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Bibliometric analysis of the emerging phenomenon of smart factories

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Abstract:

Research Question (RQ): Bibliometric studies provide a useful tool in reviewing scientific research, by using quantitative methods for analyzing all available publications in a research area of interest, in our case research on smart factories. Therefore, the following research questions occurred: 1. how much research has been done on smart factories, since the concept first appeared in 2011? 2. what characterizes the available publications?
Purpose: The purpose of our study is to analyze the extent of the available literature on the topic of smart factories, along with classifying the characteristics of available contributions, namely journal papers, conference papers and book chapter, along with their impact indicators.
Method: Bibliometric analysis and historical literature review was done with the help of the Clarivate Analytics Web of Science bases: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, and IC.
Results: We found that there are a total of 123 contributions to the field of smart factory research, from 2011 till 2017, and that most of these contributions fall under engineering and other technology related research areas, while a few fall within the social science category.
Organization: Our study can help traditional factories and emerging smart factories learn about developments in the field of new smart technologies and learn information that might help them change their business models.
Society: The number of citations helps determine the impact a paper or set of papers has had on a particular field of research or science in general, which can help other authors determine which papers might be useful for their own research.
Originality: Up-to-date bibliometric analysis of Web of Science literature in the field of smart factories.
Limitations / further research: Bibliometric studies only provide information on whether or not other authors found particular publications useful and do not provide information on why the publications were useful to those authors. Bibliometric studies thus serve a descriptive role and not a prescriptive role.

Keywords: bibliometric analysis, Clarivate Analytics Web of Science, Industry 4.0, smart factories.

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1 Introduction

We are currently witnessing the shift from a linear economy to a circular economy. An era of the fourth industrial revolution (Kagermann, 2015, pp. 23; Ivanov et al., 2016, pp. 387), often called Industry 4.0, is emerging and is based on digitalization (Yoon et al., 2012, pp. 2178; Roblek et al., 2016). Smart systems that are connecting the real and the virtual worlds (cyber-physical systems) are enabling reorganization of traditional organizations into smart organizations.

Smart factories (Lucke at al., 2008, pp. 115; Zuehlke, 2010, pp. 134; Wang et al., 2016) with their smart systems, smart technologies, smart employees, etc., are an emerging phenomenon of the modern era. The main characteristic of smart factories is the use of the Internet of Things (IoT), in combination with cyber-physical systems. In fact, the IoT has enabled the organizations to reorganize and reshape to become highly flexible in manufacturing very small batches that are customized to the needs of their customers with deep integration among various stakeholders (customers and suppliers), and sustainable (long-term growth and development) (Radziwon et al., 2014).

2 Theoretical framework

The term bibliometrics was coined in 1969, approximately the time when bibliometric research began, and within the next two decades became its own discipline (Patra et al., 2005; Bilas and Moutusi, 2013, pp. 945). Bibliometrics is increasingly being used to characterize, through quantitative analysis, the available literature on a certain topic (Mallig, 2010; Belter, 2015; Ellegaard and Wallin, 2015). The major factor that influenced the use of bibliometric methods, to study, among other things, who authored papers, development of the research field, impact indicators of specific publications, were the emergence of communication technology and online bibliographic databases (Patra et al., 2005; Mallig, 2010; Belter, 2015). The next step that seems to be necessary in the field of bibliometrics, is to create a database, specifically designed for bibliometricians, in order to increase the quality of bibliometric work, however the amount of research into the development of such a database is rare, despite the limitations of current online bibliographic databases (Mallig, 2010). However, despite their limitations, current online literature databases, such as Web of Science, Scopus and Google Scholar contributed significantly to bibliometric research, in addition to analytic software for quantitative analysis of publications (Ellegaard and Wallin, 2015).

The topic of smart factories is under-researched, however it is gaining increasing attention of scholars and practitioners, and as such a bibliometric overview of existing publications in high ranking bibliographic databases could be of interest to them. Bibliometric studies might also be useful for traditional factories that wish to transition to a smart factory, as it provides a useful tool for knowledge management within an organizational context (Patra et al., 2005). It has also been said to be useful for science policy proposal, decision making, institution/

university ranking and peer review, among other things (Patra et al., 2005; Belter, 2015; Ellegaard and Wallin, 2015).

