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ANALYSIS AND REVIEW ON FUZZY EVALUATION OF THE PERFORMANCE

JUNFENG YU, ZIJIANG YANG, JIANPING GUO, LARYSA GLOBA

Abstract. In modern conditions a comprehensive analysis of development trends and their effectiveness in various areas of human activity increasingly requires the analysis of data accumulated in numerous documents stored on the global network. Such an analysis is based on annual results in many areas of research, time trends and keywords. This analysis has certain peculiarities: it requires an analysis of not always accurate numerical information, comparison of qualitative indicators, obtaining both qualitative and quantitative characteristics, as well as the use of reference information for researchers and decision makers in related fields. In this regard, in recent years, a fuzzy assessment based on fuzzy mathematics is increasingly used in all types of assessing the effectiveness of various activities. The paper deals with conducting a bibliometric study based on the Extended Science Citation Index (SCI-E) and fuzzy performance measures to understand research trends and areas of focus. This paper takes the relevant scientific papers in Web of Science database as the research object, and analyzes the research trends with the help of bibliometrics. The results show that the number of papers published in the world is on the rise. The number of papers published in China and Iran is higher than that in other countries and regions. However, the number of papers cited in the United States and Turkey is higher than that in other countries or regions. Islamic Azad University is the largest. The research topics focus on fuzzy sets, fuzzy logic, genetic algorithms and performance evaluation. The research hotspots before 2011 included expert systems, neuro-fuzzy systems, and pattern recognition. After 2011, the research hotspots became neural networks, fuzzy sets, and machine learning.

Keywords: information and communication network, data processing system, ontology, model, analysis, scaling, class, relations.

INTRODUCTION

The fuzzy comprehensive evaluation method is gradually developed on the basis of the fuzzy mathematics theory proposed by Zadeh in 1965 into a method for comprehensive evaluation of difficult to define fuzzy targets [1]. The comprehensive evaluation method is based on the membership degree theory of fuzzy mathematics. Qualitative evaluation is transformed into quantitative evaluation, that is, using fuzzy mathematics to make an overall evaluation of things or objects restricted by multiple factors. It has the characteristics of clear results and strong systemic, can better solve the ambiguous, difficult and quantifiable problems, and is suitable for solving various non-deterministic problems.

The application of the fuzzy comprehensive evaluation method in the field of performance began in the 1980s. Lusk, EJ (1981) proposed a fuzzy method to evaluate statistics of monitoring performance [2]. Deutsch, SJ et al. (1985) proposed the use of fuzzy subsets to evaluate organizational performance indicators [3]. Mon, DL et al. (1994) propose a general decision-making method for evaluating weapon systems using fuzzy AHP based on entropy weight [4]. Ishibuchi, H et al.

(1999) discussed the performance evaluation of fuzzy classifier system for multi-dimensional pattern classification problem [5]. Tsaur, SH et al. (2002) applies the fuzzy set theory to evaluate the service quality of airline [6]. Chen, CT et al. (2006) proposed a hierarchy multiple criteria decision-making (MCDM) model-based oil fuzzy-sets theory to deal with the supplier selection problems in the Supply chain system [7]. Kou, G et al. (2014) presents an MCDM-based approach to rank a selection of popular clustering algorithms in the domain of financial risk analysis [8]. Turskis, Z et al. (2017) proposed a new fuzzy hybrid multi-criteria decision-making approach to solve personnel assessment problems [9]. Tseng, ML, et al. (2018) proposed a generalized quantitative evaluation model based on fuzzy Delphi method and analysis network process, which is used to consider the interdependence between the metrics in the development and acquisition of sustainable service supply chain management and the ambiguity of subjective metrics [10]. Lin, LK, et al. (2020) developed a novel hybrid fuzzy MCDM approach to address this kind of MCDM problems in the fuzzy environment [11]. Based on probability fuzzy theory and considering the uncertainty of chemical process, Wang, YL, et al. (2021) proposed an optimization scheme of online operation performance evaluation [12].

With the in-depth research in the field of fuzzy mathematics, fuzzy evaluation has very meaningful applications in various fields. This research conducts a bibliometric analysis of the application of fuzzy evaluation in performance evaluation, reveals the research status and trends of fuzzy evaluation in performance evaluation, and hopes to provide references for researchers and decision makers in related fields.

