Bibliometric Analysis of Published Literature on Industry 4.0

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***Abstract*—Research on Industry 4.0 was initiated in 2012. Since then, the term "Industry 4.0" has been widely used among researchers to further investigate the development of technologies in the related industry. Thus, the aim of this study is to analyze the scientific literature published in the field of Industry 4.0. Scopus database was utilized to collect all literature in Industry 4.0. Publish or Perish software was used to incorporate the obtained data, while VOSviewer was used for data visualization. SPSS and Microsoft Excel were employed for data analysis. The growth of publications, research productivity and citation analysis were presented using standard bibliometric analysis. Based on the search results, a total of 1256 documents were retrieved. The growth rate of literature in Industry 4.0 increased drastically year by year since 2012. Most of the articles were published in journals and conferences, mainly in English. Most of the research in Industry 4.0 was in the engineering field. Keywords of the Internet of Things (IoT) and Cyber-Physical Systems (CPS) were the most keywords used and represent the main areas of research covered in Industry 4.0. Most of the research related to Industry 4.0 was conducted in Germany and multi-authored with a mean collaboration index of 3.65 authors per article. This study presents the evolution of the scientific literature in Industry 4.0 and identifies areas of current research interests and potential directions for future research.**

Keywords—Industry 4.0; Bibliometric Analysis; Systematic Review

I. INTRODUCTION

Industry 4.0 (also known as the 4th Industry) is a current trend of automation and data exchange in manufacturing technologies after mechanization (1st Industry), mass production (2nd Industry), and computer and automation (3rd Industry). It transforms manufacturing into a digital, smart manufacturing processes that makes it possible to gather and analyze data across machines, enabling faster, more flexible, and more efficient processes to produce higher-quality goods at reduced costs. Further, it has changed the competitiveness of companies through increase productivity, shift economics, and foster industrial capabilities. Nine technology trends form the Industry 4.0 namely autonomous robots, simulation, horizontal and vertical system integration, internet of things (IoT), cybersecurity, cloud computing, big data and analytics, additive manufacturing, and augmented reality. These technologies do not only transform the communication and relationships among suppliers, customers, and manufacturers but also between human and machine.

The research in Industry 4.0 was initiated in 2012. Since then, this term has been widely used among researchers to further investigate the development of technologies in the related industry. Thus, the aim of this study is to analyze the scientific literature published in the field of Industry 4.0 using bibliometric analysis. Bibliometric analysis is a quantitative method used to examine the knowledge structure and development of research fields based on analysis of related publications [1]. Pritchard, [2] defines bibliometrics as "the application of mathematics and statistical methods to books and other media of communication".

This section explains the purpose of conducting a bibliometric analysis while the second section details out the methodology adopted. The third section presents the results of the relevant bibliometric indicators. The last section summaries the findings, identifies future research areas and presents some limitations of this study.

II. METHODS

This study collected all data from Scopus database as at 6th October 2018. Scopus database has been used as it is the "largest single abstract and indexing database ever built" [3] and the largest searchable citation and abstract source of searching

literature [4]. Some of the analytical results have been obtained from the collected documents such as access type, year, author name, subject area, document type, source title, keywords, affiliation, country, source type and language. For the purpose of this study, we focused on all documents related to the Industry 4.0 which were based on the title of the document. As such, the following query was conducted: (TITLE("Industry 4.0")). This query produced a total of 1262 documents. However, after data cleaning i.e. by removing some duplicates there was a total of 1256 documents for further analyze.

III. RESULTS

The data collected were analyzed to identify document types, source types, annual growth, languages, subject areas, keywords, countries' productivity, authorships, and citations. Most of the findings presented as frequency and percentage. For annual growth, we presented data as the number of retrieved documents per year including their frequency, percentage and cumulative percentage until 6th October 2018.

A. Document and Source Types

Data obtained were analyzed first to identify its document types and source types. Document types include conference papers, articles, and book chapters, while source types are journals, conference proceedings, book series, books or trade publications. The conference papers that appeared under document type were different from those appeared under source type [5]. Within document type, conference papers refer to papers presented in conferences and were probably published as full journal articles. Some conference papers were also published either in conference proceedings or as a book chapter within source type although the document type was originated from a conference paper.