3 Method

The study was performed through a literature review of three publication categories, namely journal papers, conference papers and book chapters. All publications used in this study were obtained from the following Clarivate Analytics Web of Science bases: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, and IC. In this study, we discuss the contributions published in the period from the year 2011 till the year 2017. To shed light on Industry 4.0 trends and publications, both a bibliometric analysis and a historical review were conducted to identify possible gaps in the current research in order to provide guidance for future research directions. Selected publications included "smart factory" in the title or keywords. Analyzed parameters included authorship, types of publications, publication years, publication sources, research areas, most frequent authors, authors' affiliations, authors' country and number of times cited.

The historical method proposes that "historical phenomena can be rich and complex" and provide "a better understanding by investigating the time(s), place(s) and context(s) in which events occur and develop" (Chao et al., 2007, pp. 269). Also, according to Kothari (2004) with the literature review a general overview of the phenomenon can be achieved.

Further, with bibliometric analysis of contributions in high ranking publications of smart factories new technological trends are investigated and possible future research can be identified.

4 Results

4.1 Bibliometric analysis

Since the inception of the concept of Industry 4.0 and Smart factory in the year 2011, the first contributions on the topic of smart factory were detected in the year 2013 (five contributions). In 2014, there were 10 contributions on the topic of smart factory and 12 contributions in the year 2015. Total number of contributions substantially increased in the year 2016 (43 contributions) and the year 2017 (36 contributions). It can be concluded that the number of papers in this research area is increasing, but a slight decline in the year 2017 was noticed.

A total of 123 contributions were selected from the databases investigated. 65 (52.8%) of these contributions were published as conference papers in conference proceedings, 48 (39%) as peer-reviewed journal papers, 7 (5.7%) as editorials, and 3 (2.5%) as chapters in a book.

Most contributions can be linked to the following five research areas: engineering, computer science, automation control systems, operations research management science and telecommunications (see table 1).

Table 1. Research areas

Research area	**Number of papers**
Engineering	77
Computer science	43
Automation control systems	18
Operations research management science	15
Telecommunications	13
Instruments instrumentation	6
Robotics	5
Food science technology	4
Business economics	3
Materials science	3
Science technology other topics	3
Optics	2
Social sciences other topics	2

Selected contributions were published in the following Clarivate Analytics Web of Science categories: Engineering electrical electronic (29 papers), followed by Engineering manufacturing (26 papers), Engineering industrial (23 papers), Automation control systems (18 papers), Computer science information systems (16 papers), Operations research management science (15 papers), Telecommunications (13 papers), Computer science interdisciplinary applications (11 papers), Computer science theory methods (10 papers), Engineering mechanical (9 papers), Computer science artificial intelligence (8 papers), Instruments instrumentation (6 papers), etc.

Tables 2 shows the frequency of contributions by authors' origin:

Table 2. Frequency of contributions by authors' country (≥3)

Authors' countries	**Number of papers**
Germany	27
Republic of China	23
South Korea	17
United States	7
Sweden	6
Italy	5
Australia	3
England	3
Hungary	3

Tables 3 shows the frequency of contributions by authors:

Table 3. The overview of the frequency of contributions by authors

Authors	Number of papers
Wang S.Y.	6
Li D.	5
Zhang C.H.	5
anonymous	4
Kang S.	3
Wan J.F.	3
Wang L.H.	3
Zhong R.Y.	3

Researcher Wang, S. J. authored six papers, Li, D. and Zhang, C.-H. authored five papers, and four researchers Kang, S.,Wan, J.F., Wang L.H. and Zhong, R.H. authored each three papers on the topic of smart factories.

Tables 4 shows the frequency of contributions by authors' affiliations (≥3). Top seven institutions publishing on the topic of smart factory are: Shanghai Jiao Tong University, South China University of Technology, Electronics and Telecommunications Research Institute, Korea Institute of Industrial Technology, South China University of Technology, Seoul National University, and Sungkyunkwan University.

