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Consensus in a fuzzy environment: a bibliometric study

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Abstract

In today's organizations, group decision making has become a part of everyday organizational life. It involves multiple individuals interacting to reach a decision. An important question here is the level of agreement or consensus achieved among the individuals before making the decision. Traditionally, consensus has been meant to be a full and unanimous agreement. However, it is often not reachable in practice. A more reasonable approach is the use of softer consensus measures, which assess the consensus in a more flexible way, reflecting the large spectrum of possible partial agreements and guiding the discussion process until widespread agreement is achieved. As soft consensus measures are more human-consistent in the sense that they better reflect a real human perception of the essence of consensus, consensus models based on these kind of measures have been widely proposed. The aim of this contribution is to present a bibliometric study performed on the consensus approaches that have been proposed in a fuzzy environment. It gives an overview about the research products gathered in this research field. To do so, several points have been studied, among others: countries, journals, top contributing authors, most cited keywords, papers and authors. This allows us to show a quick shot of the state of the art in this research area.

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1. Introduction

Decision making is one of the most crucial human activities. Its essence is fundamentally to find the best alternative, opinion, variant, and so on, from among some feasible ones. To do so, and due to the increasing complication of virtually all problems faced by modern societies, decision making in real world involves multiple individuals to make the decision [1]. In such a case, it is called a multiperson decision making situation.

Group decision making (GDM) is an important class among multiperson decision making settings [2]. It is defined as a situation in which there is a set of alternatives and a set of individuals who express their opinions concerning the alternatives. The problem here is to find a solution (an alternative or set of alternatives) which is best acceptable by the group of individuals as a whole. In such a context, it is expected that the process which arrives at a agreed upon opinion, maybe consensus, by using in a democratic way knowledge of the different individuals, should lead to better decisions [1, 3].

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An important question in a GDM situation is the very meaning of consensus and the problems related to the essence of it. Traditionally, consensus has been meant in different ways and in different contexts:

- One the one hand, consensus alludes to the state of agreement in a group of individuals in the sense that they show a state of common feeling as to the alternatives in question. From this point of view, consensus has been most commonly meant as a full and unanimous agreement; different authors proposed consensus measures assuming values in-between 0 (no consensus or partial consensus) and 1 (full consensus) [4–6]. This situation has been however considered unrealistic in most realistic environments because of individuals on rare occasions arrive at that unanimous agreement and, although it were the case, this could be too long for practical purposes. Hence, it was necessary the reconsideration of the very essence of consensus, which can be viewed not necessarily as a full and unanimous agreement, if not that it can be admitted that the individuals are not willing to fully change their opinions so that consensus will not be a unanimous agreement. That is, the same testimony for all, but some set of individual opinions which are similar enough. A milestone was here a special issue of the influential Synthese journal [7]. Among many papers therein, the paper written by Loewer and Laddaga [8] is the most relevant for our purpose. They clearly made the case for a soft concept of consensus saying that:

  > "...It can correctly be said that there is a *consensus* among biologists that Darwinian natural selection is an important cause of evolution though there is currently *no consensus* concerning Gould's hypothesis of speciation. This means that there is a *widespread agreement* among biologists concerning the first matter but *disagreement* concerning the second ..."