Scientific papers are the main carriers of scientific research results, which can represent the scientific scale and productivity of groups or regions. At present, bibliometrics has been widely used in many disciplines, and it is one of the most active and rapidly developing professional fields of Information Science [13–14]. Using the method of bibliometrics, we can describe, evaluate and forecast the research status and development trend of the application of the fuzzy evaluation method in performance evaluation through mathematical and statistical methods.

This research is aimed at integrating fuzzy logic mathematics methods and bibliometrics for understanding research trends and scientific areas of focus.

The structure of the paper is the following: section 2 describes research challenges. Section 3 shows data and methods for research. In section 4 the results are presented and discussed. Section 5 presents conclusions and plans for future work.

PROBLEM DEFINITION

At present, fuzzy evaluation is widely used in performance evaluation, and bibliometric method can effectively summarize the research results and reveal its future development direction. Therefore, this paper introduces the method of bibliometrics to explore the inherent relevance and potential hot spots of the existing literature of fuzzy evaluation for performance evaluation, uses statistical and mathematical methods to quantify various evaluation indicators, and describes the nature and direction of its research. By clustering, analyzing and visualizing the

retrieved literature, the knowledge map is constructed to assist researchers to explore the research hotspots, evolution paths and development frontiers in related fields. Bibliometric method is mainly based on quantitative analysis, and the results are more objective, which can provide some reference for researchers and decision makers in related fields.

DATA AND METHODS

A. Data collection

We built our bibliometric collection on 13 February, 2021 based on the Science Citation Index Expanded (SCI-E) and Social Sciences Citation Index (SSCI) database in the "Web of Science Core Collection". We chose SCI-E and SSCI as the data source for two reasons. First, these two databases, the primary bibliographic databases produced by Clarivate Analytics, provides comprehensive coverage of the most important and influential research outputs from around the world. Second, it includes detailed reference information, enabling us to trace the intellectual development of our research. In this paper, fuzzy evaluation, performance and other related words are used for subject retrieval, and the number of retrieval records is 9811.

B. Data analysis tools

VOSviewer, Microsoft Excel and Biblioshiny were used to perform data mining (e.g. annual number of outputs, institutions outputs, keywords evolution and authors), prepare figures, and visualize the data, respectively.

VOSviewer is a software tool for constructing and visualizing bibliometric networks. These networks may for instance include journals, researchers, or individual publications, and they can be constructed based on citation, bibliographic coupling, co-citation, or co-authorship relations. VOSviewer also offers text mining functionality that can be used to construct and visualize co-occurrence networks of important terms extracted from a body of scientific literature.

Biblioshiny is a shiny app providing a web-interface for bibliometrix. It supports scholars in easy use of the main features of bibliometrix: data importing and conversion to data frame collection, data gathering using Dimensions, PubMed and Scopus APIs collection, data filtering, analytics and plots for three different level metrics, analysis of three structures of knowledge.

RESULTS AND DISCUSSIONS

A. Temporal evolution of outputs

The annual output trend chart shows the development trend of the number of papers. Through the annual trend of the number of papers published, we can grasp the changes of the heat of papers published in each period from the macro level. The earliest study in the database was published in 1981. Before 1990, the number of papers published each year was less than 5. After 1991, it began to develop slowly. After 2005, the number of papers published increased significantly. From the average citation frequency in Fig. 1, there are two obvious peaks in 1991 and 2005. The number of citations increased significantly in the past two years, which can obviously promote the development of the whole field.

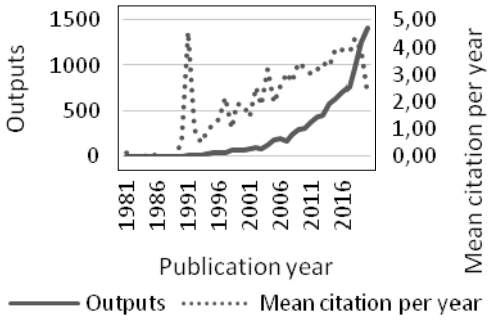

Fig. 1. Temporal evolution of outputs

B. Region analysis

The regional analysis chart shows the distribution of documents in each country or region. Through this analysis, we can understand the research and development activities of the analysis objects in different countries, so as to find the main technology sources. As can be seen from Fig. 2, China has the largest number of papers, with 6229, more than twice as many as Iran, India and USA, which rank the second, the third and the fourth. It can be seen from Table I that Denmark has the most citations per article, reaching 70,08. China, Iran, and India, which have published more articles, have average citations of 18,47, 18,04 and 14,43, which are much lower than Denmark and Lithuania and USA.