Table 4. The overview of the frequency of contributions by authors' affiliations (≥3)

Authors' affiliation	Number of authors
Shanghai Jiao Tong University	4
South China University of Technology	4
Electronics and Telecommunications Research Institute	3
Korea Institute of Industrial Technology	3
South China University of Technology	3
Seoul National University	3
Sungkyunkwan University	3

Table 5 provides the list of 10 most cited papers indicating the main research area, number of citations and average citations per year. The most cited research areas are computer science, telecommunications and engineering:

Table 5. The overview of the most cited papers

Contribution	Main research areas	Number of citations	Average citations per year
Wang, S., Wan, J., Li, D., & Zhang, C. (2016). Implementin smart factory of industrie 4.0: an outlook. *International Journal of Distributed Sensor Networks*, *12*(1), 1-10.	Computer Science; Telecommunications	167	55.67
Wang, S., Wan, J., Zhang, D., Li, D., & Zhang, C. (2016). Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination. *Computer Networks*, *101*, 158-168.	Computer Science; Engineering; Telecommunications	46	15.33
Radziwon, A., Bilberg, A., Bogers, M., & Madsen, E. S. (2014). The smart factory: exploring adaptive and flexible manufacturing solutions. *Procedia Engineering*, *69*, 1184-1190.	Engineering; Operations Research & Management Science	26	5.2
Ivanov, D., Dolgui, A., Sokolov, B., Werner, F., & Ivanova, M. (2016). A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0. *International Journal of Production Research*, *54*(2), 386-402.	Engineering; Operations Research & Management Science	18	6
Shrouf, F., Ordieres, J., & Miragliotta, G. (2014, December). 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. In *Industrial Engineering and Engineering Management (IEEM), 2014 IEEE International Conference on* (pp. 697-701). IEEE.	Engineering; Business & Economics; Operations Research & Management Science	18	3.6
Choi, S., Kim, B. H., & Do Noh, S. (2015). A diagnosis and evaluation method for strategic planning and systematic design of a virtual factory in smart manufacturing systems. *International Journal of Precision Engineering and Manufacturing*, *16*(6), 1107-1115.	Engineering	13	3.25
Chu, W. S., Kim, M. S., Jang, K. H., Song, J. H., Rodrigue, H., Chun, D. M., ... & Min, S. (2016). From design for manufacturing (DFM) to manufacturing for design (MFD) via hybrid manufacturing and smart factory: A review and perspective of paradigm shift. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *3*(2), 209-222.	Science & Technology - Other Topics; Engineering	12	4
Prinz, C., Morlock, F., Freith, S., Kreggenfeld, N., Kreimeier, D., & Kuhlenkötter, B. (2016). Learning Factory modules for smart factories in Industrie 4.0. *Procedia CIRP*, *54*, 113-118.	Engineering	11	3.67
Zamfirescu, C. B., Pirvu, B. C., Schlick, J., & Zuehlke, D. (2013). Preliminary insides for an anthropocentric cyber-physical reference architecture of the smart factory. *Studies in Informatics and Control*, *22*(3), 269-278.	Automation & Control Systems; Operations Research & Management Science	11	1.83
Shellshear, E., Berlin, R., & Carlson, J. S. (2015). Maximizing smart factory systems by incrementally updating point clouds. *IEEE computer graphics and applications*, *35*(2), 62-69.	Computer Science	9	2.25

5 Discussion

Our study provides authors with information on how many papers were found on a specific research area as a result of a search on specific databases, or how many times they were cited, along with what authors are most prominent in a particular research area. For example, if one looks at countries publishing on the topic of smart factory, we find the Republic of China, South Korea, United States, Sweden, Italy Australia, England, and Hungary, however the largest number of authors is from Germany, which is to be expected, since the new concept, Industry 4.0, started in Germany (Mosconi, 2015).

It should also be noted that impact indicators change with time, with older publications tending to have more citations than newer ones, due to more time passing since its initial publication. In our case half of the top ten cite articles were from 2016, three of these being in the top five. This is possibly due to the field of smart factory research being only approximately five years old, meaning that older articles did not have enough time to accumulate citations, which would make them have a higher impact indicator than newer, possibly more influential articles. Unfortunately, bibliometric studies do not provide information on what specifically and to what degree an article was useful to an author and can only provide information on how many times the articles was cited, which does however give us information about how many authors found a specific article(s) useful (Belter, 2015).

