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Network Analysis And Thematic Map Of Trends In Futuristic Industry 4.0 Technologies

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Abstract:
Industry 4.0 is associated with the process of information and digitization, generation, integration and analysis of a large amount of data from the life cycle of the production process, based on the Internet. The aim of this study was to implement the bibliometric method to analyze networks and trends in futuristic Industry 4.0 technologies.

The technical procedures for data collection and analysis included a bibliographic survey using the VosViewer® and Biblioshiny® tools to analyze the networks. In the methodological protocol, we highlight the application of the bibliometric method as a provider of a synthesis of the literature, compared to a quick dive into a domain or interest aimed at a structural prognosis of the network in the field of research. The results of this research show promising academic aspects, signaling a new informational horizon, aimed at helping the decision-making process of strategic planners and researchers interested in a futuristic industrial vision.

Keywords:*Industry 4.0, Prospective Scenarios, Intellectual Capital, Bibliometrics*

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I. Introdução

The Industrial Revolution has a concept linked to a change in production technologies and numerous processes of radicalized transformation, driving technological advances with financial, social and material impacts on industrial production. The First Industrial Revolution, which emerged in the second half of the 18th century, is characterized by the use of the steam engine, affecting the first changes in industry and generating the migration of the rural population to the cities. The main feature of the Second Industrial Revolution was the influence of electricity generation on the mass production system and the assembly line. The automation of production processes marks the Third Industrial Revolution. The current Fourth Industrial Revolution is among us and is associated with information and productive digitalization, the generation, integration and analysis of a large amount of data from the production process and the life cycle of products, intermediated and based on the Internet and its databases (BASCO et al., 2018).

The potential to manipulate a large amount of data and transform it into a robust and informative database of academic studies is one of the great benefits of bibliometric analysis (SCHALLER and THESENVITZ, 2019).

The aim of this research is to implement the bibliometric method to analyze networks and trends in futuristic Industry 4.0 technologies. The method of bibliometrics provides a synthesis of the literature in a given field or characteristic domain, becoming like a quick dive into a domain of interest towards the first structural prognosis of the network of the research field (SCHALLER; THESENVITZ, 2019).

II. Metodologia

This research used the Scopus textual database, which was justified by the limitations of analyzing the bibliometric networks used in the research. Considered the largest database of citations and summaries of peer-reviewed literature, often used to create datasets for bibliometric research, Scopus shows the potential for combinations and multiple possibilities for developing specific and complete search strategies, providing a broad view of the world's research production in the areas of political, economic, social, technological, environmental and engineering sciences, etc. (JESUS, 2017; GAJANAN, RAJEEV, 2017; MONGEON, HUS, 2016; ZUPIC, CATER,2015; SCHIAVI, BEHR,2018; BAAS et al, 2020). The methodology will be divided into two phases, namely:

-First phase of construction: definition of keywords and choice of search base to be considered.

The topic of Industry 4.0 was searched in the futuristic context in addition to the terms: "scenarios, future, trends, horizons, prospective", using the Boolean operators "AND" and "OR", included in the title, according to the definition of the search (Table 1):

Table 1: search string

TITLE ("Industry 4.0" OR "Fourth industrial revolution") AND TITLE (foresight) OR TITLE (scenarios) OR TITLE (future) OR TITLE (trends) OR TITLE (horizons) OR TITLE (prospects)) AND (EXCLUDE (SUBJAREA , "MATH") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "PSYC") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "IMMU") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "NURS") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "VETE")) AND (EXCLUDE (PUBYEAR , 2021)).

Source: Author's elaboration

- Second phase of bibliometrics: mapping the main authors, journals, research institutions and other research data

Bibliometrics plays an essential role in understanding the quality and performance of scientific production and knowledge activities. Considered a quantitative analysis method for scientific research, bibliometrics, through its studies, measures and contributes to scientific knowledge through production indicators, dispersion and obsolete scientific fields, the most productive authors and institutions, widely used journals, and helps to identify growth trends in a given area of knowledge, useful for organizational planning (PIMENTA et al., 2017; SOARES et al., 2016).

