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Derleme Makaleler / Review Articles

INDUSTRY 4.0 WITHIN THE FRAMEWORK OF SUPPLY CHAIN: A LITERATURE REVIEW AND FUTURE RESEARCH DIRECTIONS

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ABSTRACT

Since its introduction on 2013, Industry 4.0 concept has been applied towards the digitalization of the business environment and has been increasingly a favorite topic for academic research. Moreover, there is a high need of an efficient supply chain to gain a competitive advantage; this point has encouraged incorporations to give a high attention to Industry 4.0 as a crucial element in their structure. The aim of the authors is to examine the progress and identify any research gaps with relevance to scholarly outcomes on Industry 4.0 within the framework of the supply chain. Thus, the authors have systematically reviewed the articles regarding the topic that were published from 2013 and onwards. In this paper, the obtained results from both the generic analysis (e.g. year of publication, subject areas) and the specific one corresponding to four subject areas and the three levels of Industry 4.0 are presented, which can be used as a base for future research agenda in related topics.

Keywords: Supply Chain, Industry 4.0.

INTRODUCTION

The digital revolution of this decade is affecting people's life in almost all aspects, but it is not clear enough how it is affecting the industrial production (Glas & Kleemann, 2016). Authors refer to it as the fourth industrial revolution, which comes as the continuum of the first three: firstly, the creation of steam-powered mechanical manufacturing tools; secondly, the use of electrically powered technologies; and finally the use of electronics and information technology (IT) for manufacturing automation (Drath & Horch, 2014). Since the third one, IT has evolved enormously and new terminology and applications, such as Internet of Things (IoT) and Cyber-Physical Systems, have been introduced into the operations and business environment.

Since its introduction in Germany, on 2013, Industry 4.0 has been "defined by many as a global transformation of the manufacturing industry by the introduction of digitalization and the Internet" (Tjahjono, Esplugues, Ares, & Pelaez, 2017). Industry 4.0 has been labelled in several ways, such as Smart Factories, Smart Industry, Advanced Manufacturing or Industrial Internet of Things (IIoT) (Tjahjono et al., 2017). It includes and not limited to, the use of robotics, high technological sensors, Artificial Intelligence (AI), cloud computing, big data analytics, IoT, 3D printing, mobile devices, software-as-a-service and Cyber-Physical-Systems (CPSs) that will work as a bridge between people and machines (Geissbauer, Vedsø, & Schrauf, 2016).

As the supply chain has a substantial role into the planning and execution of a business, the introduction of Industry 4.0 has a major effect on the whole business as well. The structure of the Supply Chain Management requires a very efficient collaboration between suppliers, manufacturers and customers so that all the steps, which take place from when the order is dispatched until the end-of-life of the product, are very clear (Gilchrist, 2018). Thus, the digitalization and automation of processes that Industry 4.0 has brought, made an impact on the supply chain (Tjahjono et al., 2017). Besides the technical dimension of business digitalization (Felser, 2015), Glas and Kleemann (2016) support that Industry 4.0 is "rather the complete new organization and network coordination of value and supply chains". Thus, they adopt the Hierarchy of Industry 4.0 (see figure 1), which encompasses other concepts, such as "Smart Factory", "Internet of Things and Services" or "Cyber-Physical Systems", as sub-systems or sub-elements of the primary Industry 4.0 concept.