This study found 10 types of documents that have been published related to Industry 4.0 namely, conference papers, articles, book chapters, editorials, short surveys, notes, articles in press, reviews, books, and conference reviews. As per Table I, the majority of publications were from conference papers represented by 41.96%, followed by articles, 38.06%. The other types of documents collectively represented by almost 20%, where each type was less than 5% of total documents. The lowest two types were books and conference reviews, with less than 1% each.

TABLE I. DOCUMENT TYPE

Document Type	*Frequency*	*%*
Conference Paper	527	41.96
Article	478	38.06
Book Chapter	62	4.94
Editorial	45	3.58
Short Survey	40	3.18
Note	38	3.03
Article in Press	34	2.71
Review	29	2.31
Book	2	0.16
Conference Review	1	0.08
Total	**1256**	**100.00**

Table II presents five source types . The highest represented type is journals (43.39%), followed by conference proceedings with 32.25%. Book series and trade publications also contribute a quite significant number of documents represented by 12.26% and 10.51%, respectively. The lowest contribution was from books.

TABLE II. SOURCE TYPE

Source Type	*Frequency*	*%*
Journals	545	43.39
Conference Proceedings	405	32.25
Book Series	154	12.26
Trade Publications	132	10.51
Books	20	1.59
Total	**1256**	**100.00**

B. Year of Publications

The first research on Industry 4.0 was published in 2012 by Hofmann, Margull, Dittrich and Düntsch [6] with their paper titled, "Smartphone green vision at dawn of industry 4.0". The growth of the related publications has then risen gradually in 2013 and 2014. However, it was drastically increased (as shown in Fig. 1). Based on Fig. 1, it is expected that the number of publications during 2018 will increase more to be even the highest number of publications since 2012. As for 2019, although the year is still in the future, however, some publications have already been scheduled and indexed in the Scopus database.

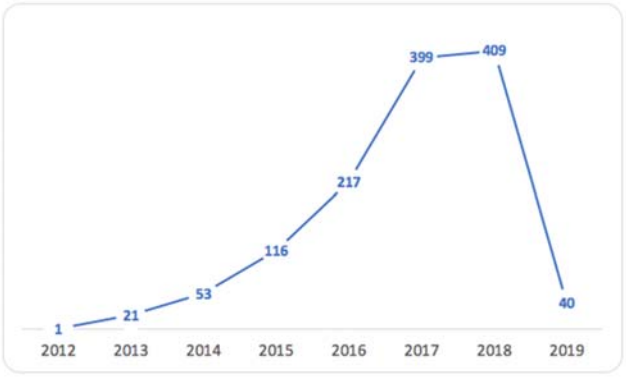

Fig. 1. Total Number of Publications by Year

C. Languages of Documents

Table III shows that most of the retrieved documents (more than 90%) were published in English (90.29%). However, some documents were published in dual languages such as English and German (146); English and Portuguese (5); English and French (2); English and Spanish (2); and English and Italian (1). Some other papers were published in a single language such as German, Chinese, Russian and Spanish. Czech and Turkish languages were the most unpopular languages in the papers studied.

TABLE III. LANGUAGES

Language	*Frequency*	*Percent*
English	978	77.87
English; German	146	11.62
German	89	7.09
Chinese	7	0.56
Russian	7	0.56
Spanish	7	0.56
English; Portuguese	5	0.40
Portuguese	4	0.32
Italian	3	0.24
Japanese	3	0.24
English; French	2	0.16
English; Spanish	2	0.16
Czech	1	0.08
English; Italia	1	0.08
Turkish	1	0.08
Total	**1256**	**100.00**

D. Subject Area

This study also tabled the published documents based on its subject areas. Most of the studies on Industry 4.0 were in the area of engineering representing 66.08% of the total documents followed by computer science (42.36%), business, management and accounting (19.9%), and decision sciences (16.4%). The other subject areas covered in Industry 4.0 research are tabulated in Table IV.

