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Analytic Hierarchy Process in Production Engineering: A Bibliometry Analysis

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Abstract**—** *AHP (Analytic Hierarchy Process) tool stands out for its reliability and effectiveness, therefore, the objective of this research was to identify the scientific productions found in the electronic databases chosen by the author on the AHP tool. The date of publication covered by the survey comprises the periods from April 1992 to January 2018. The electronic bases used for the research were Scopus, Web of Science and Scielo, which after filtering only articles that mentioned the method in the title or abstract totaled in 178 articles. The year 2013 was the most productive with 24 articles (13.48%) published. Eight researchers appeared to be more productive because they had more than one published article. The International Journal of Production Research was the most productive periodical (5.62%), China the country with the largest number of publications (34.26%) and four universities had the largest number of articles published (6.74%) and the words that more appeared in article were process, hierarchy, analytic, fuzzy and production. It is concluded that the AHP tool still has great relevance in decision support methods even after 46 years of its creation, and that its potential continues to be promising for the analysis and solution of problems.*

Keywords**— AHP, bibliometry, AMD, Multicriteria Decision Support.**

Analytic Hierarchy Process na Engenharia De Produção: Uma Análise Bibliométrica

Resumo**—** *A ferramenta AHP (Analytic Hierarchy Process) se destaca por sua confiabilidade e efetividade assim, o objetivo deste trabalho foi identificar as produções científicas encontradas nas bases de dados eletrônicas escolhidas pelo autor sobre a ferramenta AHP. A data de publicação abordada pela pesquisa compreende os períodos de abril de 1992 até janeiro de 2018. As bases eletrônicas usadas para a pesquisa foram a Scopus, Web of Science e Scielo, que após filtragem por apenas artigos que mencionassem o método no título ou resumo totalizou-se em 178 artigos. O ano de 2013 foi o mais produtivo com 24 artigos (13,48%) publicados. Oito pesquisadores figuraram como mais produtivos por terem mais de um artigo publicado. O International Journal of Production Research foi o periódico mais produtivo (5,62%), a China o país com maior número de publicações (34,26%) e quatro universidades tiveram o maior número de artigos publicados (total: 6,74%) e as palavras-chave com maior frequência no artigo foram process, hierarchy, analytic, fuzzy e production. Conclui-se que a ferramenta AHP ainda possui grande relevância*

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nos métodos de apoio à tomada de decisão mesmo depois de 46 anos de sua criação, e que seu potencial continua sendo promissor para a análise e solução de problemas.

***Palavras-chave*— AHP, bibliometria, AMD, Apoio Multicritério à Decisão.**

I. INTRODUCTION

The market is in increasing need for quality information, which makes decision support tools a pivotal force for choices involving large risks in companies.

The available tools are the most versatile, providing rational procedures to model problems and represent and quantify variables, taking into account the criteria and weights proposed by the decision makers. Currently, the AHP (Analytic Hierarchy Process) method stands out for its traditionality and reliability.

On the other hand, with the significant increase in the publications, works that classifiy and / or synthesize the knowledge produced become more relevants. Bibliometric, scientometric and web-based studies, as well as systematic reviews, stand out in this line. In this way the reader will have access to a quality material, which describes aspects predominantly quantitative of the state of the art of a certain theme.

When comparing the scientific production of bibliometrics in the Scopus site in 2006 and 2017, which had 205 and 1172 publications respectively, the 471.71% increase in publications empirically affirms the growing relevance of the theme in the academic community.

The present study aims to identify the scientific production about the AHP method pertinent to the Multicriteria Decision Support.

II. ANALYTIC HIERARCHY PROCESS (AHP)

Multicriteria Decision Support (AMD) consists of a set of methods and techniques to assist or support individuals and organizations in making decisions, when habing multiplicity of criteria (GOMES *et al*. 2002).

Another important step is the choice of the method to be used, which should depend more on its adequacy to the preference structure of decision makers than on the analyst's preference for particular models and methods.

