements with PGOWA. The equivalence between PGOWA and PMEOWA is also proven. Wang and Parkan's[40] paper represents the first attempt to propose the mini-max disparity approach as a method to identify OWA operator weights using LP under a given level of "orness." According to this approach, OWA operator weights have been determined by minimizing the maximum difference between two adjacent weights, under a given level of "orness." Within this line of research, Amin and Emrouznejad[41] extend the mini-max disparity to determine the OWA model based on LP and introduce the mini-max disparity approach between any distinct pairs of the weights. Drawing on this works, the subarea that we find between 2007 and 2009[42–44] make a step further in this direction developing models that slightly different from the previous ones. More specifically, Wang et al.'s[43] paper deals with the determination of the weights of different ranking places. Their model allows the weights associated with different ranking places to be determined in terms of a decision maker's optimism level, which is characterized by an orness degree. Llamazares[42] aims to determine the OWA operator weights that allow to extend, through the OWA operator, some classes of majority rules obtained when individuals do not grade their preferences between two alternatives. Subsequently, we find Ref. 44 that can be seen as a bridge between the previous areas of research. This new area relies on both lines of previous research and comprises works mainly dealing with induced and fuzzy OWA operators. Merigó and Gil-Lafuente[45] build on the previous line of research to introduce the induced generalized ordered weighted averaging (IGOWA) operator. It is a new aggregation operator that generalizes the OWA operator, including the main characteristics of both the generalized OWA and the induced OWA operator. They propose the application of the IGOWA in a financial decision-making problem. Merigó[46] develops a decision-making model with probabilistic information and uses the concept of the immediate probability to aggregate the information and applies it to the selection of strategies. Merigó

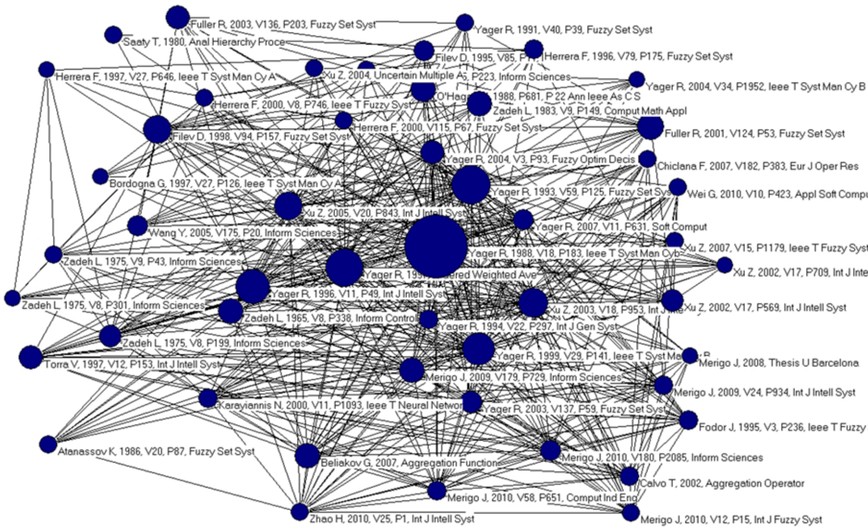

Figure 5. Map of most cocited publications.

and Gil-Lafuente[47] introduce the ordered weighted averaging distance operator and the ordered weighted averaging adequacy coefficient operator to the selection of financial products. This line of research has been further exploited by Merigó and his coauthors that successfully applied the proposed models to other disciplinary context, such as strategic and business decision making.[48,49] Within this line of research, they develop also a decision-making model with distance measures by using linguistic aggregation operators. In doing so, they propose the linguistic ordered weighted averaging distance operator and apply it to support decision makers in human resource management.[50]. Subsequently, they further developed a OWA model based on using distance measures and induced aggregation operators.[51]. This model provides a parameterized family of distance aggregation operators between the maximum and the minimum distance based on a complex reordering process that reflects the complex attitudinal character of the decision maker. The fuzzy-induced generalized aggregation operators have also been proposed in strategic multiperson decision making.[52] Merigó also works on a model that uses the weighted average and the IOWA operator in the same formulation and apply it in multiperson decision making in political management.[53]

The 50 most frequently cocited publications have been listed in Table V.[e] Yager's first OWA paper is the most frequently cocited with other references. It is often cocited with his other papers[19,36,54] and with the following publications: Refs.44 and 55–57.