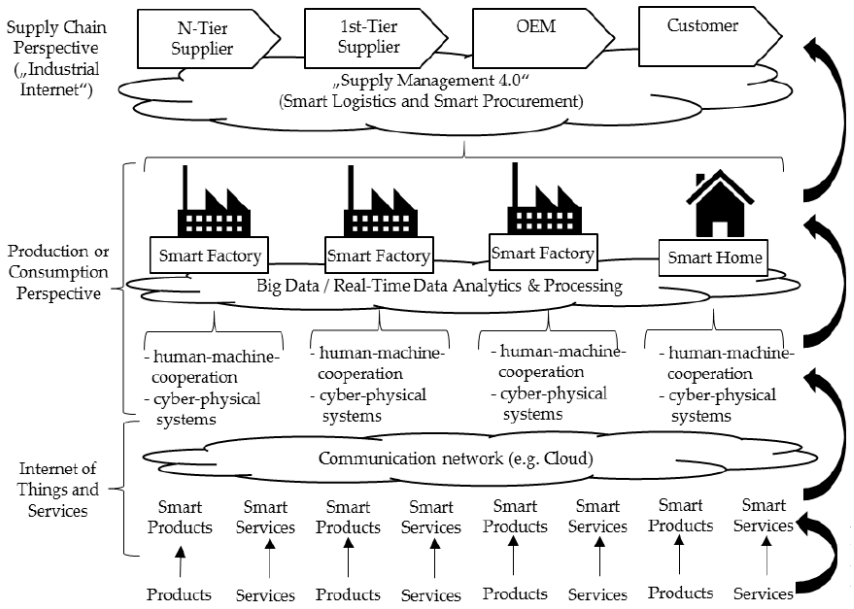

Figure 1. The "Hierarchy" of Industry 4.0 (derived from (Glas & Kleemann, 2016)*.*

Academic community is aware of the importance of Industry 4.0. Industry 4.0 related literature has increased in the last couple of years (Saucedo-Martínez, Pérez-Lara, Marmolejo-Saucedo, Salais-Fierro, & Vasant, 2018). In order to understand the degree of which this literature has dealt with the Supply Chain element, this paper presents the results of a systematic literature review on articles published from 2013 and onwards. The scope of the analysis has been intentionally limited to include only keywords related to Industry 4.0 and Supply Chain; four subject areas; and the three levels of Hierarchy of Industry 4.0 (see figure 1). The aim of the authors is to examine the progress and identify any research gaps with relevance to scholarly outcomes on Industry 4.0 within the framework of the supply chain. The results can be used as a base for future research agenda in related topics.

REVIEW METHODOLOGY

The review of the available literature was conducted through SCOPUS database; Title, Abstract and Keyword was searched by setting the keywords namely, (supply) AND (chain) AND (industry) AND (4.0), and with the restrictions of language (only English) and time of publication (from 2013 and onwards), 118 articles in various subject area categories came up. The distributions of articles based on the country, the year and citations, and the subject area are presented in figures 2, 3 and 4 respectively.

Overall, 11.9% of the total published works were reviews, and 114 of them originated from 47 countries, while 4 of them were not defined. As it can be seen, there has been a rapid increase in the number of publications with a peak on 2018, when 263 articles were published. That shows that Industry 4.0 with regards the supply chain has gotten an increased attention by scholars, something that is compatible with the overall trend on Industry 4.0 publications, which as of 2014 has doubled through the years (Saucedo-Martínez et al., 2018). Moreover, the same authors justify the specific increase due to the "opportunities provided by the emerging technologies applicable to Supply Chain Management" (Saucedo-Martínez J.A. et al., 2018).