The multi-criteria decision analysis process can be presented with the following steps (GOMES *et al.* 2004):

1) Identification of decision-makers and their objectives;

2) Definition of alternatives;

3) Definition of criteria relevant to the decision problem;

4) Evaluation of alternatives to criteria;

5) Determination of relative importance of criteria;

6) Overall assessment of each alternative;

7) Sensitivity analysis;

8) Recommendation of courses of action;

9) Implementation.

It should also be noted that a family of criteria, that is, the set of criteria used in a given decision situation, must satisfy three conditions (Roy's axioms) to be a coherent family of criteria (ROY; BOUYSSOU, 1993; MELLO *et al.* 2003): exhaustiveness (it imposes the need to describe the problem taking into account all relevant aspects); cohesion (requires the correct analysis of which are the criteria of maximization and which of the minimization criteria); and non-redundancy (it obliges to exclude criteria that are evaluating characteristics already evaluated by another criterion).

The AHP (Analytic Hierarchy Process) method was developed by Tomas L. Saaty and his first record is dated 1972 in the article An eigenvalue allocation model for prioritization and planning. It is the most widely used and well-known multicriteria method in support of decision-making in negotiated dispute resolution, in problems with multiple criteria (MARINS, SOUZA, BARROS – 2009).

Ishizaka and Labib (2011) affirm that the structural basis used in the method is inspired by past findings, such as peer comparison rather than weight allocation (Thurstone, 1927; Yokoyama, 1921), the hierarchical formulation of the criteria (Miller, 1966), scale 1-9 based on observational psychology (Fechner, 1860; Stevens, 1957) and the number of items in each level (Miller, 1956).

According to Costa (2002, p. 16-17) this method is based on three stages of analytical thinking:

1 – Hierarchical Construction: Because problems usually have complex resolutions, their structure is made hierarchically to facilitate their understanding. The first level corresponds to the general purpose of the problem, the second level the criteria and the third the alternatives.

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2 – Prioritize: In order to define such importance, the following steps must be followed:

• Joint Judgments: We judge the elements of a hierarchy level in comparison of each element in connection with a higher level, establishing the judgment matrices A, using the scales presented in the table 1. (TREVIZANO E FREITAS, 2005);

Table 1 - Saaty Number Scale

Number Escale	Verbal Scale	Explanation
1	The two elements have the same importance	The two elements contribute property equally
3	Moderate importance of one element over another	Experience and opinion favor one element over the other
5	Strong importance of one element over the other	An element is strongly favored
7	Very strong importance of one element over the other	One element is very strongly favored over the other
9	Extreme importance of one element over the other	An element is favored by at least one order of magnitude of difference
2, 4, 6, 8	Intermediate values between opinions	Consensus values

Source: Roche (2004, p.6)

The number of judgments required to construct a generic judgments matrix A is n (n-1)/2, where *n* is the number of elements belonging to this matrix. The elements of A are defined by the conditions :

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ 1/a_{n1} & 1/a_{n2} & \cdots & 1 \end{bmatrix}, \text{ onde}$$

$$a_{ij} > 0 => positive$$

$$a_{ij} = 1 \therefore a_{ji} = 1$$

$$a_{ij} = 1/a_{ji} => reciprocal$$

$$a_{ik} = a_{ij}.a_{jk} => consistency$$

• Normalization of the matrices of judgment: obtaining normalized tables by adding the elements of each column of the matrices of judgment and later division of each element of these matrices by the sum of the values of the respective column;

• Calculation of local average priorities: These are the averages of the lines of the standard tables;

• Calculation of global priorities: in this step we wish to identify a global priority vector (PG), which stores the priority associated with each alternative in relation to the main focus.