With regard to bibliometric laws, it is understood that Lotka's Law studies productivity and the contribution of each author to scientific transmission in their relative area of knowledge, with the aim of indicating the most productive authors. Bradford's Law calculates the degree of importance of journals in a key area of science, its evolutionary method in terms of the number of publications, together with the journals that have published the most on the subject. The constant occurrence of words and significant thematic approaches are estimated by Zipf's Law in a given scientific/technological text (RODRIGUES and VIEIRA, 2016).

In the studies by Maia and Di Sério (2017) and Schaller and Vatanan-Thesenvitz (2019), morphological rigor was used according to the criteria identified in bibliometrics, an adaptation of which is shown in Table 2:

Table 2: Morphological rigor criteria identified in bibliometrics

Where? (countries)	Where are the countries of the main researchers on Industry 4.0 in the co-authorship network by country of origin??
Who? (authors)	Who are the main authors on the topic of Industry 4.0 in the author co-citation network?
How? (collaborative network of journals)	What is being searched for in the keywords to identify the main trends and future technologies of Industry 4.0 in the Keyword Co-occurrence Network?
What? (keywords)	How do journals collaborate in order to monitor the main themes of Industry 4.0 in the Journal Citation Network?
What? (collaborative network of research institutions)	What is the collaborative network of research institutions on the subject of Industry 4.0 within the institutions' bibliographic coupling network?

Source:Adapted from Maia; Di Sério (2017); Schaller; Vatananan-Thesenvitz (2019).

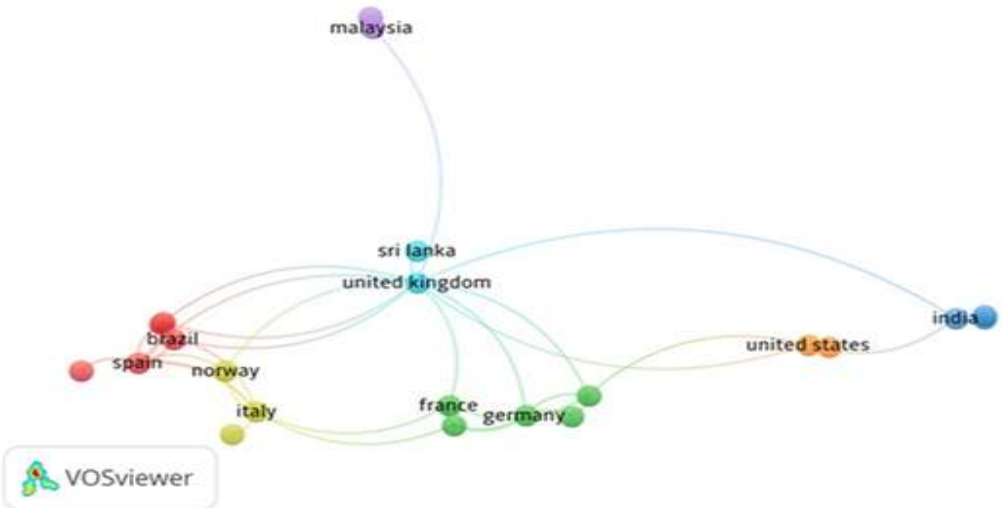
III. Results and analysis

Step 1: Where are the countries of the main researchers on the subject of Industry 4.0 located in the co-authorship network by country of origin?

The co-authorship network by country of origin connects authors when they are co-authors of the documents, with the potential to show a collaboration network and produce the social structure of the researched field (ZUPIC; CATER, 2014). In general, VOSviewer connects authors through the "nodes" of the bibliographic network, which are positioned so that the distance between them roughly indicates their relationship in accordance with the aggregation criteria, indicating the total strength or "link strength" of a given researcher's co-authorship with other researchers (PALLUDETO and FELIPINI, 2019).

The relationship between the countries was determined to meet a minimum number of 1 (one) document in collaboration and a minimum number of 1 (one) citation, resulting in a total of 22 (twenty-two) countries responding to the established parameters and coupled in 7 (seven) clusters, shown in Figure 01.

