A Bibliometric and Topic Analysis on Future Competences at Smart Factories

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Abstract: The aim of the study is to review the topic of competences that will be present at smart factories. The study used bibliometric and topic analysis to achieve insight into new trends in Industry 4.0. Bibliometric analysis and topic mining was done on 43 peer-reviewed journal articles and conference papers, published before July 2018 in the Thomson Reuters' Web of Science and Scopus databases, using the software tool Statistica Data Miner. Results are segmented into four sections: (1) personnel development in learning organizations, (2) training techniques for personnel, (3) future engineering profiles and engineering education, and (4) relational capabilities. Each section is thoroughly discussed in this paper. The study contributes to the pool of knowledge on Industry 4.0 phenomena by compiling competences needed at smart factories in the future.

1. Introduction

The term Industry 4.0 can be used as a synonym for the fourth industrial revolution. It is based on concepts and technologies that include Cyber-Physical Systems (CPS), Internet of Things (IoT), Internet of Services (IoS), and cognitive computing—technological platforms that employ artificial intelligence [1,2]. Industry 4.0 is creating a need for the transformation of traditional business models into digital business models, as well as the need to connect various technologies and robots, all of which enables mass customization in manufacturing [3,4]. In general, Industry 4.0 is presented as the application of cyber physical systems within industrial production systems [5]. Industry 4.0 has a huge influence on manufacturing, due to its focus on creating a smart environment [6].

In addition to changes in technology and the organization of work, Industry 4.0 has also brought on changes regarding job profiles and competences [7,8]. Technological changes have in turn also had a significant impact on employees and their qualifications [9]. In the future, demand for some jobs is expected to increase, particularly those involving a high level of complexity, which will require a higher level of education to perform; for example, jobs in process and production organizations, such as machine operators, software maintenance, and hardware maintenance. At the same time, this will also lead to a loss of jobs requiring a lower level of education [10,11]. Managers in production organizations will more easily manage the risks that occur during the transition, if they recognize in a timely manner the necessary competences needed for employees at these factories of the future [12].

Based on the emergence of new technologies that are forcing production organizations to increase flexibility, efficiency, and quality [13,14], and the need for new employee structures, qualifications, and competences [15,16]:

RQ 1: What are the core competences needed at smart factories in the future?

The paper consists of the following sections: After the introduction, the second section presents the background of the research on the concept of smart factories and competences. The third section describes the methodology used. The results of the study are presented and discussed in the fourth section, followed by conclusions, limitations, and future research directions.

2. The Concept of Smart Factories

A smart factory is a main feature of Industry 4.0 and is characterized "by a self-organized multi-agent system assisted with big-data-based feedback and coordination" [17]. The concept of a smart factory describes the vision of future manufacturing [18] and a future form of industrial networks [19]. It further represents a next step in the evolution of factories [20], after digital and virtual factories [8]. Lucke et al. [20] defines a smart factory "as a factory that is context-aware and assists people and machines in execution of their tasks". A smart factory can also be defined as a cyber-physical system, where flexible and agile production is implemented. It integrates physical objects, conveyers, and products with information systems. In smart factories, intelligent machines, systems, and products are interlinked, which has consequences for existing structures of production systems, such as an increasingly decentralized organization in factories of the future [21].

In a smart factory, the IoT enables a continuous interaction and exchange of information not only between humans and humans (H2H) or humans and machines (H2M), but also between the machines themselves (M2M) [22,23]. In the process of machine communication, artificial intelligence (also called machine intelligence) is understood as the intelligence displayed by machines, in contrast to the natural intelligence displayed by humans and animals. The term artificial intelligence is used to describe a machine that imitates human cognitive functions, such as learning and problem solving [4]. Smart machines, conveyers, and products communicate and negotiate which each other (M2M) to reconfigure themselves for flexible production of multiple types of products. The industrial network collects massive data from smart objects and transfers them to the cloud. This enables system-wide feedback and coordination of production based on big data analytics to optimize system performance and to achieve high efficiency [23].

With current technology, factories can develop a product virtually by running virtual experiments on digital prototypes. Cyber-physical systems in a smart factory monitor physical processes, make decentralized decisions, and create a virtual copy of the physical world, all within the modular structured smart factories. Over the Internet of Things, cyber-physical systems communicate and cooperate with each other and with humans in real-time, both internally and across organizational services offered, and are as such used by participants of the value chain [4]. Digital manufacturing and design is influencing careers, practices, and processes in companies [3].

Production organizations have not yet reached a level of development desired by smart factories, despite increased interest by researchers and extensive research done on the topic of Industry 4.0. Some of the concepts of Industry 4.0, such as interoperability, are seen in practice when looking at current production systems used in factories [24]. There are many topics that still need to be covered within the field of Industry 4.0, for example, research on human factors—which is the topic of our study—is scarce, especially in regards to competences needed at smart companies.

3. Competences in the Production Sector

The use of technologies in production organizations changes the organization of work and has a significant impact on job qualifications. Industry 4.0 therefore brings, and will continue bringing, changes in production, technology and organization and competences, as well as job profile changes [8].

The study and deployment of competences in today's time is increasingly widespread. It has spread to the point that it no longer represents a specific competitive advantage, but has rather become a fundamental way of operation in organizations. The standard competences that individuals acquire through regular schooling are often not sufficient to successfully manage ongoing internal and external organizational changes, therefore the need to identify, measure, and develop key competences of

employees is of the utmost importance. The concept of competence is widespread and used in many scientific disciplines from management to law [25], resulting in the use of various different definitions of the concept. Boyatizs [26] defines competences as "the characteristics of a person, which are necessary but not sufficient for the efficient and/or superior performance of the work". Roberts [27] defines competence as a set of personality traits, knowledge, experience, skills, and values that we need to successfully perform a job.