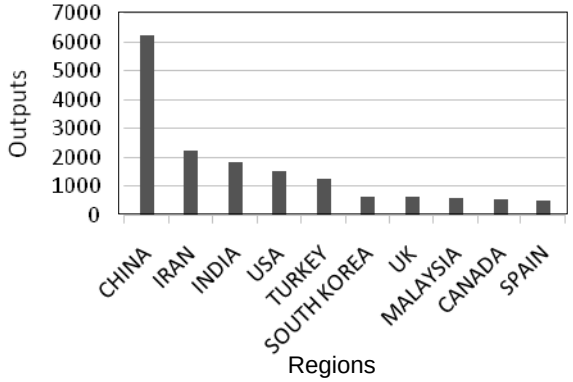

Fig. 2. Region ranking

T a b l e 1. Average article citations(regions)

Regions	Average Article Citations
USA	35,43
TURKEY	30,79
UNITED KINGDOM	26,74
SPAIN	25,06
CANADA	24,63
MALAYSIA	21,12
CHINA	18,47
IRAN	18,04
SOUTH KOREA	15,32
INDIA	14,43

C. Research areas analysis

"Web of Science Research Areas" is assigned by Clarivate Analytics, and is used to classify the research papers. Each paper can be classified into at least one research area by the Web of Science database. The research areas of the publications revealed the main subjects related to the increasing scientific productivity of fuzzy evaluation in performance research. This research areas involves more than 100. The 10 most productive research areas were Engineering, Computer Science, Environmental Sciences Ecology, Operations Research Management Science, Science Technology Other Topics, Automation Control Systems, Telecommunications, Mathematics, Energy Fuels, Business Economics (Fig. 3).

It can be seen from Fig. 4 that the number of papers published by Engineering and Computer Science is significantly higher than that in other directions, with more than 4500 papers published by Engineering and nearly 4000 papers published by Computer Science. Environmental Sciences Ecology, Operations Research Management Science, Science Technology Other Topics, Automation Control Systems, Telecommunications, Mathematics, Energy Fuels, Business Economics the number of papers published is 400–900. The publishing trend of Engineering and Computer Science is basically exponential.

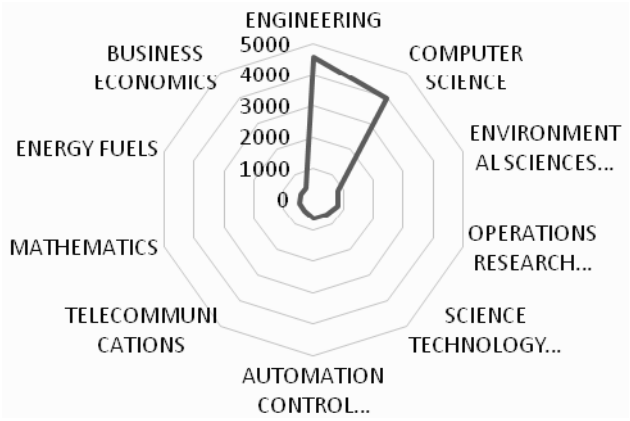

Fig. 3. Outputs of research areas (top 10)

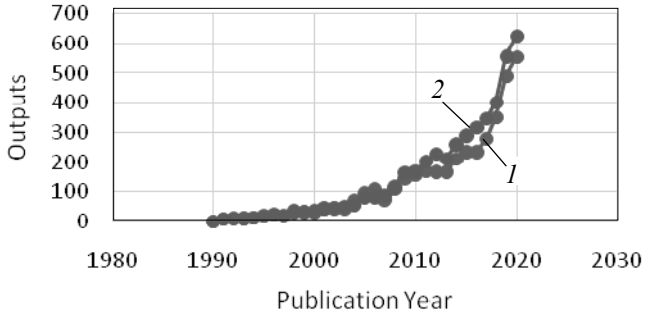

Fig. 4. Temporal evolution of the two most productive research areas: *1* — Computer Science; *2* — Enginering