Figure 01: Co-authorship network by country of origin



Source: Vosviewer and Scopus (2013-2020)

Table II. Clusters of the co-authorship network by country of origin grouped by link strength

Cluster	Countries	Documents	Citations	Total link (Strength)
1	Brazil	11	844	5
	Canada	01	14	4
	Mexico	04	106	4
	Spain	13	217	6
	Sweden	02	143	1
2	Austria	06	878	4
	China	04	57	5
	France	03	23	4
	Germany	30	780	5
	Hong Kong	02	2	2
3	India	09	338	4
	Namibia	01	21	1
	South Africa	05	61	1
4	Italy	12	164	7
	Norway	03	65	3
	Switzerland	04	509	1
5	Ghana	01	2	1
	Malásya	04	3	2
6	Sri Lanka	1	60	1

	United Kingdom	11	163	12
7	Czech Republic	2	2	1
	United States	12	1018	4

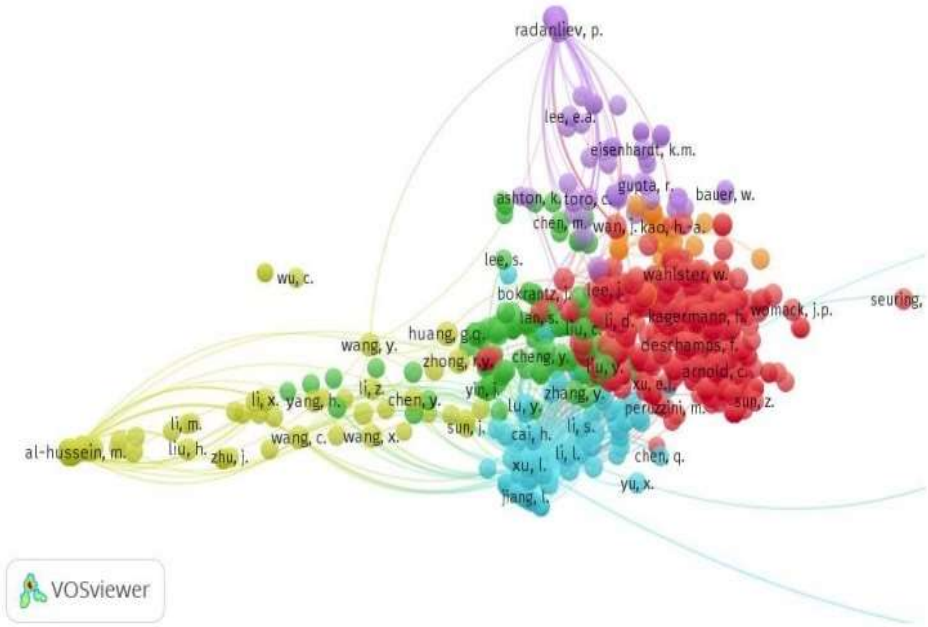
Source: Author's elaboration

It should be noted that the United Kingdom has one of the highest number of interactive links between countries. In turn, Brazil demonstrates its collaborative influence among the countries that study the futuristic theme of Industry 4.0, by occupying one of the fourth positions in the links of connecting force; third place in the number of citations; and fourth place in the number of documents.

Step 2: Who are the main authors on Industry 4.0 in the author co-citation network?

The unit of analysis of the co-citation network is the authors, showing that each author (or set of authors) with more than one text referenced in the database is grouped together in the map, bringing together the authors whose texts appear cited together. It is worth noting that it is not necessary for the author to have indexed publications, what is important is that they appear cited together with other texts within the database (PALLUDETO and FELIPINI, 2019). Seven clusters were identified in Figure 02, described in order of connection or link strength of their main authors.

Figure 02: Author co-citation network



Source: Vosviewer and Scopus (2013-2020)

The most cited authors were: Xu, L., Lee, J., Li, L., Liu, Y., Wan, J., Li, D., Wang, S., Zhong, R.Y., Lu, Y., and Li, S.

Leadership in the seven (7) clusters by authors who aggregate surrounding authors in their approaches to the research theme:

- Sky blue cluster, led by author Xu, L., composed of authors who address aspects of I4.0 (emerging technologies, enterprise architecture and industrial information integration, etc.).

- The lilac cluster brings together authors who permeate the I4.0 theme (cybersecurity, A.I., machine learning, decision support, information management, etc.), with author Radanliev as its main integrative influence.

- Red cluster, with Lee standing out, J as an aggregating force in the composition of authors who move across approaches relating to I4.0 (environmental issues, pollution taxes, costs, knowledge management, human resources management, etc.).