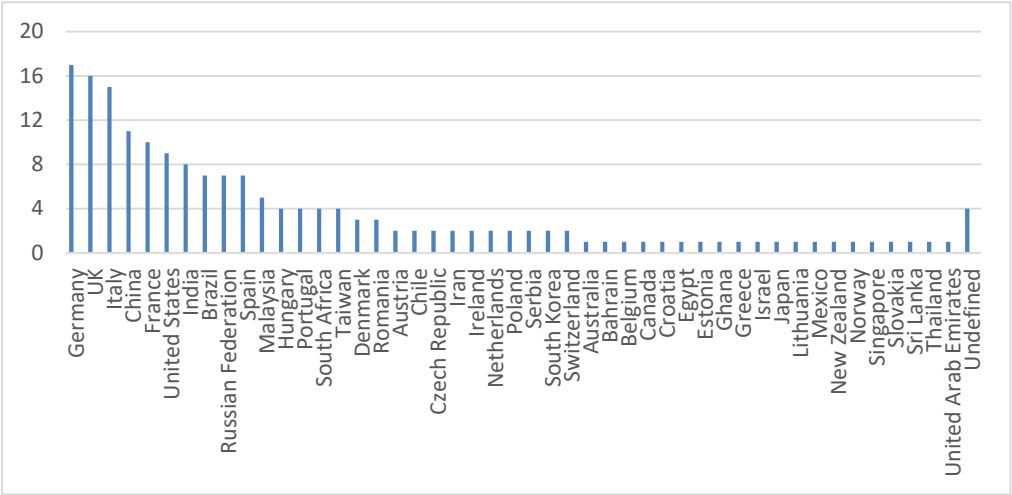

Figure 2. Published articles in different countries

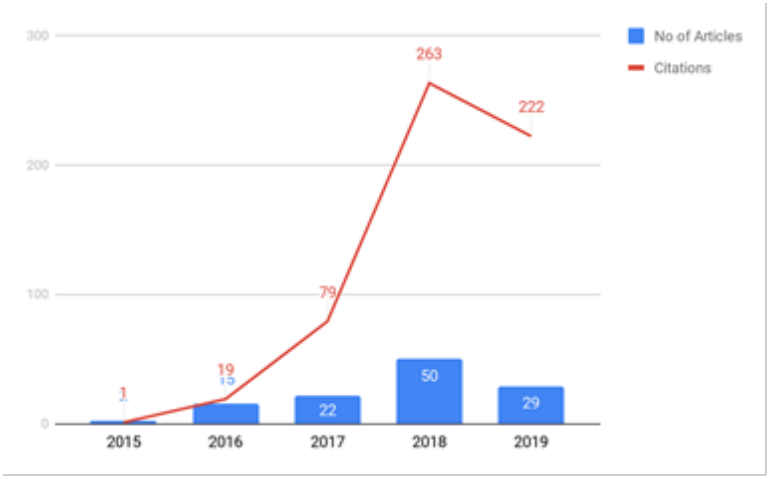

Figure 3. Number of articles and their citations per year

Furthermore, the authors decided to further restrict their search outcomes by selecting the top 4 among the subject areas, namely Engineering, Business, Management and Accounting, Decision Sciences and Computer Science, which counted for the 81.7% of the total publications. The specific areas were chosen due to close relevance with MIS domain. Following the initial screening and having read their titles, abstracts and keywords, the authors found necessary a further restriction that was based on the keywords of the articles (KEY (supply) AND KEY (chain) AND KEY (industry 4.0)), which would ensure that all selected papers are explicitly and specifically dedicated to Industry 4.0 and Supply Chain. Thus, the final selection constitutes of 51 publications.

For the analysis of the publications to take place, two elements were taken into consideration:

a. Subject areas (Scopus classification):

- Engineering,

- Business, Management and Accounting,
- Decision Sciences and
- Computer Science

b. "Hierarchy" of Industry 4.0 (derived from (Glas & Kleemann, 2016)):

- Supply Chain Perspective
- Production or Consumption Perspective
- Internet of Things and Services