D. Organization Analysis

The paper output chart of major institutions shows the ranking of institutions based on their publishing status. This analysis can identify institutions with more research results, and further analyze their research strength based on this. From Fig. 5, it can be seen that Islamic Azad University, with 344 articles, ranked second and third respectively, with 205 and 200 articles. Other institutions are less than 200. It can be seen from Table 2 that Hong Kong Polytechnic University, University Technology Malaysia and University Malaya have not published many articles, but their citations are all above 25. It can be seen that these three schools have a certain degree of influence.

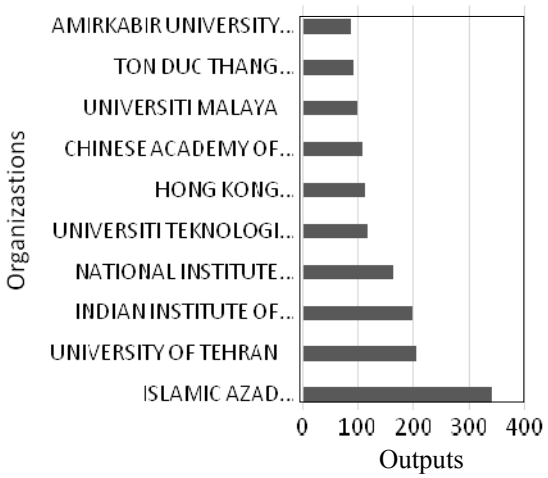

Fig. 5. Organization ranking (top 10)

T a b l e 2 . Average citations per item (organizations)

Organizations	Sum of Times Cited	Averagecitationsperitem
HONG KONG POLYTECHNIC UNIVERSITY	4018	35,25
UNIVERSITI TEKNOLOGI MALAYSIA	3248	27,53
UNIVERSITI MALAYA	2600	26
INDIAN INSTITUTE OF TECHNOLOGY SYSTEM	4433	22,17
ISLAMIC AZAD UNIVERSITY	7584	22,05
UNIVERSITY OF TEHRAN	4173	20,31
CHINESE ACADEMY OF SCIENCES	1979	18,32
TON DUC THANG UNIVERSITY	1681	18,08
AMIRKABIR UNIVERSITY OF TECHNOLOGY	1409	15,83
NATIONAL INSTITUTE OF TECHNOLOGY NIT SYSTEM	2418	14,57

Fig. 6 and 7 show the cooperation of major global institutions that use fuzzy evaluation in the field of performance evaluation. Through the cooperation network of institutions, it can be seen that Islamic Azad University is currently the core institution of research in this field, and it has related research cooperation with many universities, research institutes or enterprises around the world.