- Royal blue cluster, made up of authors with a wider range of research focused on the theme of I4.0 (engineering education, labor market, A.I., intelligent scheduling of robotic and flexible assembly cells, etc.) with Brynjolfsson standing out for his agglomerative leadership.

- The green cluster, which brings together authors around the I4.0 theme (cyber physical systems, digital technology, augmented reality, virtual reality, etc.) finds its main agglutinating representation in the author Liu,Y.

- Yellow cluster, which brings together authors on the I4.0 theme (disruptive technologies, modular construction, prefabricated construction, internet of things, etc.) with emphasis on Wang,C, as the main grouping force.

- Orange Cluster, made up of authors with a smaller scope of research within the context of I4.0 (manufacturing systems, holonic control architecture, holonic manufacturing systems, etc.), whose connective leadership is represented by Trentesau.

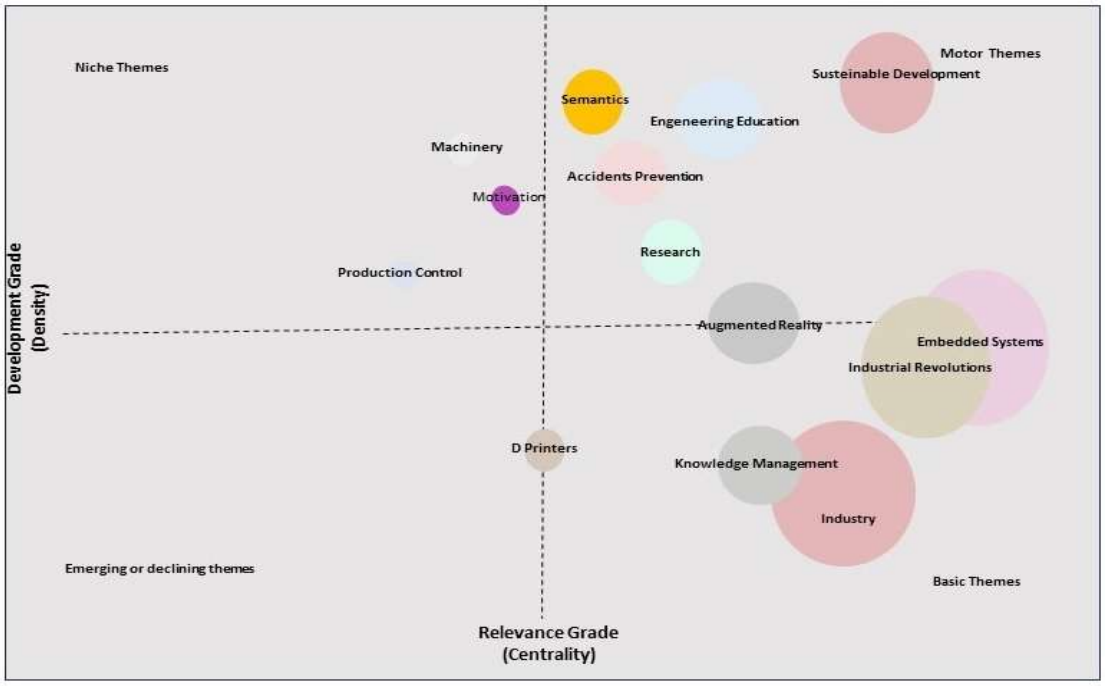
Step 3: What is being searched for in the keywords in order to identify the main trends and future technologies of Industry 4.0 in the Keyword Co-occurrence Network?

The keyword competition network connects keywords when they appear in documents in the title, abstract or list of keywords, representing the intimate relationship of the concepts of these words in a network of themes, pointing out the dynamics of the conceptual structure of an area, and the topics associated with a particular line of research with their respective conceptual evolution (ZUPIC; CATER, 2014).

The thematic map, also known as an evolutionary map, can be used to show the standard development of a theme over an analyzed period, from driving themes, highly developed and isolated themes, to basic and transversal themes. The colored areas represent groupings of topics belonging to the same theme, the size of the spheres is proportional to the number of publications associated with each theme and the continuous line represents the thematic link between different areas (COBO et al., 2012; HERRERA-VIEDNA et al., 2020).