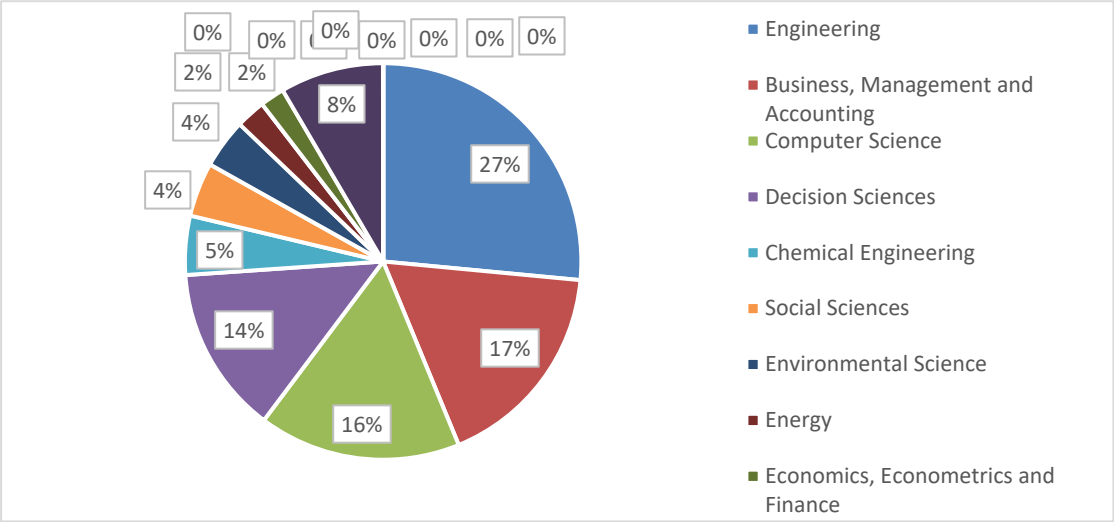

Figure 4. Distribution of articles according to subject area

To be able to classify the articles into the subject area and level of Industry 4.0 they belong to, authors checked the abstracts, keywords and in some cases the full article (see table 1). For the validity of results, all sources were examined by two people.

FINDINGS

As aforementioned, the final selection is consisted of 51 articles. The observations of the authors are the following:

a. Regarding the year of publication: the majority of the articles (42 ones) were published in the last two years (see figure 5), which shows that the interest towards the Industry 4.0 within the supply chain context was recently increased, following the trend of the overall Industry 4.0 related publications (Saucedo-Martínez et al., 2018).

b. Regarding the type of publication: out of the 51 articles, 12 of them were review works (there were 14 review articles in the primary screening with the 118 publications).

c. Regarding the country (articles may have more than one country of origin): on top of the list is Germany with 12 articles, something that should have been expected, as Industry 4.0 was first introduced there. UK and Italy follow with 9 articles, showing that they are the 2 EU countries that after Germany took the lead on the subject. Then, we find the two world-manufacturing centers, USA and China with 7 articles each; France and India follow with 6 articles; Brazil and Russia Federation with 5 articles; and South Africa and Spain with 4 ones.

d. The comprehensive summary of the 51 articles with respect to author, publication year, subject area and Industry 4.0 level is presented in table 1.

e. Regarding to "Hierarchy" of Industry 4.0 (derived from (Glas & Kleemann, 2016)): 55% of the articles covers one level of Industry 4.0, while 29% covers two levels and 16% covers all three levels of Industry 4.0.

