Some Basic Results of Fuzzy Research in the ISI Web of Knowledge

José M. Merigó, Anna M. Gil-Lafuente

Department of Business Administration, University of Barcelona,
Av. Diagonal 690, 08034 Barcelona, Spain
jmerigo@ub.edu, amgil@ub.edu

Abstract

We present an overview of fuzzy research according to the results found in the ISI Web of Knowledge. Among the different ways and particular results to be used, we have selected the most cited articles, the top authors, the top journals, the evolution by years, and the top countries. Note that the results given in the paper are only a general overview because the rankings can be developed in different ways depending on the variables that we want to take into account.

1. Introduction

Fuzzy set theory appeared in 1965 [6]. Since then, it has received increasing attention by the scientific community and applied in almost all the general disciplines known in the world [1-5,7-8]. Initially, it took time for the scientific community to accept these theories but since the publication of the first books [4] in the seventies, it became more and more popular. Today, there are thousands of researchers dedicated to some particular area of fuzzy research and there are a lot of journals and conferences dedicated to these topics.

In this paper, we present a general overview of the fuzzy research according to the results found in the ISI Web of Knowledge. The ISI Web is an institution that collects the data of different journals, conferences, etc., that are officially recognized to be the most relevant in the world in their respective topics. Therefore, we believe that these results are useful for the fuzzy community because they give a general overview of the main research in fuzzy theories. However, it is worth noting that the results can be studied in different ways depending on the criteria that we follow in the development of the rankings. Note also that the results are the statistical result found in the data but as it is known, sometimes there exist other variables that are not included that are also relevant in the research.

This paper is organized as follows. In Section 2, we present the most cited articles. In Section 3, we give a general overview of the top authors. Section 4 presents the top journals. In Section 5 we analyze the evolution by years and in Section 6 the top countries. Section 7 summarizes the main results of the paper.

2. Most cited articles in the ISI Web of Knowledge

In this Section, we are going to present the most cited papers with the word "fuzzy". Note that inside the ISI Web, we will use the Web of Science (WoS) because it considers the journals listed in the ISI Web. Other alternatives could be considered such as the ISI Proceedings (now the Conference Proceedings Citation Index) but we have tried to focus only in the main journals recognised by the ISI.

An interesting aspect to mention in the search process is that there may exist particular results that could produce mistakes in the "search process with the keyword FUZZY". For example, one problem is that some articles use the word fuzzy but are not a research paper in fuzzy theories (this happens because the word FUZZY can be used with different meanings). A further problem is all the papers in fuzzy research that does not use the word fuzzy. This problem is becoming increasingly relevant because there are a lot of new theories that may not use the word fuzzy such as in soft computing. And so on.

This paper uses the results found in the ISI Web of Knowledge the day 22-06-2009 but considering the data until the 31-12-2008.

The word "fuzzy" has obtained 31030 articles. Note that this number only includes the articles. If we include conference proceedings indexed in the ISI Web and other material, then the number is 81214. Most of them can be considered as research papers about fuzzy theories. Note that an additional problem is that there are a lot of papers about fuzzy theories that do not use the word fuzzy such as those that deal with linguistic

information (some of them). For example, the papers by Zadeh about linguistic information [7] are not found by the search tool when using the word fuzzy and obviously, they are key papers in fuzzy research. This problem will be considered in further research.

In this paper, we present the top 20 articles most cited in the ISI Web. Obviously, it is possible to consider longer lists with the top 50, top 100, or with sub classifications by fuzzy topic, by years, etc. The 30 articles most cited in the *Web of Science* that uses the word fuzzy are the following ones.