This network can be seen in Figure 03 through the thematic map which, based on the keywords in the Scopus document database on the future of Industry 4.0, shows the general strategic diagram of this theme for the period 2013-2020.

Figure 03. Thematic map of Industry 4.0 futuristic technology trends in the keyword co-occurrence network



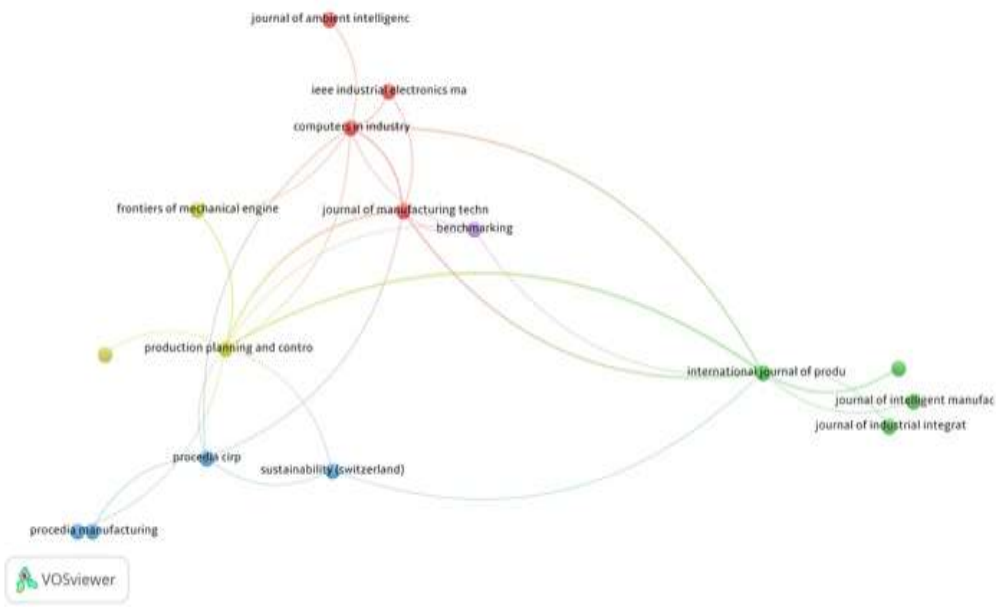
Source: Biblioshiny and Scopus (2013-2020)

In the view of Chen et al. (2019), some keywords with a relatively low frequency, although they may have significant potential, are disregarded in the construction of the thematic map. This aspect can be a trigger for reflection on the reasons that led to the absence of words in the emerging or declining themes in the third quadrant on the subject of Industry 4.0. In the context of this research approach, the important and defined driving themes are Sustainable Development; Engineering Education; Research; Accident Prevention; Semantics. The basic, cross-cutting and underdeveloped themes are Industry 4.0; Embedded Systems; Industrial Revolution; Knowledge Management; Augmented Reality, 3D Printing. The highly developed and isolated themes are Machines; Motivation and Production Control.

Step 4: How do journals collaborate in order to monitor the main themes of Industry 4.0 in the Journal Citation Network

In citation analysis the researcher is allowed to identify popular sources and publications and their estimated influence of documents through citation rates. Consisting mainly of a measure of impact in the analysis of the most dominant journals in a given line of research, leading to a quick finding of significant works in the field and signaling what the reading list is for a specific area (SCHALLER; VATANAN-THESENVITZ, 2019; ZUPIC; CATER, 2014).

Figure 04. Citation network of journals



Source: Vosviewer and Scopus (2013-2020)

Gianordoli (2016) mentions the type of citation analysis, the complete count method and the source analysis unit. Figure 04 was generated by virtue of the intermediation of the minimum number of (1) one publication and the minimum number of 20 citations per journal. 16 journals were consistently connected to one or more journals, totaling 4,076 citations or 62% of the total citations in general. Eight journals have an average of 168.63 citations per 1 publication; three journals have an average of 215 citations per 2 publications. Five journals have an average of 416.4 citations for 3 publications.