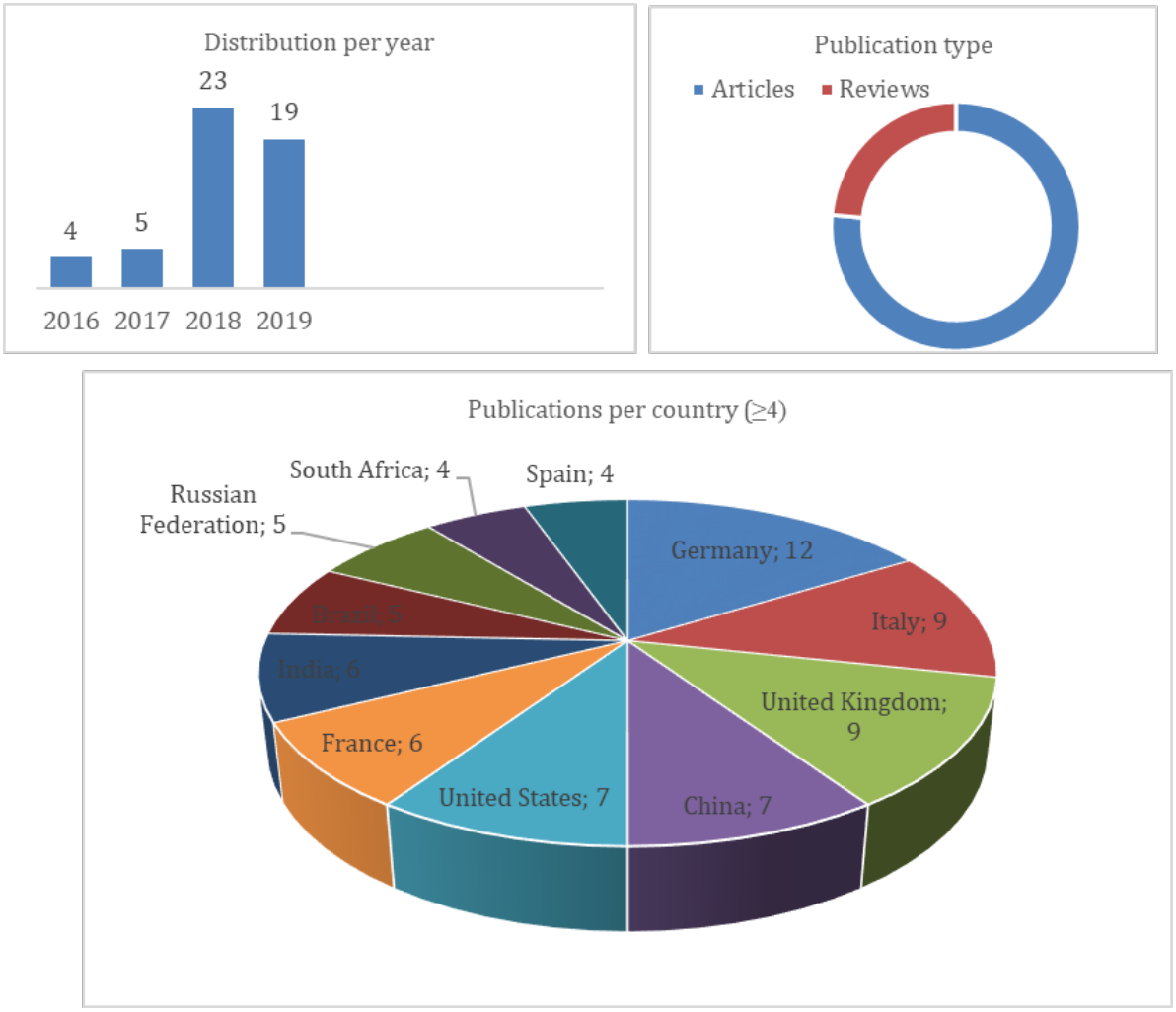

Figure 5. Distribution of articles according to year, type and country.

Table 1. Comprehensive summary of articles with respect to author, publication year, subject area and Industry 4.0 level.

No.	Authors/ Year	Subject Areas				Industry 4.0 Level		
		ENG	CS	BMA	DS	1	2	3
1	Rajput S., Singh S.P./2019		•			•		
2	Galati F., Bigliardi B. /2019	•	•			•	•	•
3	Müller F., *et al.* /2019		•			•	•	•
4	da Silva V.L., *et al.* /2019			•	•	•	•	
5	Nascimento D.L.M., *et al.* /2019	•	•	•			•	
6	Ardito L., *et al.* /2019			•		•	•	•
7	Frank A.G., *et al.* /2019	•		•	•		•	
8	Tortorella G., *et al.* /2019			•			•	
9	Culot G., *et al.* /2019	•		•		•	•	•
10	Ivanov D., *et al.* /2019	•		•	•		•	
11	Dolgui A., *et al.* /2019	•		•	•		•	
12	Ghadimi P., *et al.* /2019	•	•			•		•
13	Panetto H., *et al.* /2019	•	•				•	
14	Manavalan E., Jayakrishna K. /2019	•	•			•		•
15	de la Fuente-Mella H., *et al.* /2019	•	•				•	
16	Sundarakani B., *et al.* /2019			•		•		•
17	Zheng M., *et al.* /2019		•				•	•
18	Rahman N.A.A., *et al*/2019.		•	•	•	•	•	
19	Pirvulescu P., Enevoldsen P. /2019		•	•	•	•	•	
20	Bär K., *et al.* /2018	•					•	
21	Mazzola L., *et al.* /2018		•				•	•
22	Ding B. /2018	•				•	•	
23	Wang B., Ha-Brookshire J.E. /2018	•				•		
24	Dallasega P., et al. /2018	•	•			•		
25	Pasetti Monizza G., et al. /2018	•					•	
26	Telukdarie A., et al. /2018	•					•	
27	Bienhaus F., Haddud A. /2018			•		•		
28	Luthra S., Mangla S.K. /2018	•					•	
29	Lenz J., et al. /2018	•	•				•	
30	Fernández-Caramés T.M., et al. /2018	•						•
31	Gružauskas V., et al. /2018	•		•		•		
32	Byrne G., et al. /2018	•					•	
33	Cruz Introini S., *et al.* /2018				•	•	•	•
34	Xue X., *et al.* /2018		•		•			•
35	Melnyk S.A., *et al.* /2018	•		•	•	•	•	•
36	Ivanov D., *et al.* /2018	•	•				•	
37	Tombido L.L., *et al.* /2018	•				•		
38	Dallasega P. /2018	•		•		•	•	
39	Dolgui A., *et al.* /2018	•					•	
40	Barata J., *et al.* /2018		•	•	•	•	•	•
41	Ante G., *et al.* /2018	•					•	
42	Müller J.M., Voigt K.-I. /2018	•				•	•	
43	Shamim S., *et al.* /2017	•					•	•
44	Haverkort B.R., Zimmermann A. /2017		•				•	•
45	Majeed M.A.A., Rupasinghe T.D. /2017		•	•	•		•	•
46	Tjahjono B., et al. /2017	•	•			•	•	•
47	Dallasega P., *et al.* /2017	•	•				•	
48	Huang Y., *et al.* /2016	•					•	
49	Reddy G.R.K., *et al.* /2016	•					•	
50	Kovács G., Kot S. /2016			•		•	•	
51	Ivanov D., *et al.* /2016	•					•	