1) L.A. Zadeh, "Fuzzy sets," *Information and Control,* vol. 8, no. 3, pp. 338-353, 1965.
   - Times cited: 10339.
2) T. Takagi, and M. Sugeno, "Fuzzy identification of systems and its applications to modeling and control," *IEEE Transactions on Systems Man and Cybernetics,* vol. 15, no. 1, pp. 116-132, 1985.
   - Times cited: 3623.
3) L.A. Zadeh, "Fuzzy sets as a basis for a theory of probability," *Fuzzy Sets and Systems,* vol. 1, no. 1, pp. 3-28, 1978.
   - Times cited: 2440.
4) C.C. Lee, "Fuzzy logic in control systems – Fuzzy logic controller 1", *IEEE Transactions on Systems, Man and Cybernetics*, vol. 20, no. 2, pp. 404-418, Mar-Apr. 1990.
   - Times cited: 2400.
5) J.S.R. Jang, "ANFIS – Adaptative-network-based fuzzy inference system," *IEEE Transactions on Systems Man and Cybernetics,* vol. 23, no. 3, pp. 665-685, May-Jun, 1993.
   - Times cited: 1877.
6) E.H. Mamdani, and S. Assilian, "Experiment in linguistic synthesis with a fuzzy logic controller," *International Journal of Man-Machine Studies,* vol. 7, no. 1, pp. 1-13, 1975.
   - Times cited: 1029.
7) E.H. Mamdani, "Application of fuzzy algorithms for control of simple dynamic plant," *Proceedings of the Institution of Electrical Engineers-London,* vol. 121, no. 12, pp. 1585-1588, 1974.
   - Times cited: 888.
8) L.X. Wang, and J.M. Mendel, "Generating fuzzy rules by learning from examples," *IEEE Transactions on Systems Man and Cybernetics,* vol. 22, no. 6, pp. 1414-1427, Nov-Dec, 1992.
   - Times cited: 875.
9) K. Tanaka, and M. Sugeno, "Stability analysis and design of fuzzy control-systems," *Fuzzy Sets and Systems,* vol. 45, no. 2, pp. 135-156, Jan, 1992.
   - Times cited: 791.

10) H.O. Wang, K. Tanaka, and M.F. Griffin, "An approach to fuzzy control of nonlinear systems: stability and design issues," *IEEE Transactions on Fuzzy Systems,* vol. 4, no. 1, pp. 14-23, Feb, 1996.
    - Times cited: 780.
11) M. Sugeno, and G.T. Kang, "Structure identification of fuzzy model," *Fuzzy Sets and Systems,* vol. 28, no. 1, pp. 15-33, Oct, 1988.
    - Times cited: 739.
12) L.A. Zadeh, "Similarity relations and fuzzy orderings," *Information Sciences,* vol. 3, no. 2, pp. 177-200, 1971.
    - Times cited: 722.
13) L.A. Zadeh, "Probability measures of fuzzy events," *Journal of Mathematical Analysis and Applications,* vol. 23, no. 2, pp. 421-427, 1968.
    - Times cited: 650.
14) J.A. Goguen, "L-fuzzy sets," *Journal of Mathematical Analysis and Applications,* vol. 18, no. 1, pp. 145-174, 1967.
    - Times cited: 631.
15) G.A. Carpenter, S. Grossberg, N. Markuzon *et al.*, "Fuzzy artmap – A neural network architecture for incremental supervised learning of analog multidimensional maps," *IEEE Transactions on Neural Networks,* vol. 3, no. 5, pp. 698-713, Sep, 1992.
    - Times cited: 576.
16) G.A. Carpenter, S. Grossberg, and D.B. Rosen, "Fuzzy art – Fast stable learning and categorization of analog patterns by an adaptative resonance system," *Neural Networks,* vol. 4, no. 6, pp. 759-771, 1991.
    - Times cited: 571.
17) L.A. Zadeh, "Fuzzy logic equals computing with words," *IEEE Transactions on Fuzzy Systems,* vol. 4, no. 2, pp. 103-111, May, 1996.
    - Times cited: 561.
18) C.T. Lin, and C.S.G. Lee, "Neural-network-based fuzzy-logic control and decision system," *IEEE Transactions on Computers,* vol. 40, no. 12, pp. 1320-1336, Dec, 1991.
    - Times cited: 547.
19) L.A. Zadeh, "A computational approach to fuzzy quantifiers in natural languages," *Computers & Mathematics with Applications,* vol. 9, no. 1, pp. 149-184, 1983.
    - Times cited: 530.
20) C.L. Chang, "Fuzzy topological spaces," *Journal of Mathematical Analysis and Applications,* vol. 24, no. 1, pp. 182-190, 1968.
    - Times cited: 530.

In the next list, we will present the top 10 articles published since 2000 until now. Note that this list will permit us to identify recent trends in the fuzzy community.