  According to this statement, it is clear that a rigid majority as, for instance, more than 80% would not evidently reflect the very essence of the above given quotation. However, it is suggested that a fuzzy majority is suitable, and that it makes sense to speak about a degree of consensus, or a distance from ideal consensus. The linguistic quantifiers, which are exemplified by 'most", "almost all", "much more than a half", and so on, are a natural manifestation of a fuzzy majority. They can be formally handled by a calculus of linguistically quantified propositions, notably due to Zadeh [9], and also by using Yager's OWA (Ordered Weighted Average) operators [10], which provide a much needed generality and flexibility [11–13]. The concept of a fuzzy majority related to a fuzzy linguistic quantifier was introduced into GDM by Kacprzyk [2, 14–16], but one should bear in mind that Nurmi's seminal paper [17] on novel definitions of GDM solutions under fuzzy preferences and crisp, but valued, majorities is here a point of departure. It is important to note that the fuzzy majority has then been the key point for the new definitions of soft consensus proposed by Kacprzyk and Fedrizzi [18–21], which assess the degree of consensus in a more flexible way, reflecting the large spectrum of possible partial agreements and guiding the discussion process until widespread agreement, not always full, is achieved among the group of individuals.
- On the other hand, consensus is meant as a way to reach agreement. It involves an evolution of the opinions of the group of individuals towards agreement with respect to their opinions. Here, the point of departure is a set of opinions expressed by the particular individuals concerning in general opinions as to the values of some quantities. These opinions have been originally equated with some utilities resulting from some courses of actions, probabilities of them, and alike. However, as the process of decision making, especially of group type, is focused on human beings, with their inherent vagueness, imprecision and subjectivity in the articulation of opinions, the Theory of Fuzzy Sets [22] have been used in this field for a long time. It is a more general and richer representation of individual opinions than a subjective probability of the occurrence of an event (option) in question that was the point of departure of many traditional consensus approaches [23–25]. Said that, we can distinguish two approaches in the formulation of a consensus reaching process. The first one, traditional, is the one in which the process is modeled by using matrix calculus or Markov chains to model the time evolution of changes of opinions toward consensus [26–28]. The approaches exemplified by the above citations have contributed much to the understanding of the process and its dynamics. However, it has been considered much more promising to run the consensus reaching process with the help of a special agent, called a moderator, whose task is to help the individuals involve while changing their testimonies towards consensus, by rational argument, persuasion, and so on. This second approach, in which there is a moderator, is more promising in practice and the most used.

Given the importance of obtaining an accepted solution by the whole group, the consensus has attained a great attention and it is virtually a major goal of GDM problems [29–31]. In particular, the interpretation of the consensus based on the concept of fuzzy majority has been used in the most of the consensus models proposed in the literature [29–31], as it is more human-consistent and suitable for reflecting human perceptions of the meaning of consensus. Therefore, after some decades of fruitful research in the field of soft consensus approaches, we think it is a good time for looking backward and review what the research has been developed, what are the main trends, the most prevalent topics and the most recurrent authors in this research field.

The aim of this contribution is to present a bibliometric study performed on the research field of consensus approaches to show a quick shot of the state of the art in this research area. In particular, we focus on the consensus models defined in a fuzzy environment and based on soft consensus measures as they have been successfully applied to GDM problems. An overview about the research products gathered in this research field is shown. To do so, we study the following points: countries, journals, top contributing authors, most cited keywords, papers and authors.

The rest of the contribution is organized as follows: Section 2 describes the method used to identify the data used in this study. Section 3 shows the obtained results. Finally, some conclusions are pointed out in Section 4.

2. Methodology

A systematic review is an important instrument for research synthesis whose main purpose is to show a photo shot of the state of the art in a research field [32]. It can be defined as a compilation of the research done in a certain field, in which we exhaustively compile certain items as, for instance, authors, journals, keywords, and so on. In addition, it describes the situation of the published research. A systematic review becomes very relevant due to its facility to display at the same time the main trends and the diversity in the research field which is being studied. In the recent past, some academic studies about how to deal with this type of analysis have been proposed [33, 34].

A step further than systematic review is the meta-analysis which defines a codification over the outcomes of the review and performing a statistical analysis with the aim of interpreting the results [35]. Furthermore, going to a more specific field of domain, other type of bibliometric study can be performed when studying the internal relationship among the data. In such a way, different types of analysis can be found in the literature.

On the one hand, when analyzing the research in a vast field, co-word analysis regarding fields or sub-fields is a common technique that usually provides mapped outcomes as strategic diagrams or thematic networks reflecting not only the occurrences but also the internal structure of the most important appearances [36]. On the other hand, when studying smaller data sets, tag clouds, more formally known as weighted lists, are very useful graphic representations. They are visual depictions of content tags in a certain field. To do so, more frequent tags are depicted in a larger or emphasize font. Tag clouds were originally introduced for website analyses and have been proved as very useful in the analysis of social networks [37]. However, their use has been also extended to bibliometric studies [38].

In this contribution, with the aim of producing an interpretable outcome, we have designed a bibliometric study with the following characteristics:

- Selection of the bibliographic database to retrieve the scientific production and citations. ISI Web of Science was selected as bibliographic database due to it contains the most reliable and accurate citations data.
- Set the research area under study by defining a query to retrieve the documents of this research field. The query used to retrieve the papers was: TS=(“consensus” AND “fuzzy”), which returned about 781 papers. After a manual manipulation of the papers retrieved, an amount of 220 documents were selected in the scope of this study. This information has been collected in February 2015. Since the manipulation of the data has been developed manually, it is possible a non-significant percentage of human errors in the results.
- Studied issues. We have identified the number of contributions per year in order to establish the evolution on papers published on this research field. Furthermore, we have used descriptive techniques in order to identified the main contributing countries and journals. We have also determined the top contributing authors and the top cited keywords. And finally, we have identified the most cited papers and authors on this research area.