According to Vaidya and Kumar (2006), one of the main advantages of the AHP method is its flexibility, allowing integration with other techniques for problem solving, such as Quality Function Deployment, Fuzzy Logic and Linear Programming. This enables the decision-maker to derive the benefits of all the combined methods, helping to achieve the desired results optimally.

Tam and Tummala (2001) describe the AHP as being very useful for reaching a consensus when it involves several decision makers with different conflicting objectives.

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According to Silva and Hamacher (2008), one difficulty that persists in problems structured with the AHP method is the quantification of project quality assessments.

Grandzol (2005) says that improper application of the method in unfavorable environments is perceived as oversimplification or as a waste of time.

Although the fault is not blamed on the tool's structure, most decision makers are unaware of the successive improvements that have been developed over time to specific thematic problems (ISHIZAKA, LABIB, 2011).

Vaidya and Kumar (2006) find in their review of the main developments of the method, articles in the most diverse areas, including: manufacturing, engineering,

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education, industrial, government, sports, administration, etc. In order to measure the classification of the areas of application of AHP, the authors classify in three groups: (a) applications based on themes, (b) specific applications and (c) applications combined with other methodologies.

The themes encompassed by the first group are selection, evaluation, cost-benefit analysis, planning and development, priorities and ranking, and decision making. The second group is focused on specific applications in meteorology and medicine related areas, while the third group has AHP problems integrated with the Quality Function Deployment (QFD) tool.

It is also interesting to highlight some works that made use of the method. Kengpol and O'brien (2001) present a decision-making tool for selection of advanced technology, integrating as criteria cost-benefit analysis, an effective decision-making model and a common criteria model for a choice of Time Compression Technologies (TCT).

III. BIBLIOMETRY

Tarapanoff et al. (1995) establish bibliometrics as the study of quantitative aspects of scientific production, sharing and use of information recorded, from mathematical models, to the decision-making process.

According to Lopes et al. (2012), bibliometrics is a quantitative and statistical method to measure indicators of production and dissemination of knowledge, as well as observing the development of several scientific areas and the patterns of authorship, publication and use of research results. The evaluation of the scientific production, important for the analysis of the researchers in the scientific community, is made through the application of several bibliometric indicators, which are divided into indicators of scientific quality, importance and impact.

Bibliometry has laws that use statistical and mathematical techniques that determine the principles of research and ordering in scientific analysis, such as the laws of Lotka, Bradford and Zipf (GUEDES AND BORSCHEVIER, 2005).

According to Urbizagastegui (2008), Lotka's Law states that the number of authors who make n contributions in a given scientific field is approximately $\frac{1}{n^2}$ of those making a single contribution, and that the proportion of those making a single contribution is about 60 percent.

According to Bradford (1934), there is a conception of core formation of journals that address a specific subject. The author states that with the advent of initial articles on a particular topic, they will go through the selective process of journals to which they submitted, and if accepted, will promote the scientific production of articles on the same theme, creating a nucleus of more productive journals followed by areas of less dedication to the theme.

Zipf's Law is based on the principle of least effort: it accounts for the frequency of words in an article. According to Amaral et al. (2004), the law states that if the words appearing in an article are counted and sorted in descending order of number of occurrences, the multiplication of the number of occurrences by the ranking position for each word is a constant.

IV. METHODOLOGICAL PROCEDURES

The article analyzed three electronic databases for this study. Two reference bases (Scopus and Web of Science) and one textual (Scielo). The first two databases are not open to the public, and access has been granted through the partnership established between Brazilian universities and databases, the third being open to the public.

We use the term "Multicriteria Decision Support Tools" OR "AHP" OR "Analytic Hierarchy Process" AND "Production Engineering" in three databases: Scopus, Web of Science and Scielo. All articles that used the AHP method to solve problems were counted for research done in April 2018, the oldest article being dated from April 1992 until the most recent one published, dated January 2018.

Then, the data were exported to the Microsoft Excel 2013 software and stratified into the following items: author, H index, co-authors, year, university, country, journal, CAPES qualis, impact factor, title, keywords, and digital base.