Table 03: Clusters in the journal citation network

Cluster	Journals	Number of documents	Citations	Total link strength
1	Computers in Industry	2	555	10
1	Jornal of Manufactuting Techonology Mnagement	3	279	9
1	IEEE Industrial Electronic Journal	1	661	2
1	Journal Ambinet Inteligence and Smart Enviro	1	54	1
2	International Journal of Production research	3	1277	13
2	Computers and Industrial Engineering	1	26	2
2	Journal of Industrial Integration and Management	1	50	1
2	Journal of Inteligent Manufacturing	1	22	1
3	Procedia Cirp	3	219	5
3	Sustainabity (Switzeland)	3	137	3
3	Procedia Manufacturing	3	170	2
3	Process Safety and Environmental	1	243	2
4	Production Planning and Control	2	27	13
4	Frontiers of Mechanical Engineering	1	204	3
4	Manufacting Letters	1	89	1
5	Benchmarking	2	63	4

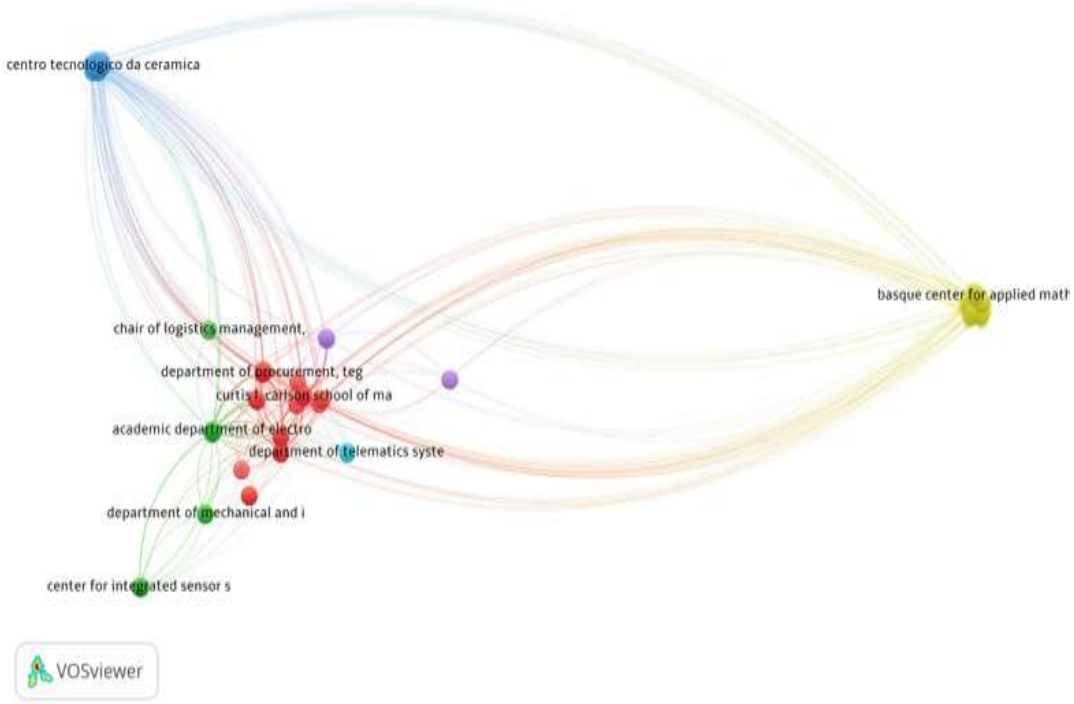
Source: Author's elaboration

As can be seen in Table 03, of the total of sixteen (16) journals connected, four (4) of them (Computers in Industry, International Journal of Production Research, Procedia Cirp, Production Planning and Control) have the strongest links and represent 2,078 citations or 31% of the total citations of the total base.

Step 5 - What is the collaborative network of research institutions on the subject of Industry 4.0 within the institutions' bibliographic coupling network?

The bibliographic coupling between organizations determines the relationship between the author's universities of origin, connecting them based on the number of authorial references they share (ZUPIC; CATER, 2014), Figure 5.

Figure 5: Bibliographic coupling network between organizations



Source: Vosviewer e Scopus (2013-2020)

The relationship between these organizations seen in Figure 05 was determined by meeting a minimum number of 1 (one) document in collaboration and a minimum number of 70 (seventy) citations, resulting in a total of 24 (twenty-four) organizations responding to the parameters established and coupled in 5 (five) clusters.