1) B.D. Liu, Y.K. Liu, "Expected value of fuzzy variable and fuzzy expected value models", *IEEE Transactions on Fuzzy Systems*, vol. 10, no. 4, pp. 445-450, 2002.
   - Times cited: 316.
2) Y.Y. Cao, P.M. Frank, "Analysis and synthesis of nonlinear time-delay systems via fuzzy control approach", *IEEE Transactions on Fuzzy Systems*, vol. 8, no. 2, pp. 200-211, 2000.
   - Times cited: 269.
3) L.I. Kuncheva, J.C. Bezdek, R.P.W. Duin, "Decision templates for multiple classifier fusion: an experimental comparison", *Pattern Recognition*, vol. 34, no.2, pp. 299-314, 2001.
   - Times cited: 231.
4) C.T. Chen, "Extensions of the TOPSIS for group decision-making under fuzzy environment", *Fuzzy Sets and Systems*, vol. 114, no.1, pp. 1-9, 2000.
   - Times cited: 231.
5) J.M. Mendel, R.I. John, "Type-2 fuzzy sets made simple", *IEEE Transactions on Fuzzy Systems*, vol. 10, no. 2, pp. 117-127, 2002.
   - Times cited: 215.
6) L.A. Zadeh, "Toward a generalized theory of uncertainty (GTU) – an outline", *Information Sciences*, vol. 172, no. 1-2, pp. 1-40, 2005.
   - Times cited: 209
7) M. Setnes, H. Roubos, "GA – fuzzy modeling and classification: complexity and performance", *IEEE Transactions on Fuzzy Systems*, vol. 8, no. 5, pp. 509-522, 2000.
   - Times cited: 203.
8) E. Kim, H. Lee, "New approaches to relaxed quadratic stability condition of fuzzy control systems", *IEEE Transactions on Fuzzy Systems*, vol. 8, no. 5, pp. 523.534, 2000.
   - Times cited: 200.
9) C.H. Lee, C.C. Teng, "Identification and control of dynamic systems using recurrent fuzzy neural networks", *IEEE Transactions on Fuzzy Systems*, vol. 8, no. 4, 2000.
   - Times cited: 189.
10) B.S. Chen, C.S Tseng, H.J. Uang, "Mixed H-2/H-infinity fuzzy output feedback control design for nonlinear dynamic systems: An LMI approach", *IEEE Transactions on Fuzzy Systems*, vol. 8, no. 3, pp. 249-265, 2000.
    - Times cited: 189.

11) F. Herrera, E. Herrera-Viedma, "Linguistic decision analysis: stops for solving decision problems under linguistic information", *Fuzzy Sets and Systems*, vol. 115, no. 1, pp. 67-82, 2000.
    - Times cited: 188.
12) Q.L. Liang, J.M. Mendel, "Interval type-2 fuzzy logic systems: Theory and design", *IEEE Transactions on Fuzzy Systems*, vol. 8, no. 5, pp. 535-550, 2000.
    - Times cited: 180.
13) M.N. Ahmed, S.M. Yamany, N. Mohamed, et al., "A modified fuzzy C-means algorithm for bias field estimation and segmentation of MRI data", *IEEE Transactions on Medical Imaging*, vol. 21, no. 3, pp. 193-199, 2002.
    - Times cited: 177.
14) F. Herrera, L. Martinez, "A 2-tuple fuzzy linguistic representation model for computing with words", *IEEE Transactions on Fuzzy Systems*, vol. 8, no. 6, pp. 746-752, 2000.
    - Times cited: 175.
15) U.C. Benz, P. Hofmann, G. Willhauck, et al., "Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information", *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 58, no. 3-4, pp. 239-258, 2004.
    - Times cited: 174.

3. Top authors in the ISI Web of Knowledge

In the following, we show the 20 authors that has the highest number of citations in the ISI Web. As they are researchers specialized in fuzzy theories, we accept the number of entries as correct. Note that we put a column with the articles published with the word fuzzy, the total number of articles published and the times cited in the ISI Web.

The authors are ordered according to the number of citations received. Note that we have omitted some Asian (or other) authors because sometimes it is difficult for the search tool to identify the same author or distinguish between different authors (because sometimes the name is not written equal in different papers, etc). Note also that we have added a secondary list with authors highly cited that have also some highly cited paper in the fuzzy community.

As we can see, the results are more or less what we should expect about them before doing the analysis. Most of the world leading experts in fuzzy research are in the first positions such as Lotfi Zadeh, Ronald Yager, Witold Pedrycz, Didier Dubois, etc. Note that the citations include both journal and conference

proceedings citations, indexed in the ISI Web. If we just include the citations from the journals, then, the number of citations decreases, in average, between 50% and 100%.