CAPES classifies the production from the quality of journals by the Qualis system, in a ranking by levels A1, A2, B1, B2, B3, B4, B5 and C and can be found on the Sucupira Platform (online). Its importance is determined through the note, which takes into account the quality and number of published works (BARATA, 2016). The area of Engineering III was chosen for the research. The impact factor of journals can be found in the publications' own databases, which take into account the number of citations received by articles published in the journal in the two years prior to the evaluation, divided by the number of articles published in the period.

The H index of researchers was also found in databases, which take into account the largest "h" number

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of articles of a researcher who has the same "h" number of citations each.

For the quantification of the indicators of years with the highest scientific production, the articles were ordered and counted per year of publication. The same method was used (ordering the appropriate variables for each index) to create the index of the most productive researchers, journals with more articles published on the topic, countries with more publications, more productive universities and keywords.

For the Cluster Word image, the keywords were placed on the website www.wordclouds.com, which generates clouds of words showing more prominently the words more frequently in the text.

V. RESULTS

The search terms resulted in 115 (one hundred and fifteen) articles from the Scopus database, of which 8 (eight) were withdrawn for not mentioning the method in the title of the paper or abstract. The Web of Science database returned 92 (ninety-two) articles, of which 21 (twenty-one) were excluded for not mentioning the method. And finally, the textual base Scielo, returned 0 (zero) articles. Unlike the previous databases that have articles in English, the Scielo database has many articles in Portuguese. An attempt was made to translate the term using "Multicriteria Decision Support Tools" OR "AHP" OR "Hierarchical Analysis Process" AND "Production Engineering" to search, but the result of the search again was 0 (zero).

Table 2 - Ten years that have had more articles published on the AHP.

Year	Number of articles
2017	8
2015	10
2014	15
2013	24
2012	11
2011	9
2010	13
2009	17
2008	11
2007	8
TOTAL	**126**

Source: The author, 2018.

Table 2 shows the 10 years that most had articles published. Starting with 2007, which had 8 articles published, 2008 with 11 articles, followed by 2009 with 17, with 13 articles, 11 articles with 11 articles, 11 with 11 articles, eleven) articles, 2013 with 24 (twenty four) articles, 2014 with 15 (fifteen) articles, 2015 with 10 (ten) articles and 2017 with 8 (eight) published articles, totaling 126 one hundred and twenty six articles.

The year 2013 was the most productive year of the study, with twenty-four (n = 24) total publications, contrasting with eight (n = 8) publications in 2007. Of the 27 years of publications found, the last 10 (except 2016, which had 7 publications), correspond to 70.78% of the total research. This shows that the growth of scientific production in recent decades has boosted bibliometrics as well as the generation of indicators to measure the results of scientific and technological activities (FILIPPO; FERNANDEZ, 2002).

Table 3 – Authors who have had two or more publications on the AHP tool

Authors	Number of publications	Index H
Chan, F.T.S.	3	49
Kodali, R.	2	23
Sharma, S.	2	13
Korpela, J.	2	10
Bascetin, A	2	8
Chen, X.-L.	2	1
Li, Z.	2	1

Fonte: Dados da pesquisa, 2018.

Table 3 shows the eight (n = 8) authors who had more than one publication in the research and its respective H index (according to the electronic database in which the file was found). Chan, FTS is the author with more publications, totaling 3 (three articles) and with an H index of 49 (forty-nine) points, being the author with the highest H index among the most productive authors.