Figure 5 helps in understanding the intensity of such cocitation frequency. Old papers appear on the left-hand side, whereas the newer ones are located to the

[e] In this table, we use only first author's name to indicate the publication.

Table V. Most frequent reference citation and associated highest cocitations

Publication	Co-cit value	Publication most cocited with
Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*	162	Yager, R., 1993, *Fuzzy Sets and Systems*
Yager, R., 1997, *The ordered weighted averaging operators: Theory and applications*	148	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*	122	Yager, R., 1996, *International Journal of Intelligent Systems*
Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*	116	Yager, R., 1999, *IEEE Transactions on Systems, Man and Cybernetics Part B-Cybernetics*
Xu, Z., 2003, *International Journal of Intelligent Systems*	95	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Filev, D., 1998, *Fuzzy Sets and Systems*	86	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Xu, Z., 2005, *International Journal of Intelligent Systems*	82	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Yager, R., 1997, *The ordered weighted averaging operators: Theory and applications*	76	Yager, R., 1993, *Fuzzy Sets and Systems*
Merigo, J., 2009, *Information Sciences*	74	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Fuller, R., 2001, *Fuzzy Sets and Systems*	71	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Beliakov, G., 2007, *Aggregation Function*	68	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Yager, R., 1993, *Fuzzy Sets and Systems*	67	Yager, R., 1999, *IEEE Transactions on Systems, Man and Cybernetics Part B-Cybernetics*
Yager, R., 1997, *The ordered weighted averaging operators: Theory and applications*	67	Yager, R., 1999, *IEEE Transactions on Systems, Man and Cybernetics Part B-Cybernetics*
O'Hagan, M., 1988, *Annual Conference IEEE Asilomar Conference Signals*	65	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Fuller, R., 2003, *Fuzzy Sets and Systems*	64	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Yager, R., 2004, *Fuzzy Optimization and Decision Making*	63	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Merigo, J., 2009, *Information Sciences*	63	Yager, R., 1993, *Fuzzy Sets and Systems*
Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*	62	Zadeh, L., 1983, *Computers & Mathematics with Applications*
Torra, V., 1997, *International Journal of Intelligent Systems*	62	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Xu, Z., 2003, *International Journal of Intelligent Systems*	60	Yager, R., 1993, V59, P125, *Fuzzy Sets and Systems*
Xu, Z., 2003, *International Journal of Intelligent Systems*	60	Yager, R., 1997, *The ordered weighted averaging operators: Theory and applications*
Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*	59	Zadeh, L., 1965, *Information and Control*

(*Continued*)