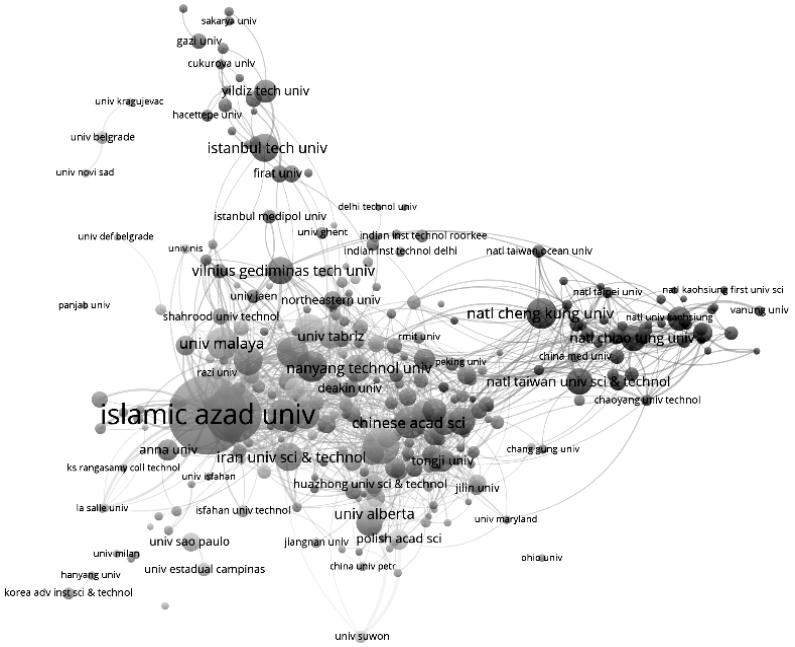

Fig. 6. Global organization Cooperation Network

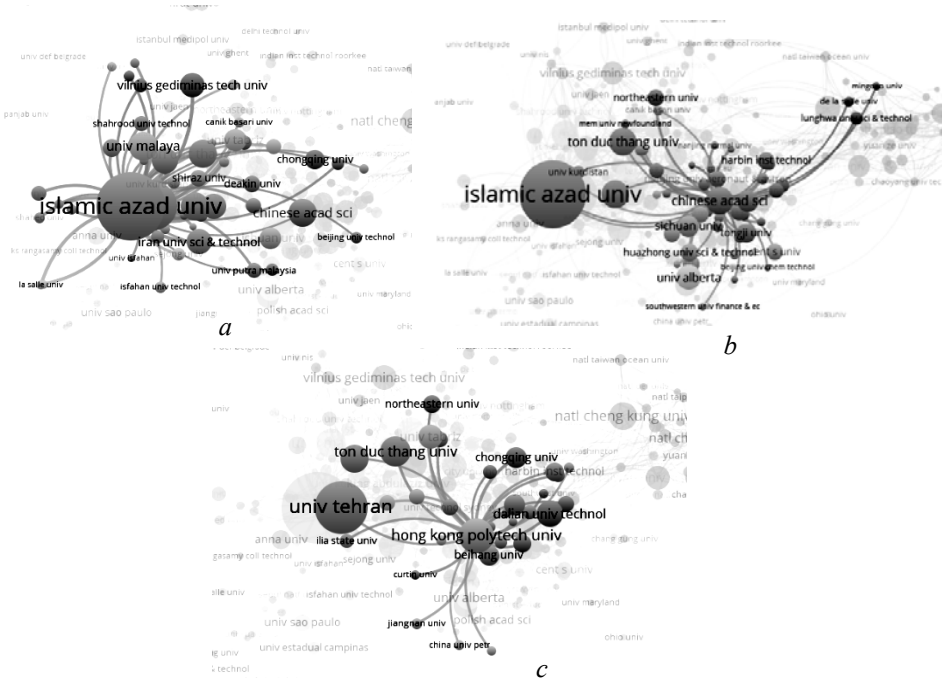

Fig. 7. Islamic Azad University cooperation network (*a*); Chinese Academy of Sciences cooperation network (*b*); Hong Kong Polytechic University cooperation network (*c*)

E. Research focus and hot spot

Keywords provide important information about research trends, frontiers, and reveal research fields [15–16]. Table 3 shows the 20 most frequent words, among

which the frequency of fuzzy logic reached 811 words. The scientific research in Fig. 8 shows the changes in research hotspots. The research hotspots before 2011 included expert system, neuro-fuzzy system, and pattern recognition. After 2011, the research hotspots became neural network, fuzzy sets, and machine learning.

Fig. 9 shows the thematic map, the horizontal axis represents centrality, and the vertical axis represents density. The meanings of the four quadrants are as follows:

- the first quadrant (upper right corner): motor themes, both important and well developed;
- the second quadrant (upper left corner): highly developed and isolated themes, which have been well developed, but are not important to the current field;
- the third quadrant (lower left corner): emerging or declining themes, edge themes, there is no good development, may have just emerged, or may be about to disappear;
- the fourth quadrant (lower right corner): basic and transversal themes, which are very important to the field, but have not been well developed. Generally, refers to basic concepts.

Fig. 9 shows that the subject of "fuzzy logic" belongs to basic research, and "genetic algorithm" and "classification" belong to well-developed and very important research field.