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Table 4 – Journal with two or more publications on the AHP tool

Journal's name	Quantity	Qualis	Impact Factor
International Journal of Production Research	10	A2	2,40
Advanced Materials Research	8	C	0,23
International Journal of Production Economics	7	A1	4,34
Expert Systems with Applications	5	A1	4,68
Environmental Progress and Sustainable Energy	4	-	1,46
International Journal of Advanced Manufacturing Technology	4	B1	2,15
Computer Integrated Manufacturing Systems	4	-	0,37
Journal of Manufacturing Systems	4	C	3,2
Production Planning and Control	4	-	1,54
Applied Mechanics and Materials	3	C	0,16
Process Safety and Environmental Protection	3	A2	2,57
CIRP Annals - Manufacturing Technology	2	-	3,62
Journal of Cleaner Production	2	A1	5,84
Production Engineering	2	B3	0,78
Management and Production Engineering Review	2	-	1,28

Source: The author, (2018)

Table 4 shows the 15 journals that had more than one article published in the survey, totaling 64 articles counted and representing 35.96% of the 178 articles. It was not possible to find the qualis of the journals Computer Integrated Manufacturing Systems, Environmental Progress and Sustainable Energy, Production Planning and Control, CIRP Annals - Manufacturing Technology and Management and Production Engineering Review. The journal with the most publications was the International Journal of Production Research (IJPR), with 10 articles published and above the average of 4.26% of articles published by this journal.

IJPR is a well-established and highly successful journal reporting production and manufacturing research. It is published monthly and includes articles on manufacturing technology and the fundamental behavior of production resources, as well as the complex and interdisciplinary analysis and control problems that arise in combining these features in the design of production systems. The strategy of manufacturing, formulation and evaluation of policies and the contribution of technological innovation are the main concerns of the journal. Techniques developed in computational and mathematical sciences used in design, measurement or operation of production systems are also considered.

Although five publications were made in Brazil, no Brazilian journal appeared in this research (Table 5).

Table 5 – Countries with more articles published on the AHP tool

Country	Number of articles
China	61
Turkey	17
Iran	14
USA	14
India	9

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Brazil	5
United Kingdom	5
South Korea	4
Finland	4
Italy	4

Source: The author, 2018

Table 5 shows the ten countries that had the most publications on the AHP tool. The sum of the publications of these countries corresponds to 76.97% (137 articles) of the total of articles of the research.

China was the country with most publications, leading the ranking with 61 (sixty one) articles and a very significant difference of 44 articles for the second place, Turkey, with 17 (seventeen) publications. This is an interesting number for discussion, as it reiterates data from the 2018 edition of the journal Science & Engineering Indicators, which states that China surpassed the United States in the absolute number of articles produced, the country with the most published articles of the world.

Unlike the US that spends about $ 500 billion in research and technology but with near-frozen spending in recent years, China has been steadily increasing its investment in the area, currently spending $ 408 billion a year. In 2006, the country had approximately 190,000 published articles, and in 2016 reached the top position in the world leadership with more than 426,000, a substantial growth around 124%.