Table V. Continued

Publication	Co-cit value	Publication most cocited with
Yager, R., 1993, *Fuzzy Sets and Systems*	59	Yager, R., 1996, *International Journal of Intelligent Systems*
Filev, D., 1998, *Fuzzy Sets and Systems*	57	Yager, R., 1993, *Fuzzy Sets and Systems*
Xu, Z., 2005, *International Journal of Intelligent Systems*	57	Yager, R., 1993, *Fuzzy Sets and Systems*
Merigo, J., 2009, *Information Sciences*	56	Yager, R., 1997, *The ordered weighted averaging operators: Theory and applications*
Beliakov, G., 2007, *Aggregation Function*	53	Yager, R., 1993, *Fuzzy Sets and Systems*
Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*	51	Yager, R., 2003, *Fuzzy Sets and Systems*
Xu, Z., 2003, *International Journal of Intelligent Systems*	51	Yager, R., 1999, *IEEE Transactions on Systems, Man and Cybernetics Part B-Cybernetics*
Merigo, J., 2010, *Information Sciences*	51	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Yager, R., 1997, *The ordered weighted averaging operators: Theory and applications*	51	Yager R, 1996, *International Journal of Intelligent Systems*
Filev, D., 1998, *Fuzzy Sets and Systems*	50	Fuller R, 2001, *Fuzzy Sets and Systems*
Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*	49	Yager R, 2007, *Soft Computing*
Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*	49	Zadeh L, 1975, *Information Sciences*
Beliakov, G., 2007, *Aggregation Function*	49	Merigo, J., 2009, *Information Sciences*
Beliakov, G., 2007, *Aggregation Function*	49	Yager, R., 1997, *The ordered weighted averaging operators: Theory and applications*
Xu, Z., 2002, *International Journal of Intelligent Systems*	48	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Wang, Y. , 2005, *Information Sciences*	48	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Merigo, J., 2009, *Information Sciences*	48	Yager, R., 1999, *IEEE Transactions on Systems, Man and Cybernetics Part B-Cybernetics*
Merigo, J., 2009, *Information Sciences*	48	Xu, Z., 2003,IEEE *International Journal of Intelligent Systems*
Filev, D., 1995, *Information Sciences*	47	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Yager, R., 2004, *Fuzzy Optimization and Decision Making*	47	Yager, R., 1993, *Fuzzy Sets and Systems*
Yager, R., 1999, *IEEE Transactions on Systems, Man and Cybernetics Part B-Cybernetics*	45	Yager, R., 2003, V137, P59, *Fuzzy Sets and Systems*
Merigo, J., 2009, *International Journal of Intelligent Systems*	44	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Beliakov, G., 2007, *Aggregation Function*	43	Xu, Z., 2003, *International Journal of Intelligent Systems*
Merigo, J., 2009, *International Journal of Intelligent Systems*	43	Yager, R., 1993, *Fuzzy Sets and Systems*
Fodor, J., 1995, *IEEE Transactions on Fuzzy Systems*	43	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*
Merigo, J., 2009, *Information Sciences*	43	Yager, R., 2004, *Fuzzy Optimization and Decision Making*
Calvo, T., 2002, *Aggregation Operator*	42	Yager, R., 1988, *IEEE Transactions on Systems, Man and Cybernetics*

right-hand side. The right-hand side shows a higher degree of concentration and a higher number of ties. This informs about the most cocited publications, whereas the biggest shape indicates the highest number of total citations received. In fact, Yager[1] is the most cited, but also the most cocited.

5. CONCLUSIONS

This study investigates the dominant direction within the OWA literature. As it is the first systematic review of this topic, we focus on the dominant direction instead of describing the several areas of applications of the OWA. Despite this, we have also been able to identify within the dominant direction some subareas of research that are strongly represented within the OWA CPM result and for this reason we expect to be further exploited by researchers in the future development of the discipline.

First, we show the historiograph to provide a descriptive and chronological reconstruction of publications dealing with this topic. The second step of the analysis consists with the description of the CPM results that give a more fine-grained picture of the evolution of studies using the OWA operators, allowing us to suggest future line of research.

Major efforts have been dedicated by scholars in determining the OWA operator weights.

While over the first 22 years, two clear lines of research emerged and have been developed by different authors, the past 4 years, as mapped by the CPM algorithm, do not show a clear path of research but remark the previous two. Furthermore, the most recent applications of OWA operators are in different disciplines, from financial to strategic decision making and human resource management.[47,49,58]

The OWA research is growing in different fields ranging from computer science to operational research to and economics. A great part of the literature deals with different approaches proposed to obtain the associated weights.

It is worth noting that scholars active in this area of research belong mainly to two main disciplinary areas, operational research and computer science on the one hand and economics on the other.

The analysis of core papers along the intellectual trajectory of the OWA field shows that among the most active journals, two published the most important papers in terms of core knowledge contributors, *International Journal of Intelligent Systems* and *Information Science*.

6 SUPPORTING INFORMATION

A list of all 537 references is available as the online supplement document in the online issue of the journal.