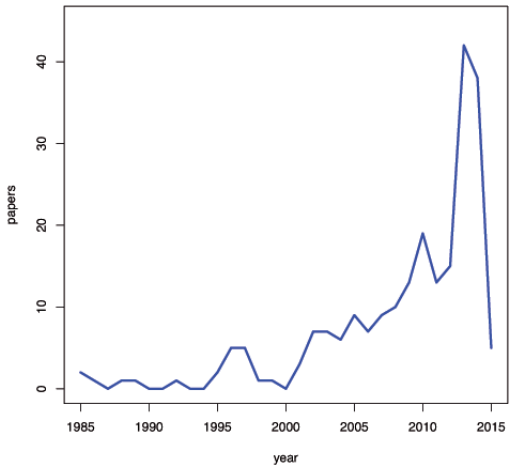

Fig. 1. Distribution of published papers per year.

Finally, it should be pointed out that the retrieved raw data was imported into the science mapping analysis open source software SciMAT [39, 40] in order to build a knowledge base and perform a preprocessing step. A deduplication step was carried out over authors, affiliations and keywords with the aim of merging into one entity those items that represent the same author, affiliation, or concept, respectively. Furthermore, Wordle[1] was used to build the cloud tags.

3. Results

In this section, the results obtained by the bibliometric study which is carried out in the research field of soft consensus models in a fuzzy environment are shown.

Figure 1 displays the number of published papers about soft consensus models as a function of the year of their publication. From the first papers of Kacprzyk in the middle of the 1980s, it seems evident that the scientific literature concerning this topic has increased since then, especially during the last decade. In fact, 2013 and 2014 are the years where more papers have been published. Concretely, about 40 papers have been published in each one of these years. Hence, it is clear that the research on consensus approaches based on soft consensus measures is nowadays an important topic.

[1] http://www.wordle.net/

Table 1. Documents published by each country.

Rank	Country	#Documents
1	People's Republic of China	74
2	Spain	51
3	Poland	25
4	United Kingdom	21
5	Taiwan	18
6	USA	17
7	Canada	10
8	Italy	9
9	Australia	7
10	India	7

Fig. 2. Contributing authors.

The quantitative measures of authors and their countries of affiliation are displayed in Figure 2 and Table 1, respectively. On the one hand, Table 1 shows the top ten countries of affiliation of the authors. From this table, we can observe that the People's Republic of China and United Kingdom have published a high number of papers. They together with Spain and Poland, are the four countries that more have contributed to the field of soft consensus approaches in a fuzzy environment.

On the other hand, to show the most contributing authors, and to classify them by number of published papers, tag clouds are used. The tag cloud showed in Figure 2 represents the whole set of authors proportionally to their number of contributions in this research area. According to it, Enrique Herrera Viedma (Spain) and Janusz Kacpryzk (Poland) are the authors that more have contributed to the development of this research field with 36 and 25 papers, respectively.

In Table 2, the top ten journals that have published more papers in this research field are shown. We should remark that the journals Knowledge-Based Systems and Fuzzy Sets and Systems are the most important journals in the field of soft consensus models in a fuzzy environment, due to 16 and 15 papers have been published in them. In addition, together with these journals, the journals Expert Systems with Applications and the European Journal of Operational Research, with 12 and 9 papers, respectively, have significantly contributed to the development of this topic.

With the aim of discovering the thematic covered by the papers published in this research field, a tag cloud was built using the keywords provided by the authors. Examining keywords is a usual technique in bibliometric analysis to detect main trends in a research field. In this case, we describe the occurrence of the terms appearing in the keywords. Previously, a stemming analysis has to be performed in order to identify similar keywords and count

Table 2. Documents published by each journal.