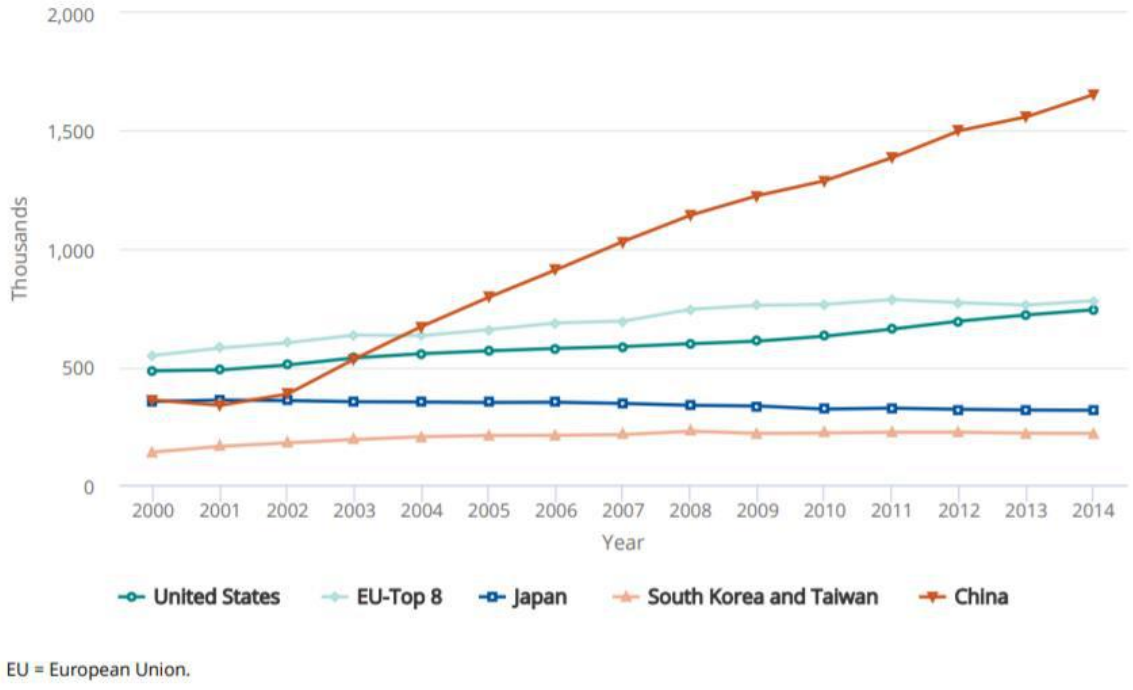

Fig.1 – Bachelor's graduates in the fields of Science and Engineering, from 2000 to 2014

Source: *Science & Engineering Indicators*, 2018.

One of the consequences of China's large research investment can be measured by the number of bachelors graduated in the field of Science and Engineering in the country, which from 2003 to 2014 more than tripled, with a remarkable increase of 240%.

For comparative purposes, Brazil in the period from 2006 to 2016 had a 89% increase in the number of publications, but this increase is far behind the emerging economies. This situation is further weakened by the decrease in the budget for investments in the area in 2018, which is about 19% lower than the previous year (SMAILI, 2018).

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Table 6 - Institutions with the largest number of publications on the AHP tool

Institutions	Number of articles
Islamic Azad University	3
Istanbul Technical University	3
Lappeenranta University of Technology	3
University of Tehran	3
Amir Kabir University of Technology	2
Beihang University	2
Beijing University of Chemical Technology	2
Engineering of Guangzhou University	2
Department of Mechanical Engineering	2
Indian Institute of Technology	2

Source: The author, 2018

There were four universities with more published articles tied with three articles, Islamic Azad University and University of Tehran, both from Iran, Istanbul Technical University, and Lappeenranta University of Technology, Turkey and Finland, respectively. The final table of universities that had two more publications adds up to 19 universities, which together have 42 publications representing 23.59% of the 178 articles.

Originally from Iran, Islamic Azad University began operations in 1982 and now has facilities in the United Kingdom, United Arab Emirates and Lebanon. The university has courses aimed at the most diverse areas, which include: Engineering, Agriculture and Veterinary, Humanities, Arts and Medicine. The Engineering areas correspond to about 42% of the students of the university, which has an investment of US $ 140.9 million for research and maintenance of the facilities.

The University of Tehran opened its doors in 1934 and is considered the Center of Excellence by the Iranian Ministry of Science and Technology in the areas of Sustainable Urban Planning and Development, Architectural Technology, High Performance Materials, Planning and Rural Studies among 11 other categories. With a funding of $ 199.7 million, the university publishes more than 50 scientific journals and encourages teaching by giving full scholarships to students with the best marks in college entrance exams.

Istanbul Technical University is the oldest of the four, dating from 1773. With more than 20 institutes and research centers, the university was voted by QS World University Rankings as one of the 500 best university in the world and the best university in Istanbul in the field of Engineering and Technology.

Finally, Lappeenranta University of Technology began its activities in the year 1969. The university is known for awarding the Viipuri Prize, which boasts outstanding achievements in the field of strategic research.