Bibliometric studies provide a useful tool for studying trends with a research area and can help identifying new and growing fields of research (Ellegaard and Wallin, 2015). In our study, we found that smart factory research has grown significantly with each year, since it was first started as an area of research. It would not be surprising that smart factory research will continue to grow in the following years, as according to Research and Markets (2017) the smart factory market "is projected to grow at a CAGR of 9.3% between 2017 and 2022, to reach USD 205.42 billion by 2022. The key driving factors for the growth of the smart factory market are the increase in adoption of industrial robots, the evolution of Internet of Things (IoT), growth in demand for smart automation solutions, and increase in emphasis on regulatory compliances. However, the factors such as huge capital investments and the risks associated with security of cyber-physical system are the major factors restraining the growth of this market."

6 Conclusion

We can conclude that smart factory research has grown significantly with each year, since it was first started as an area of research. With the results of our study, emerging smart factories might learn about developments in the field of new smart technologies and learn information that might help them change their business models. While our study is up-to-date on the topic of smart factories, we only looked at articles listed in the Web of Science database, so we did not cover journals that might only be available in other databases, such as Scopus (Ellegaard and Wallin, 2015) Future bibliometric studies on smart factories should look at other databases, in order to determine which articles were potentially missed by our study. The

topic is still under-researched given the fact that it is a new phenomenon. Even more so in the area of management and behavior sciences. Smart factory research is still a young field and based on if we look at our findings, we can see that the field is growing with each year, which means that future studies will have to update outdated bibliometric studies.

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Povzetek:
Bibliometrična analiza nastajajočega fenomena pametnih tovarn

Raziskovalno vprašanje (RV): Bibliometrična analiza je koristno orodje za pregled znanstvenih objav, kjer z uporabo kvantitativnih metod raziskovanja analiziramo znanstvene objave na izbranih raziskovalnih področjih, v našem primeru so to pametne tovarne. Postavljata se sledeči raziskovalni vprašanji: 1. koliko je bilo objavljenih znanstvenih objav o pametnih tovarnah od leta 2011dalje in 2. katere so karakteristike obstoječih znanstvenih objav?
Namen: Namen raziskave je podati kritičen pogled na zastavljeno raziskovalno vprašanje z analizo obstoječih znanstvenih objav, t.j. znanstvenih člankov, znanstvenih prispevkov s konferenc in samostojnih prispevkov v znanstvenih monografijah, na področju pametnih tovarn. Namen študije je tudi klasifikacija karakteristik znanstvenih objav in analiza njihove odmevnosti.
Metoda: Bibliometrična analiza je bila izvedena na podlagi baz Clarivate Analytics Web of Science: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, and IC.
Rezultati: Identificirali smo skupno 123 znanstvenih objav na tematiko pametnih tovarn za obdobje od 2011 do 2017, večina objav je na področju tehničnih ved, zelo malo pa na področju družboslovnih ved.

Organizacija: Naša raziskava podaja pregled znanstvene literature na področju pametnih tovarn, iz katerega lahko tradicionalne kot tudi nastajajoče pametne tovarne črpajo koristne informacije glede pametnih sistemov in tehnologij, ki jim lahko pomagajo pri prilagoditvah poslovnih modelov.
Družba: Pregled znanstvenih objav in analiza njihove odmevnosti na izbranem znanstvenem področju pametnih tovarn lahko pomaga raziskovalcem kot tudi praktikom pri izbiri literature za lastne raziskave ali kot vir koristnih informacij.
Originalnost: Aktualna bibliometrična analiza znanstvenih objav v bazah Web of Science za področje pametnih tovarn.
Omejitve/nadaljnje raziskovanje: Bibliometrične študije imajo deskriptivni pomen in nimajo predpisovalne vloge.

Ključne besede: bibliometrična analiza, pregled literature, Clarivate Analytics Web of Science, Industrija 4.0, pametne tovarne.