Table 1: Authors with the most number of citations with the word "fuzzy" in the ISI Web of Knowledge

	Name	Fuz.	99-08	Total	Cited
1-	L.A. Zadeh	38	40	118	25205
2-	R.R. Yager	199	141	351	7869
3-	M. Sugeno	37	20	55	7130
4-	D. Dubois	81	129	277	6869
5-	H. Prade	73	121	254	6445
6-	J.M. Mendel	46	58	186	5933
7-	J.C. Bezdek	69	38	130	5418
8-	W. Pedrycz	289	266	419	4502
9-	F. Herrera	83	142	182	4327
10-	S.K. Pal	83	108	230	4140
11-	K. Tanaka	57	34	57	3922
12-	E. Mamdani	18	1	18	3447
13-	N.R. Pal	46	69	119	3150
14-	J.S.R. Jang	10	6	10	2998
15-	H. Ishibuchi	33	91	132	2916
16-	H. Tanaka	48	30	82	2879
17-	J.J. Buckley	91	35	106	2527
18-	J.A. Goguen	15	15	64	2513
19-	L.X. Wang	30	7	30	2491
20-	C.T. Lin	89	73	89	2302
	Other authors				
	S. Grossberg	7	87	243	14635
	G. Carpenter	6	14	48	4690
	J.M. Keller	34	45	90	2123
	Herrera-Viedma	39	72	82	2079
	D.A. Linkens	74	90	218	2078
	R. Lowen	40	31	107	1715
	E.E. Kerre	73	135	184	1652
	J.L. Verdegay	51	24	64	1642
	G.J. Klir	42	29	114	1588
	Zimmermann	28	14	46	1550
	A. Kandel	113	70	174	1541
	M. Sakawa	100	80	181	1402
	I.B. Turksen	54	57	98	1362
	S.M. Chen	104	71	105	1311

Note that these results are only an orientation of the main researchers. But the positions may change in the reality because the impact of an author may arrive from different perspectives and not only from papers published in journals indexed in the ISI Web of Knowledge. Therefore, we would like to mention that these results only want to present some of the main authors. But we would like to mention that there are a lot of very good researchers that are not included here but should be in the list according to other merits such as books published, articles published in journals not indexed in the ISI Web, articles in conferences, patents, etc. And obviously, the ranking of this list may also change if we change the merits to be taken into account. For example, if we include the citations in the ISI Web coming from books, then, George J. Klir and Hans J. Zimmermann would have more than 5000 citations and other authors such as Arnold Kaufmann about 3000 citations.

A further interesting aspect is that these results are very general and it is possible to consider a lot of particular cases that gives different types of particular rankings. For example, for identifying the young top authors, it is possible to classify the results according to the publications in the last three, five or ten years. Another interesting point is to divide the authors by countries, continents or institutions. A further interesting aspect is to divide the analysis by topics and see the authors with the highest number of publications in fuzzy set theory, in fuzzy systems, in fuzzy mathematics, in fuzzy decision making, in fuzzy engineering, etc.

Finally, note that if we want to strictly establish a ranking, then, the citations will be probably the key aspect to consider together with the number of publications. But it is really difficult to establish this ranking because there are a lot of other aspects to be considered.

4. Top Journals in the ISI Web of Knowledge

In this Section, we present the journals with the highest number of publications with the word fuzzy. For doing so, we give the number of articles published in the journal with the word fuzzy, the total number of articles published in the journal, the total citations received and the impact factor for 2008.

Note that when analyzing the journals with the word "fuzzy", we have included editorial material, notes and corrections. As we can see, Fuzzy Sets and Systems is the journal with the highest number of publications with the word "fuzzy" and together with IEEE Transactions on Fuzzy Systems, they are the two journals strictly dedicated to fuzzy research. Note that this can be proved by looking to the percentage of papers published in the journal with the word fuzzy.

However, it is worth noting that in the last years there is a really strong increase in the number of publications with the word "fuzzy" in the world. Therefore, there are a lot of new journals that are

becoming more relevant in the research. For more information, see [5].

Table 2: Journals with the highest number of papers with the word *fuzzy* in the ISI Web of Knowledge:

Journals	Art.	Total	Times Cited	I.F. 2008
Fuzzy Sets Syst.	5372	6110	73858	1.833
IEEE Tr. Fuz. Syst.	1044	1149	27060	3.624
Information Sci.	1006	3809	30032	3.095
IEEE Trans.SMC B	495	1557	20250	2.361
Eur. J. Oper. Res.	462	11445	99222	1.627
Int. J. Intel. Syst.	433	1152	6843	0.860
IJ Uncer. Fuz. KBS	430	678	3382	1.000
IJ. Approx. Reas.	339	737	5688	1.708
Expert Syst. & App.	329	2150	11455	2.596
J. Intel. Fuzzy Syst.	318	461	1012	0.649
Soft Computing	289	639	1522	0.984
Eng. App. Art. Inl.	278	1197	5477	1.397
J Math. Anal. Appl.	270	17647	116862	1.046
Pattern Rec. Let.	268	3711	31378	1.559
IJ General Systems	254	1116	5757	0.826
Pattern Recog.	247	4744	67112	3.279
IJ Adv.Manuf.Tech.	213	3636	11721	0.743
Comp.&Math. App.	215	6123	25740	0.997
IEEE Tr. Ind. Elect.	214	3507	39015	5.468
IEEE Tr.PowerSyst.	207	5796	68492	1.875