Rank	Journal	#Documents
1	Knowledge-Based Systems	16
2	Fuzzy Sets and Systems	15
3	Expert Systems with Applications	12
4	Information Sciences	9
5	European Journal of Operational Research	7
6	Information Fusion	7
7	IEEE Transactions on Fuzzy Systems	6
8	Computers & Industrial Engineering	6
9	IEEE Transactions on Systems, Man and Cybernetics Part A - Systems and Humans	6
10	International Journal of Uncertainty Fuzziness and Knowledge-Based Systems	5

Fig. 3. Main topics cited in keywords.

them together. We use a tag cloud representation to show the results of this analysis over the stems, proportionally to their frequency (see Figure 3). We observe that, naturally, "consensus" and "group-decision-making" are the most important keywords, as the consensus processes are mainly used in GDM problems. But it is remarkable how other related terms have a strong importance. Some of them are mainly related to the structure in which the decision makers express their preferences ("preference-relations", "fuzzy-preference-relations", "linguistic-preference-relations") and others are related with the aggregation of the opinions expressed by the decision makers ("aggregation", "aggregation-operators", "owa-operators").

Finally, as bibliometrics is a science based on the citation analysis of the research documents [41–43], which is used to evaluate research performance, we show the most cited papers and the most cited authors in Table 3 and Figure 4, respectively. A basic assumption of citation analysis is that the more often a paper becomes cited the greater its influence on the field [41]. In such a way, a higher citation rate indicates a higher quality [44]. In this sense, the highly cited papers are an important reference point in a research field. In addition, the most cited authors identify those who have published significant findings on particular research topics as well as the short- or long-term impact of their work from the literary perspective [44].

Table 3. Top cited papers.

Rank	Paper	#Citations
1	Herrera, F, Herrera-Viedma, E, Verdegay, JL. A model of consensus in group decision making under linguistic assessments. Fuzzy Sets and Systems 78:1 73–87 (1996)	378
2	Kacprzyk, J. Group Decision-making with a fuzzy linguistic majority. Fuzzy Sets and Systems 18:2 105–118 (1986)	307
3	Bordogna, G, Fedrizzi, M, Pasi, G. 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 27:1 126–133 (1997)	177
4	Herrera-Viedma, E, Herrera, F, Chiclana, F. A consensus model for multiperson decision making with different preference structures. IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans 32:3 394–402 (2002)	217
5	Kacprzyk, J, Fedrizzi, M, Nurmi, H. Group decision-making and consensus under fuzzy preferences and fuzzy majority. Fuzzy Sets and Systems 49:1 21–31 (1992)	210
6	Herrera-Viedma, E, Martinez, L, Mata, F, Chiclana, F. A consensus support system model for group decision-making problems with multigranular linguistic preference relations. IEEE Transactions on Fuzzy Systems 13:5 644–658 (2005)	207
7	Herrera-Viedma, E, Alonso, S, Chiclana, F, Herrera, F. A consensus model for group decision making with incomplete fuzzy preference relations. IEEE Transactions on Fuzzy Systems 15:5 863–877 (2007)	167
8	Herrera, F, Herrera-Viedma, E, Verdegay, JL. A rational consensus model in group decision making using linguistic assessments. Fuzzy Sets and Systems 88:1 31–49 (1997)	164
9	Hsu, HM, Chen, CT. Aggregation of fuzzy opinions under group decision making. Fuzzy Sets and Systems 79:3 279–285 (1996)	142
10	Mata, F, Martinez, L, Herrera-Viedma, E. An adaptive consensus support model for group decision-making problems in a multigranular fuzzy linguistic context. IEEE Transactions on Fuzzy Systems 17:2 279–290 (2009)	113

Fig. 4. Top cited authors.

On the one hand, to obtain the most relevant papers about soft consensus models in a fuzzy environment, we identify in Table 3 the top ten cited papers in this research topic. Most of these papers proposed original consensus models which contained the seeds for future development, that is, they presented new and original ideas that turned out to be the foundation of very important future developments, and, therefore, they have received a high number of citations.

On the other hand, in the last analysis we identify the most cited authors. Over 180 different authors are cited in the literature, which are represented in the tag cloud shown in Figure 4. Here, we can see that the most cited authors are Enrique Herrera-Viedma, Francisco Herrera and Janus Kacpryzk with 1899, 1074 and 1034 citations, respectively. We can also observe that they are the authors of the most of the top cited papers shown in Table 3.

4. Conclusions

The research field of soft consensus approaches in a fuzzy environment has grown to currently become an important topic in the scientific community. From its origins, a high number of both papers and authors have contributed to its development.

In this contribution a bibliometric analysis in order to show a quick shot of the state of the art in this research area has been performed. An amount of 220 documents have been identified and analyzed in order to show their authors, countries of affiliation, journals and topics covered. In addition, the most cited authors and the most cited papers have been identified.

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