It should be noted that leadership among these organizations is based on link strength and not on the number of citations, as can be seen in the order of the clusters:

The red cluster highlights the United States of America (USA), by virtue of its influence and leadership in the link strength of the organizations: Curtis l. Carlson School of Management, University of Minnesota and Department of Information Technology & Decision Sciences, Old Dominion University.

The green cluster emphasizes Brazil through influence in the leadership of the link of force in the organizations: Academy of Electrotechnology Department, Federal Technological University of Paraná (UTFPR), Department of Mechanical Engineering (DEMEC), Federal University of Paraná (UFPR) and Polytechnic School, Pontifical Catholic University of Paraná (PUCPR).

The blue cluster highlights Spain and Sweden by forming one of the largest links of interactive strength and leadership between the organizations: Basque Center for Applied Mathematics (BCAM); Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology; Department of Communications Engineering, University of the Basque Country (UPV/EHU); Department of Computer Sciences and Artificial Intelligence, University of the Basque Country; Tecnalia, Donostia-San Sebastián.

The yellow cluster highlights Germany and Austria through leadership in the link force in the organizations Center for Integrated Sensor Systems, Danube University Krems, Institut Industrial it, Ostwestfalen-Lippe University, Tu Dresden, Dresden.

The purple cluster emphasizes Austria by virtue of Fraunhofer Austria Research GMBH- Tu Wien, Vienna University of Technology.

III. Final considerations

The aim of this research was to implement bibliometrics to analyze networks and the futuristic trends and technologies of Industry 4.0.

Its practical applicability focused primarily on the development of the five (5) steps of bibliometrics and network analysis in the search for answers to questions previously established in the methodological protocol:

1. Where are the countries of the main researchers on the subject of trends and futuristic

and futuristic technologies of Industry 4.0 in the co-authorship network by country of origin? The leading countries are (1) Spain, (2) Germany, (3) India, (4) Italy, (5) Malaysia, (6) the United Kingdom and (7) the United States. Brazil stands out as a collaborative influence as it ranks fourth in link strength, third in the number of citations and fourth in the number of documents on the futuristic theme of Industry 4.0.

2. Who are the main authors on the topic of futuristic trends and technologies in Industry 4.0 in the Author Co-Citation Network? Leadership in the seven (7) clusters by authors who aggregate surrounding authors in approaches to the research theme (Xu,L; Radanliev; Lee,J; Brynjolfsson; Liu,Y; Wang,C; Trentesau).

3. What is being searched for in the keywords aimed at identifying the main trends and futuristic technologies of Industry 4.0 in the Keyword Co-occurrence Network? In the context of this research approach, the important and defined driving themes are Sustainable Development; Engineering Education; Research; Accident Prevention; Semantics. The basic, cross-cutting and underdeveloped themes are Industry 4.0; Embedded Systems; Industrial Revolution; Knowledge Management; Augmented Reality, 3D Printing. The highly developed and isolated themes are Machines; Motivation and Production Control.

4. How do journals collaborate in order to monitor the main themes of technological and futuristic trends in Industry 4.0 in the Journal Citation Network? Of the total of sixteen (16) journals connected in the Citation Network, four (4) of them (Computers in Industry, International Journal of Production Research, Procedia Cirp, Production Planning and Control) have the highest strength links and represent 2,078 citations or 31% of the total citations of the total base, identifying significant warning signs for monitoring.

5. What is the collaborative network of research institutions on the subject of technological and futuristic trends in Industry 4.0 within the bibliographic coupling network of institutions? Among the seven (7) clusters identified in the collaborative network of research institutions included in the bibliographic coupling network of institutions, Brazil (green cluster) stands out as the influential representative in the link of strength in the collaborative network of institutions/organizations: Academia of the Department of Electrotechnology of the Federal Technological University of Paraná (UTFPR), Department of Mechanical Engineering (DEMEC), Federal University of Paraná (UFPR) and Polytechnic School, Pontifical Catholic University of Paraná (PUCPR).

Therefore, in order to provide insights into future research directions, we suggest looking for ways to explore the periodic thematic evolution considering all the keywords, including other themes related to bibliometric indicators or the academic deepening of Industry 4.0.

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