T a b l e 3. The TOP 20 most frequent keywords

No	Keywords	Frequency
1	fuzzy logic	811
2	anfis	260
3	fuzzy sets	224
4	performance evaluation	207
5	fuzzy sett heory	181
6	topsis	178
7	genetic algorithm	163
8	fuzzy control	146
9	classification	135
10	fuzzy	133
11	neural networks	129
12	artificial neural network	120
13	sustainability	115
14	uncertainty	114
15	clustering	112
16	ahp	111
17	fuzzyinferencesystem	111
18	fuzzyclustering	110
19	optimization	110
20	Particles warm optimization	106

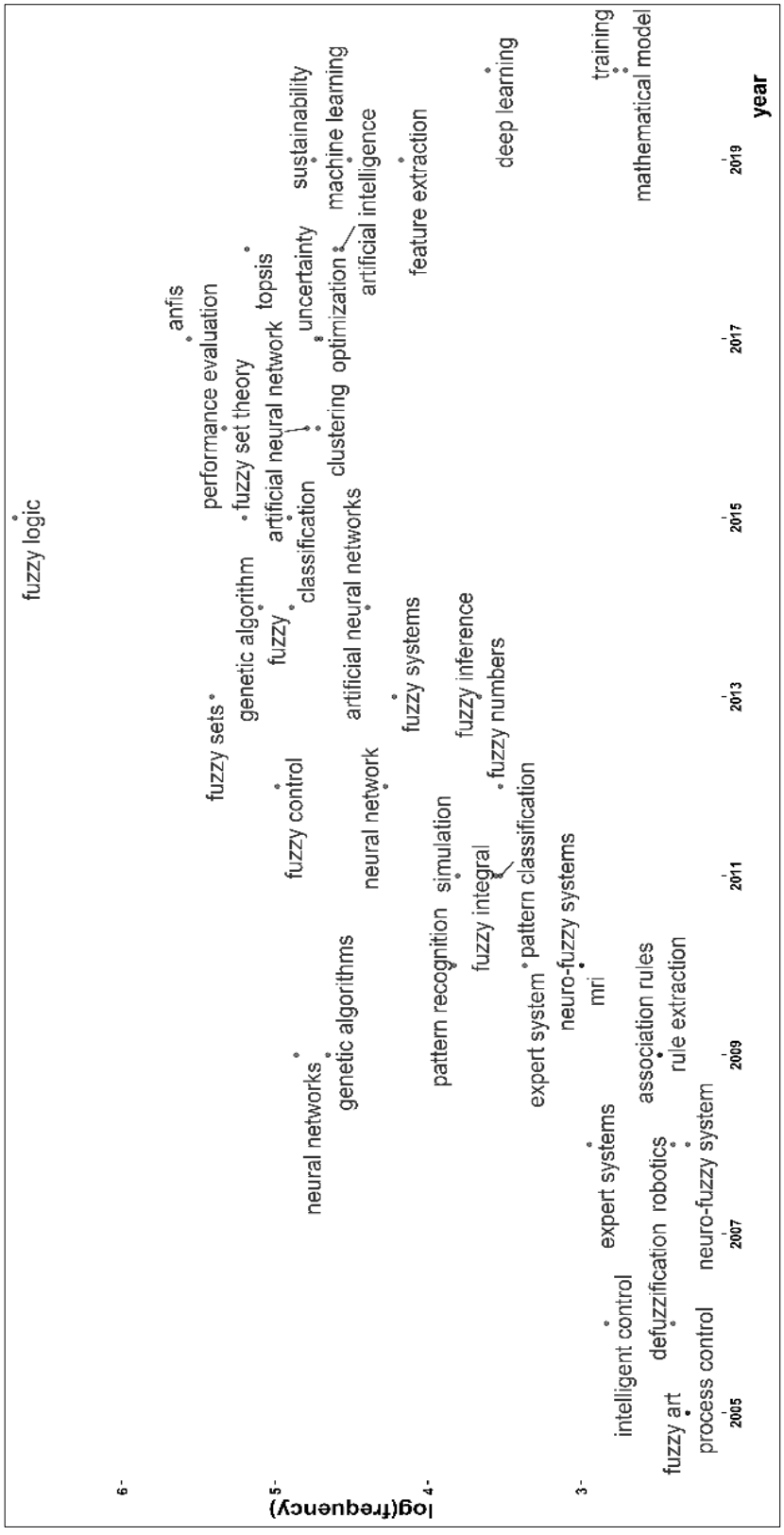

Fig. 8. The temporal evolution of hot spots

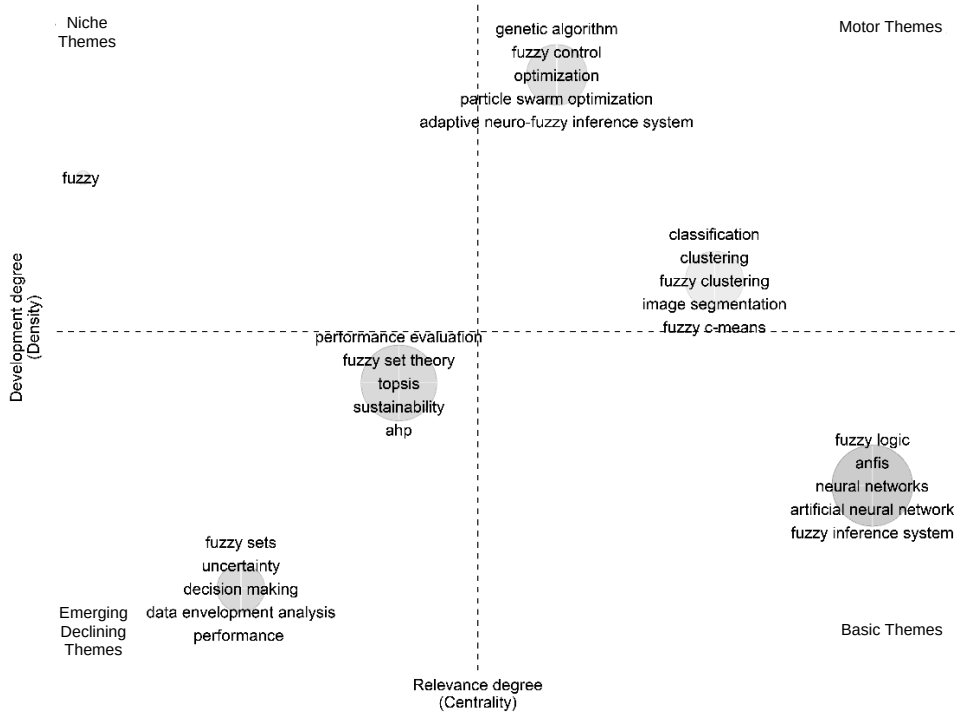

Fig. 9. Thematic map

F. Results and analysis

The number of papers published in the world is on the rise. The number of papers published in China and Iran is higher than that in other countries and regions. However, the number of papers cited in the United States and Turkey is higher than that in other countries or regions. Islamic Azad University is the largest. The research topics focus on fuzzy sets, fuzzy logic, genetic algorithm and performance evaluation. The research hotspots before 2011 included expert system, neuro-fuzzy system, and pattern recognition. After 2011, the research hotspots became neural network, fuzzy sets, and machine learning.

CONCLUSIONS

Based on Bibliometric software, this paper systematically analyzes the research papers published in SCI-E and SSCI databases about fuzzy evaluation for performance evaluation, summarizes the trend of papers, the research situation of research institutions and regions, and research hotspots, etc.

We presented a comprehensive overview of the fuzzy evaluation in the performance research field based on the bibliometric analysis. This method is mainly based on published outputs and their citations.

1. This study has designed more than 100 research areas, and only the two fields of engineering and computer science are developing fastest. In the future, more attention should be paid to the cross-development of other areas.

2. There are needed to pay attention to international cooperation, especially organizations with a high volume of articles and high frequency of citations.

3. On the basis of attaching importance to basic research on "fuzzy logic", there is needed to pay more attention to the development of "genetic algorithm" and "classification".

To some extent, the hot spots and trends of this research are influenced by the key words, database and clustering algorithm.

There are still many areas to be improved in this study, especially in the citation network analysis, which will be further studied in order to provide better decision-making reference for relevant personnel in the field.