Moreover, there are a lot of other journals that are not indexed in the ISI Web of Knowledge that publishes papers related with fuzzy research. A more complete list is found in [5]. However, there are still a lot of journals not included in [5] such as those ones that are not written in English (this problem is especially relevant for Chinese journals) and those ones related with other fields different from [5].
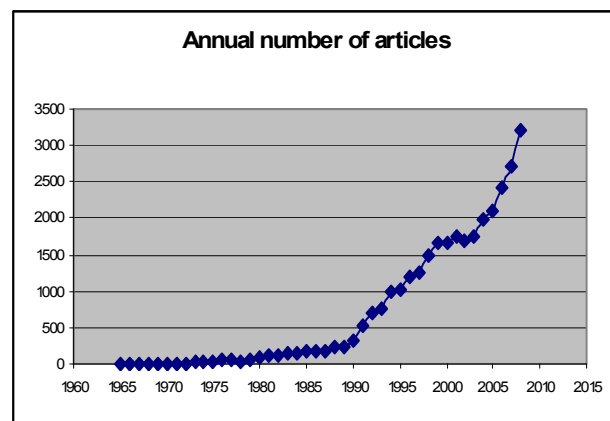
5. Articles divided by years

In this Section, we briefly present the number of publications with the word fuzzy divided by years. Note that the information is until the 31-12-2008. The results are shown in Figure 1.

As we can see, in the beginning, the number of articles published was very low. In the eighties, it started to increase but still the number of publications every year was lower than 500. The strong increase started in the nineties arriving in 2000 with more than 1500 publications each year. Since then, the increase still continue, specially because there are more and more young researchers entering this field and there are more journals indexed in the ISI Web of Knowledge. Today, the number of publications is higher than 3000 articles per year. Note also that this number is much higher if we include the ISI Proceedings. And the total number of articles published in the world each year is very difficult to know because not all the journals, conferences, etc., are available in internet but as estimation, it is easy to assume that it is higher than 10000 articles per year and probably more. Note that further research is necessary to get a good approximation about the total number of articles published each year in the world including journals, conferences, books, thesis, etc.

Figure 1: Number of articles by years

6. Articles divided by countries

In this Section, we present a short ranking of the top 10 countries in fuzzy research according to the ISI Web of Knowledge. We consider the total number of publications, the citations received and the results found in the period 1999-2008. The ordering of the ranking is developed according to the total number of citations.

As we can see, the USA is the most relevant country in the fuzzy community although in the last years, China is getting more relevance. Specially, if we only consider the last 3 years, then, China is already publishing more than the USA in fuzzy research. Moreover, we also see that Taiwan is also very relevant in fuzzy research. In Europe, England, France, Spain and Italy seem to be the leading countries in fuzzy research. Note that Lotfi Zadeh has been included in the USA. Otherwise, Iran would also be in the list.

Table 3: Articles with the word *fuzzy* by countries

	Country	Total fuzzy	Total Citations	Art. 1999-2008	Cited 1999-2008
1-	USA	5985	93979	3375	34029
2-	Taiwan	3115	28619	2571	19016
3-	Japan	1880	26956	940	7139
4-	China	3743	26236	3042	19470
5-	England	1461	19502	1024	9032
6-	Canada	1552	15774	1096	7585
7-	France	1128	14896	662	5231
8-	Spain	1392	12629	1066	7775
9-	India	1710	11135	1167	5644
10-	Italy	1151	9561	804	5179
	Total	31030	328760	20944	146686

7. Conclusions

We have presented a brief overview of fuzzy research in the ISI Web of Knowledge. We have seen that this tool permits to make rankings between a wide range of options. We have focussed on detecting the most cited papers in fuzzy research, the top authors according to the number of citations, the top journals, the evolution by years and the top countries. The results are more or less clear and they are not surprising in the sense that they are in accordance with our intuition. For example, Zadeh's 1965 seminal paper is the most cited one and at the same time, he is the most cited author. Other key authors also appear in the rankings. However, it is worth noting that the results are only a general orientation but they are not strictly a classification because then, we need to consider a lot of variables that are not included or other forms of establishing this ranking.

In future research, we expect to improve this analysis by studying more particular cases and extending it to other rankings.

8. Acknowledgment

9. References

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