References

1. Yager RR. On ordered weighted averaging aggregation operators in multicriteria decision making. IEEE Trans Systems Man and Cybernet 1988;18(1):183–190.
2. Yager RR. 1995. An approach to ordinal decision making. Int J Approx Reason 12(3): 237–261.
3. Yager RR, Kreinovich, V. Decision making under interval probabilities. Int J Approx Reason 1999;22(3):195–215.
4. Kacprzyk J, Zadrożny S. Computing with words in intelligent database querying: standalone and Internet-based applications. Inform Sci 2001;134(1): 71–109.
5. Herrera-Viedma E, Cordón O, Luque M, Lopez AG, Muñoz AM. A model of fuzzy linguistic IRS based on multi-granular linguistic information. Int J Approx Reason 2003;34(2–3):221–239.
6. Torra V. OWA operators in data modeling and reidentification. IEEE Trans Fuzzy Syst 2004;12(5):652–660.
7. Garfield E, Sher I, Torpie R. 1964. The use of citation data in writing the history of science. Philadelphia, PA: Institute for Scientific Information; 1964. Available at www.garfield.library.upenn.edu/papers/useofcitdatawritinghistofsci.pdf.
8. Garfield E. From the science of science to scientometrics visualizing the history of science with HistCite software. J Informetrics 2009;3(3):21–26.
9. Kejžar N, Černe SK, Batagelj V. Network analysis of works on clustering and classification from Web of Science. In Locarek-Junge H, Weihs C, editors. Classification as a tool for research, studies in classification, data analysis, and knowledge organization. Berlin: Springer; 2010. pp 525–536.
10. Garfield E. Why do we need algorithmic historiography? J Am Soc Inform Sci Technol 2003;54(3):400–412.
11. De Stefano D, Giordano G, Vitale MP. Issues in the analysis of co-authorship networks. Qual Quant 2011;45(5):1091–1107.
12. Lee JD, Baek C, Kim HS, Lee J-S. Development pattern of the DEA research field: a social network analysis approach. J Product Anal 2014;41(2):175–186.
13. Calero-Medina C, Noyons ECM. Combining mapping and citation network analysis for a better understanding of the scientific development: The case of the absorptive capacity field. J Informetrics 2008;2(4):272–279.
14. Ding Y, Liu X, Guo C, Cronin, B. The distribution of references across texts: Some implications for citation analysis. J Informetrics 2013;7(3):583–592.
15. Liu JS, Lu L, Lu WM, Lin BJY. Data envelopment analysis 1978–2010: A citation-based literature survey. Omega 2013;41(1):3–15.
16. Hummon NP, Doreian P. Connectivity in a citation network: The development of the DNA theory. Social Netw 1989;11(1):39–63.
17. Batagelj V. Efficient algorithms for citation network analysis. Working paper, Department of Theoretical and Computer Science, University of Lubjana; 2003.
18. Leydesdorff L, Vaughan L. Co-occurrence matrices and their applications in information science: Extending ACA to the web environment. J Am Soc Inform Sci Technol 2006;57(12):1616–1628.
19. Yager RR. Families of OWA operators. Fuzzy Sets Syst 1993;59(2):125–148.
20. Yager RR. 1995. Measures of entropy and fuzziness related to aggregation operators. Inform Sci 82(3–4): 147–166.
21. Yager RR, Filev DP. Parameterized and-like and or-like operators. Int J Gen Syst 1994;22(3):297–316.
22. Marichal J. Aggregation operators for multicriteria decision aid. Ph.D. thesis, Institute of Mathematics, University of Liège, Liège, Belgium; 1999.
23. Fernández Salido JM, Murakami S. Extending Yager's orness concept for the OWA aggregators to other mean operators. Fuzzy Sets Syst 2003;139(3):515–542.
24. Yager RR. Generalized OWA aggregation operators. Fuzzy Optim Decis Making 2004;3(1):93–107.