TABLE IV. SUBJECT AREA

Subject Area	*Frequency*	*%*
Engineering	830	66.08
Computer Science	532	42.36
Business, Management and Accounting	250	19.90
Decision Sciences	206	16.40
Mathematics	176	14.01
Materials Science	157	12.50
Physics and Astronomy	89	7.09
Social Sciences	81	6.45
Economics, Econometrics and Finance	58	4.62
Chemical Engineering	53	4.22
Chemistry	47	3.74
Energy	43	3.42
Environmental Science	38	3.03
Medicine	13	1.04
Agricultural and Biological Sciences	9	0.72
Earth and Planetary Sciences	9	0.72
Pharmacology, Toxicology and Pharmaceutics	9	0.72
Psychology	8	0.64
Arts and Humanities	6	0.48
Biochemistry, Genetics and Molecular Biology	5	0.40
Multidisciplinary	3	0.24
Nursing	1	0.08

E. Keywords Analysis

The author keywords were mapped with VOSviewer, a software tool for constructing and visualizing bibliometric networks. Figure 2 presents a network visualization of the author keywords in which color, square size, font size, and thickness of connecting lines were used to present the relationships with other keywords. For example, keywords with the same color were commonly listed together. So, in this study, for example, Industry 4.0, manufacturing, production, digital transformation, digitalization, and automation have a similar color (red) suggesting these keywords have a close relation and usually co-occur together.

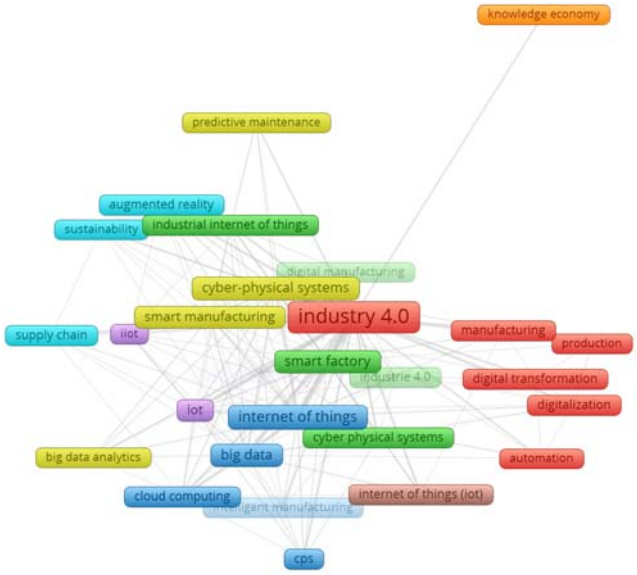

Fig. 2. Keyword Map

Based on the number of occurrences (after conducting data cleaning on the author keywords), keywords such as the Internet of Things (IoT) and Cyber-Physical Systems (CPS) were encountered as the most used keywords in the Industry 4.0 study. The top 20 keywords used in the Industry 4.0 research are shown in Table V.

TABLE V. KEYWORDS

Rank	*Keywords*	*Frequency*
1	internet of things (IoT)	151
2	cyber-physical systems (CPS)	101
3	big data	48
4	smart factory	47
5	industry 4.0	46
6	smart manufacturing	38
7	industrial internet of things (IIoT)	35
8	cloud computing	20
9	cyber-physical system	19
10	digitalization	19
11	augmented reality	17
12	big data analytics	14
13	digital transformation	14
14	manufacturing	14
15	supply chain	14
16	sustainability	12
17	intelligent manufacturing	11
18	automation	10
19	digital manufacturing	10
20	predictive maintenance	10
21	production	10

F. Geographical Distribution

Researchers from 69 different countries contributed to the publication of retrieved documents. Top 20 countries contributed to the publications in Industry 4.0 are listed in Table VI. Germany was ranked first with a total of 404 documents

followed by Italy (82), China (79) and the United Kingdom (UK) (74). In terms of the number of total citations by country, Germany was ranked first with a total of 1858 citations followed by United States (US) (1073).

TABLE VI. TOP 20 COUNTRIES CONTRIBUTED TO THE PUBLICATIONS

Rank	*Country*	*Total Publications*	*Total Citations*
1	Germany	404	1858
2	Italy	82	240
3	China	79	525
4	United Kingdom	74	364
5	Spain	56	295
6	United States	53	1073
7	Austria	51	87
8	Russian Federation	51	229
9	Portugal	47	98
10	Taiwan	37	146
11	Czech Republic	36	92
12	Poland	35	107
13	Brazil	33	116
14	France	30	106
15	India	22	31
16	Sweden	22	914
17	Hungary	16	30
18	Slovakia	15	26
19	Canada	13	45
20	Switzerland	13	94

G. Number of Author

Table VII shows the number of authors per documents. A total of 309 (24.6%) documents were single-authored publications, while the remaining documents were multi-authored publications.