Taking into consideration the abovementioned elements, Table 2 provides a summary of the results, which show the following:

The majority of publications (66.6%) have Engineering related subject, while Computer Science, Business, Management and Accounting, and Decision Sciences account for 41.2%, 35.3 % and 21.6% respectively. All three levels of Industry 4.0 are covered within all subject areas, and in several proportions: The Supply Chain Perspective (level 1) has been discussed more from a Business, Management and Accounting framework (66.7%) followed by Computer Science with 61.9%. The Production or Consumption Perspective (level 2) has a 100% presence in Decision Science related articles, and 83.3% in Business, Management and Accounting. The Internet of Things and Services (level 3) is present in 45.5% in Decision Science related articles, and 33.3% in Business, Management and Accounting. Under Engineering subject area, the most popular among the levels is No 2, which accounts for the 24 articles, and is justified since level 2 covers the production (manufacturing) operations. The same goes for the Business, Management and Accounting and Decision Science related subjects. Under Computer Sciences area, there are almost the same number of articles for the first 2 levels, while the Internet of Things and Services stays low with only 4 publications. The latest is a common element for the rest of the subject areas, where level 3 accounts for the less proportion compared to the other two.

Table 2*. Summary of results.*

*	ENG		CS		BMA		DS	
	#	%	#	%	#	%	#	%
Articles: 51	34	66.6	21	41.2	18	35.3	11	21.6
Level 1	15	44	13	61.9	12	66.7	4	36.4
Level 2	24	70.6	12	57.1	15	83.3	11	100
Level 3	10	29.4	4	19	6	33.3	5	45.5

*An article may cover more than one subject area and may discuss more than one level of Industry 4.0 hierarchy.

DISCUSSION AND CONCLUSIONS

This paper has reviewed articles about industry 4.0 within the framework of supply chain from the time when Industry 4.0 was introduced. The aim of the authors was to examine the progress and identify any research gaps with relevance to scholarly outcomes on the topic. The authors utilized a deductive method in order to select the final 51 articles for a more detailed screening, which showed the following observations:

a. The topic is still in its early stages for researchers and more studies can deal with the supply chain in the context of industry 4.0.
b. The majority of the articles focus on the production perspective, while the service and the supply chain as a whole perspectives account less interest;

c. Only (16%) of the publications cover all three levels of Industry 4.0 Hierarchy, an element that can be addressed more in the future.
d. From the findings, we can see that the majority of publications (66.6%) is concentrated on Engineering; authors feel that other subject area need more attention from researchers.

As it can be derived from the aforementioned, researchers can move towards applications of Industry 4.0 within the supply chain context from a more holistic point of view. This refers to both Supply Chain and Industry 4.0 elements.

Moreover, and based on the limitations of the current work regarding the selection of the database and the applied deductive methodology, further and more detailed bibliographical review can occur, taken into consideration a more extended variety of criteria and subject areas.

In summary, this systematic literature review has provided the status of the Industry 4.0 in relation to supply chain through the analysis of academic publications. It has also underlined suggestions for some potential directions based on gaps that were detected.

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