25. Mitchell HB, Estrakh DD. An OWA operator with fuzzy ranks. Int J Intell Syst 1998;13(1):69–81.
26. Mitchell HB, Schaefer PA. Multiple priorities in an induced ordered weighted averaging operator. Int J Intell Syst 2000;15(4):317–327.
27. Xu ZS, Da QL. The uncertain OWA operator. Int J Intell Syst 2002;17(6):569–575.
28. Xu ZS, Da QL. The ordered weighted geometric averaging operators. Int J Intell Syst 2002;17(7):709–716.
29. Herrera F, Herrera-Viedma E, Chiclana, F. A study of the origin and uses of the ordered weighted geometric operator in multicriteria decision making. Int J Intell Syst 2003;18(6):689–707.
30. Yager RR. Using fuzzy methods to model nearest neighbor rules. IEEE Transactions on systems, man, and cybernetics. IEEE Trans Syst Man Cybernet, Part B 2002;32(4):512–525.
31. Yager RR. Induced aggregation operators. Fuzzy Sets Systems 2003;137(1):59–69.
32. Xu Z. On generalized induced linguistic aggregation operators. Int J Gen Syst 2006;35(1):17–28.
33. Xu ZS. Intuitionistic Fuzzy Aggregation Operators. IEEE Trans Fuzzy Syst 2007;15(6):1179–1187.
34. Zhao H, Xu Z, Ni M, Liu S. Generalized aggregation operators for intuitionistic fuzzy sets. Int J Intell Syst 2010;25:1–30.
35. Merigó JM, Casanovas M. Fuzzy generalized hybrid aggregation operators and its application in fuzzy decision making. Int J Fuzzy Syst 2010; 12(1):15–24.
36. Yager RR. Constrained OWA aggregation. Fuzzy Sets Syst 1996;81(1):89–101.
37. Yager RR. On the analytic representation of the Leximin ordering and its application to flexible constraint propagation. Eur J Oper Res 1997;102(1):176–192.
38. Ogryczak W, Śliwiński, T. On solving linear programs with the ordered weighted averaging objective. Eur J Oper Res 2003;148(1):80–91.
39. Liu X, Chen L. On the properties of parametric geometric OWA operator. Int J Approx Reason 2004;35(2):163–178.
40. Wang YM, Parkan, C. A minimax disparity approach for obtaining OWA operator weights. Inform Sci 2005;175(1):20–29.
41. Amin GR, Emrouznejad, A. An extended minimax disparity to determine the OWA operator weights. Comput Ind Eng 2006;50(3): 312–316.
42. Llamazares B. Choosing OWA operator weights in the field of Social Choice. Inform Sci 2007;177(21):4745–4756.
43. Wang YM, Luo Y, Hua, Z. Aggregating preference rankings using OWA operator weights. Inform Sci 2007;177(16):3356–3363.
44. Merigó JM, Gil-Lafuente AM. The induced generalized OWA operator. Inform Sci 2009;179(6):729–741.
45. Merigó JM, Casanovas M. Decision making with distance measures and linguistic aggregation operators. Int J Fuzzy Syst 2010; 12(3):190–198.
46. Merigó JM. Fuzzy decision making with immediate probabilities. Comput Ind Eng 2010;58(4):651–657.
47. Merigó JM, Gil-Lafuente AM. New decision-making techniques and their application in the selection of financial products. Inform Sci 2010;180(11):2085–2094.
48. Merigó JM, Casanovas M. 2010. Induced and heavy aggregation operators with distance measures. Syst Eng Electron 21(3):431–439.
49. Merigó JM, Casanovas M. Decision-making with distance measures and induced aggregation operators. Comput Ind Eng 2011;60(1):66–76.
50. Merigó JM, Casanovas M. 2010. The fuzzy generalized OWA operator and its application in strategic decision making. Cybernet Syst 41(5):359–370.
51. Merigó JM, Casanovas M. Induced aggregation operators in the Euclidean distance and its application in financial decision making. Expert Syst Appl 2011;38(6): 7603–7608.

52. Merigó JM, Gil-Lafuente AM. Fuzzy induced generalized aggregation operators and its application in multi-person decision making. Expert Syst Appl 2011;38(8):9761–9772.
53. Merigó JM. A unified model between the weighted average and the induced OWA operator. Expert Syst Appl 2011;38(9):11560–11572.
54. Yager RR. Induced ordered weighted averaging operators. IEEE Trans Systems Man,and Cybernet Part B 1999;29(2):141–150.
55. Filev D, Yager RR. On the issue of obtaining OWA operator weights. Fuzzy Sets Syst 1998;94(2):157–169.
56. Xu ZS, Da QL. An overview of operators for aggregating information. Int J Intell Syst 2003;18(9):953–969.
57. Xu Z. An overview of methods for determining OWA weights. Int J Intell Syst 2005;20(8):843–865.
58. Zeng S, Merigó JM, Su, W. The uncertain probabilistic OWA distance operator and its application in group decision making. Appl Math Model 2013;37(9):6266–6275.