TABLE VII. AUTHOR COUNT

Author Count	*Frequency*	*Percent*
0	22	1.75
1	309	24.60
2	248	19.75
3	245	19.51
4	224	17.83
5	99	7.88
6	58	4.62
7	26	2.07
8	13	1.04
9	5	0.40
10	5	0.40
13	1	0.08
15	1	0.08
Total	1256	100.00

Several documents gathered from the Scopus database had no information available on the author's details. Further investigation conducted to get the information about the authors however it was unsuccessful. Assuming all these documents were written by one author, a mean collaboration index of Industry 4.0 research equals 3.65 authors per document.

H. Citation Analysis

We used Harzing's Publish or Perish software to seek the citation metrics for the retrieved data. Data gathered from the Scopus database has been imported into this software to generate the citation metric as well as the total citation for each document based on Google Scholar citations. Table VIII summaries the citation metrics for the retrieved documents as at 7th October 2018. The summary includes the total number of citations with their citation per year, citations per paper, and citations per author.

TABLE VIII. METRICS

Reference date:	7/10/18 21:09
Publication years:	2012-2019
Citation years:	6 (2012-2018)
Papers:	1256
Citations:	5059
Citations/year:	843.17
Citations/paper:	4.03 (*count=58)
Citations/author:	1892.72
Papers/author:	606.69
Authors/paper:	2.94/3.0/1 (mean/median/mode)
Age-weighed citation rate:	2777.50 (sqrt=52.70), 1037.09/author
Hirsch h-index:	32 (a=4.94, m=5.33, 2849 cites=56.3% coverage)
Egghe g-index:	58 (g/h=1.81, 3391 cites=67.0% coverage)
PoP hI,norm:	19
PoP hI,annual:	3.17

Top 20 cited articles in the field of Industry 4.0 were listed in Table IX. An article entitled "A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems" by Lee, Bagheri, and Kao [7] received the highest citation (based on Scopus database) with a total of 583 citations (194 citations per year). Based on the total citations counted by Google Scholar as at 7th October 2018, the same paper also obtained the highest number of citations with the total of 1013 citations and 337.67 citations per year.

TABLE IX. TOP 20 CITED ARTICLES IN INDUSTRY 4.0 STUDY

No	*Document title*	*Authors*	*Year*	*Source*	*Cited by*	*Cites per Year*	*GS[a] Cites*	*GS[a] Cites per Year*
1	A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems	Lee, J., Bagheri, B., Kao, H.-A. [7]	2015	Manufacturing Letters	583	194	1013	337.67
2	Service innovation and smart analytics for Industry 4.0 and big data environment	Lee, J., Kao, H.-A., Yang, S. [8]	2014	Procedia CIRP	272	68	514	128.5
3	Industry 4.0	Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., Hoffmann, M. [9]	2014	Business and Information Systems Engineering	245	61	510	127.5
4	Cyber physical systems in the context of Industry 4.0	Jazdi, N. [10]	2014	Proceedings of 2014 IEEE International Conference on	109	27	230	57.5