Brazil had no prominent university in the subject, despite having 5 published articles, corresponding to 2.81% of the total articles found in the research.

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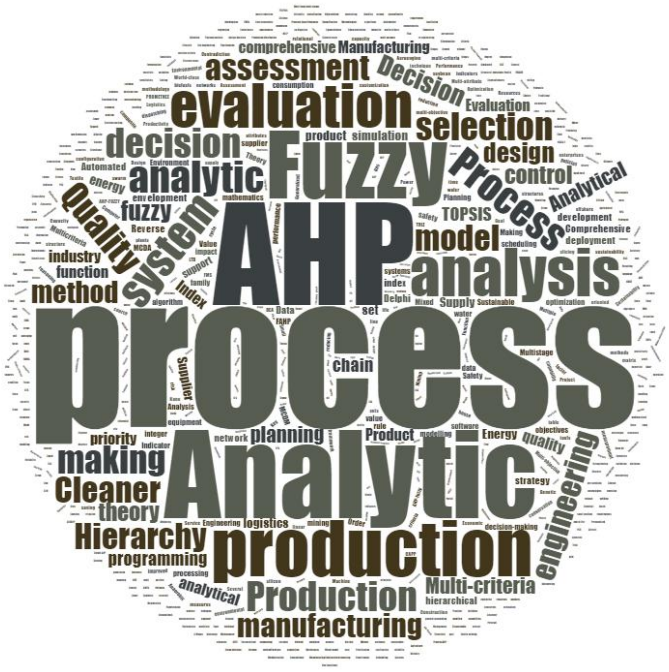

Fig.2 – Cluster Words from the keywords on AHP tool.

Source: www.wordclouds.com.br

The articles totaled 1660 keywords, which represent on average 9.33 ± 3.12 keywords per article. The most prominent words were process (n = 89, corresponding to 5%), hierarchy (n = 69, corresponding to 4%), analytic (n = 60, corresponding to 4%), fuzzy (n = 49, corresponding to 3%) and production (n = 44, corresponding to 3%).

The high average for keywords is due to the fact that most definitions had multiple words. The similarity of the keywords can be explained by the directed nature of the research, which already had a defined thematic area to be explored.

VI. FINAL CONSIDERATIONS

The present article aimed to present a bibliometric study of publications between 1992 and 2018 on the method of decision support Analytic Hierarchy Process (AHP). The publications were classified by author, index H, co-authors, year, university, country, journal, qualis CAPES, impact factor, title, keywords, and digital base. Productivity indexes were then based on: year, author, journal, countries and keywords with the highest frequency.

The year 2013 was the year with the most publications, the most productive author was Chan, F.T.S with three publications on the subject and with the highest H index (49 points) among the most productive authors. The journal International Journal of Production Research appeared as the largest number of publications, China as the country with the most publications, four universities had the largest number of articles published, including Islamic Azad University, Istanbul Technical University, Lappeenranta University of Technology and University of Tehran and the keywords that appeared most frequently in the text were process, hierarchy, analytic, fuzzy and production.

This work showed the importance of the AHP method with regard to decision making, specifically focused on the area of Production Engineering. More than 178 researchers relied on their accuracy to prioritize and solve problems, showing that even after 46 years the method still shows relevance.

The research also has an alarming side, when it takes into account the scientific production of Brazil in relation to other countries. The low positions of the country in all indexes surveyed ends up being a small signal of the major problem that is lack of investment in the sector of Research and Technology.

The work presents as a limitation only one thematic area, which made it difficult to create a classification of an index of the works by theme. Due to

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this fact, the work had a more directed nature and found similar examples.

It is suggested for future research that the thematic area should be broader, not limited to Production Engineering but to other Engineering, or even open research. It would be interesting also to make a bibliometric comparison between other methods of support to decision making, coming from a distinction between date of creation or even schools of thought.

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