Acknowledgment

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INFORMATION ON THE ARTICLE

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АНАЛІЗ І ОГЛЯД НЕЧІТКОЇ ОЦІНКИ ДІЯЛЬНОСТІ / Ц. Юй, Ц. Ян, Ц. Го, Л. Глоба

Анотація. У сучасних умовах всебічний аналіз тенденцій розвитку людської діяльності в різних галузях і оцінювання їх ефективності дедалі більше потребують аналізу даних, нагромаджених у численних документах, що зберігаються в глобальній мережі. Аналіз засновано на річних звітах про напрями досліджень, часових тенденціях, ключових словах і має певні особливості: потребує не завжди точної числової інформації, порівняння якісних показників, отримання як якісних, так і кількісних характеристик, а також використання довідкової інформації для дослідників і осіб, які приймають рішення в суміжних галузях. У зв’язку з цим в останні роки нечітку оцінку, що ґрунтується на нечіткій математиці, дедалі частіше використовують у різноманітних видах оцінювання ефективності багатьох видів діяльності. Проведено бібліометричне дослідження на основі системи розширеного індексу наукового цитування (SCI-E) і нечітких критеріїв ефективності для вивчення тенденції розвитку та напрямів дослідження. Як об’єкт дослідження використано відповідні наукові статті з бази даних Web of Science, а тенденції досліджень проаналізовано за допомогою методу бібліометрії. Результати показують, що кількість статей, які публікуються в світі, збільшується. Статей, опублікованих в Китаї та Ірані, більше, ніж в інших країнах і регіонах світу. Утім кількість цитованих робіт в США і Туреччині більша, ніж в інших країнах або регіонах світу. Ісламський університет Азад опублікував найбільшу кількість статей у світі. Теми дослідження зосереджені на нечітких множинах, нечіткій логіці, генетичному алгоритмі та оцінці продуктивності. «Гарячими» напрямами досліджень до 2011 р. були експертні системи, нейронечіткі системи і розпізнавання образів, а після 2011 р. стали нейронні мережі, нечіткі множини і машинне навчання.

Ключові слова: інформаційно-комунікаційна мережа, система оброблення даних, онтологія, модель,аналіз, масштабування, клас, відношення.

АНАЛИЗ И ОБЗОР НЕЧЕТКОЙ ОЦЕНКИ ДЕЯТЕЛЬНОСТИ / Ц. Юй, Ц. Ян, Ц. Го, Л. Глоба

Аннотация. В современных условиях всесторонний анализ тенденций развития человеческой деятельности в различных сферах и их эффективности все больше требуют анализа данных, накопленных в многочисленных документах, хранящихся в глобальной сети. Анализ основан на годовых отчетах о направлениях исследований, временных тенденциях, ключевых словах, и имеет определенные особенности: требует не всегда точной числовой информации, сравнения качественных показателей, получения как качественных, так и количественных характеристик, а также использования справочной информации для исследователей и лиц, принимающих решения в смежных областях. В связи с этим в последние годы нечеткая оценка, основанная на нечеткой математике, все чаще используется во всех видах оценивания эффективности различных видов деятельности. Проведено библиометрическое исследование на основе системы расширенного индекса научного цитирования (SCI-E) и нечетких критерий эффективности для изучения тенденции развития и направлений исследования. В качестве объекта исследования использованы соответствующие научные статьи из базы данных Web of Science, а тенденции исследований проанализированы с помощью метода библиометрии. Результаты показывают, что количество статей, публикуемых в мире, увеличивается. Статей, опубликованных в Китае и Иране, больше, чем в других странах и регионах мира. В то же время, количество цитируемых работ в США и Турции, больше, чем в других странах или регионах мира. Исламский университет Азад опубликовал наибольшее количество статей в мире. Темы исследования сосредоточены на нечетких множествах, нечеткой логике, генетическом алгоритме и оценке производительности. «Горячими» направлениями исследований до 2011 г. были экспертные системы, нейронечеткие системы и распознавание образов, а после 2011 г. стали нейронные сети, нечеткие множества и машинное обучение.

Ключевые слова: информационно-коммуникационная сеть, система обработки данных, онтология, модель, анализ, масштабирование, класс, отношения.