No	*Document title*	*Authors*	*Year*	*Source*	*Cited by*	*Cites per Year*	*GS[a] Cites*	*GS[a] Cites per Year*
				Automation, Quality and Testing, Robotics, AQTR 2014				
5	Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm	Shrouf, F., Ordieres, J., Miragliotta, G. [11]	2014	IEEE International Conference on Industrial Engineering and Engineering Management	109	27	181	45.25
6	Human-machine-interaction in the industry 4.0 era	Gorecky, D., Schmitt, M., Loskyll, M., Zühlke, D. [12]	2014	Proceedings - 2014 12th IEEE International Conference on Industrial Informatics, INDIN 2014	105	26	187	46.75
7	Opportunities of Sustainable Manufacturing in Industry 4.0	Stock, T., Seliger, G. [X]	2016	Procedia CIRP	99	50	205	102.5
8	Software-Defined Industrial Internet of Things in the Context of Industry 4.0	Wan, J., Tang, S., Shu, Z., Li, D., Imran, M., Vasilakos, A.V. [13]	2016	IEEE Sensors Journal	93	47	148	74
9	The future of industrial communication: Automation networks in the era of the internet of things and industry 4.0	Wollschlaeger, M., Sauter, T., Jasperneite, J. [14]	2017	IEEE Industrial Electronics Magazine	91	91	163	163
10	Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination	Wang, S., Wan, J., Zhang, D., Li, D., Zhang, C. [15]	2016	Computer Networks	70	35	224	112
11	Towards Industry 4.0 - Standardization as the crucial challenge for highly modular, multi-vendor production systems	Weyer, S., Schmitt, M., Ohmer, M., Gorecky, D. [16]	2015	IFAC-PapersOnLine	61	20	146	48.67
12	Industry 4.0 - Potentials for creating smart products: Empirical research results	Schmidt, R., Möhring, M., Härting, R.-C., Reichstein, C., Neumaier, P., Jozinović, P. [17]	2015	Lecture Notes in Business Information Processing	61	20	125	41.67
13	A review of industrial wireless networks in the context of Industry 4.0	Li, X., Li, D., Wan, J., Vasilakos, A.V., Lai, C.-F., Wang, S. [18]	2017	Wireless Networks	59	59	108	108
14	A Categorical Framework of Manufacturing for Industry 4.0 and beyond	Qin, J., Liu, Y., Grosvenor, R. [19]	2016	Procedia CIRP	58	29	116	58
15	Industry 4.0: Towards future industrial opportunities and challenges	Zhou, K., Liu, T., Zhou, L. [20]	2016	2015 12th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2015	56	28	92	30.67
16	Change through digitization—value creation in the age of industry 4.0 (Book Chapter)	Kagermann, H. [21]	2015	Management of Permanent Change	56	19	131	43.67
17	Industry 4.0: A survey on technologies, applications and open research issues	Lu, Y. [22]	2017	Journal of Industrial Information Integration	54	54	120	120
18	A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0	Ivanov, D., Dolgui, A., Sokolov, B., Werner, F., Ivanova, M. [23]	2016	International Journal of Production Research	53	27	97	48.5
19	Lean Automation enabled by Industry 4.0 Technologies	Kolberg, D., Zühlke, D. [24]	2015	IFAC-PapersOnLine	45	15	113	37.67
20	Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry	Oesterreich, T.D., Teuteberg, F. [25]	2016	Computers in Industry	44	22	100	50

[a] GS = Google Scholar

IV. CONCLUSION

This paper presents a bibliometric review to gain a clearer insight into the trends, historical review, forecasts and contributions of the Industry 4.0 literature. The research on this topic started in 2012 and increased year by year since then. The number of publications drastically increased in 2017 with a total of 399 publications compared to 217 in 2016. It is expected the total number of publications in Industry 4.0 will increase more in 2018 where, as of October 2018, the total publications already reached 409 documents. Articles related to Industry 4.0 also were written by multiple authors with a mean collaboration index of 3.65 authors per article.

This study also reveals that the areas mostly covered in the Industry 4.0 research are related to IoT and CPS based on the keywords used by authors. Other potential topics worth exploring include big data, smart factory, smart manufacturing and the industrial internet of things (IIoT).

The geographic dispersion of the literature shows that Germany has the largest number of publications as well as influence in terms of the number of citations as compared to other developed countries such as the US and the UK. We

propose that the research on Industry 4.0 should be conducted in other developing countries, as the impact on the technologies were globally affected.

Our study has a few limitations that are inherent to the database used. Thus, it should be emphasized that even though Scopus is one of the largest databases, there are still journals unindexed, and therefore publications in these journals might have been ignored. Furthermore, this study only focused on the topic related to Industry 4.0 based on the title of the documents. Thus, all the other literature that related to Industry 4.0 but not explicitly use it in the title was also excluded. It is also important to highlight that no search query is 100% perfect, false positive and false negative results may occur. The citation analysis presented in our study was based on data from Scopus and Google Scholar. The total number of publications and citations is only correct at the time of the search or the. Despite all these limitations, this study is among the first to analyze the detailed bibliometric indicators of the published literature in Industry 4.0 apart of the bibliometric study conducted by Trotta et al (2018) who discussed only keywords used in publications related to Industry 4.0.

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