Similar to the definition of competences, there is no uniform classification of competences. Thus, several classifications of competences are known. One is the division between the competences of individuals and those of an organization. Torres and colleagues [28] define organizational competences as an organization's ability to realize defined objectives in accordance with the resources and capabilities available. Spencer and Spencer [29] define competences of the individual as the visible and hidden characteristics of the individual, which are reflected in the level of success in specific tasks. The above authors define five characteristics of competences: (1) the motivators of the individual, (2) the specific characteristics of the individual, (3) the individual's self-image, (4) knowledge of the individual (from certain fields), and (5) individual skills (diverse abilities for performing tasks). Competences can be classified into four categories; personal, social, action, and domain-related competences, as suggested by Erpenbeck and Von Rosenstiel [30] and Erol et al. [31]. Personality related competences include the ability of a person to act in an autonomous way, the ability to learn, and the ability to develop for themselves a system of ethical values. Social competences include the ability to communicate, collaborate, and enable individuals to establish and manage relationships with other individuals and groups. Action competences are the capabilities and knowledge of an individual that are important for critical thinking and problem solving. Domain-related competences relate to the ability to use domain knowledge for work including knowledge of methodologies, languages, and tools that are important for successful future work [31]. Hecklau et al. [32] classify competences into four categories, namely technical, methodological, social, and personal competences. Technical competences include skills, such as work-related skills. Methodological competences include knowledge and skills related to successful problem solving and decision making. Social competences include knowledge, abilities, and skills for the communication and cooperation with other individuals and groups. Personal competences include individual values, motivation, and attitudes [31].

4. Methods

For the purpose of the study, a literature review on future competences at smart factories was done, where articles and conference papers published on or before June 2018 were analyzed.

Four databases were searched to gain access to leading publications within Web of Science and Scopus databases. Literature was gathered using the following steps. First, research platforms were used in order to identify appropriate papers. The Boolean keyword combination option was used to find relevant publications TITLE-ABS-KEY (((Industry 4.0) OR (smart AND manufacturing) OR (smart AND factory)) AND ((competences) OR (job AND profile))).

Our study used conferences in addition to scientific articles, because the number of articles published in peer-reviewed journals was low in both Scopus and Web of Science databases. The results of the search were limited only to articles published in peer-reviewed journals and conference proceedings on the topic of employee competences. In addition, the review was limited to scholarly literature written in English, and was therefore not intended to offer a full-scale assessment of the state of the art. The search resulted in 106 articles, of which 64 were published in Scopus and 42 published in Web of Science (WOS).

A careful review of abstracts and full text was performed. Based on our exclusion criteria of choosing only articles that dealt with employee competences, 43 out of the 106 articles were selected. Firstly, the bibliometric analysis was conducted. Secondly, the data mining was conducted using Statistica Data Miner. Thirdly, the retrieved papers were analysed according to the clusters identified

by the topic mining and analysed with the method of content analysis. We used the method of content analysis to gain new knowledge based on secondary data.

5. Results and Discussion

This literature review presents insight into employee competences at smart factories and targeted 43 articles and conference papers published on or before June 2018 published in Scopus and Web of Science databases.

5.1. Bibliometric Analysis

The first contributions on competences at smart factories were detected in the year 2012. The number of contributions has been increasing dramatically since 2015. There are also some contributions that will be published in the following year (see Figure 1).
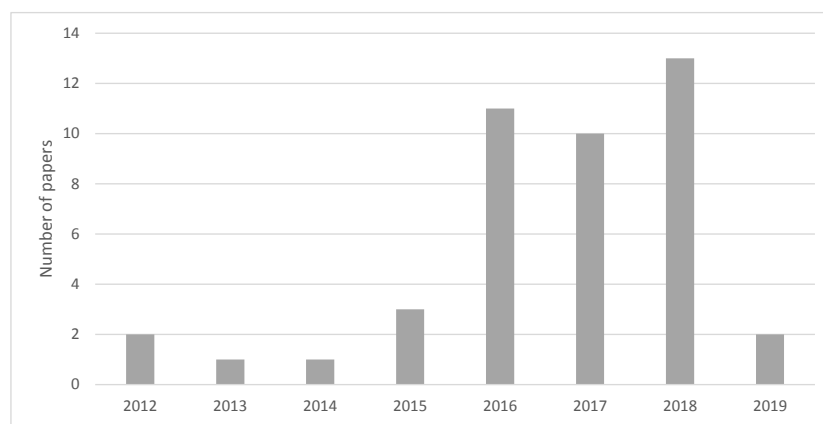

Figure 1. Year of publication.

Most of the papers regarding competences were published in journals and proceedings. The following journals and proceedings published at least three contributions: Advances in Intelligent Systems and Computing (4), Procedia CIRP (4), ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb (4), Procedia Manufacturing (4), and International Journal of Fashion Design, Technology and Education (3) (Table 1).

Table 1. Conferences and journals publishing papers in the area of future competences at a smart factory.

Conference	#	Journals	#
Proceedings of AICS	4	ZWF	4
Procedia CIRP	4	International Journal of Fashion Design, Technology and Education	3
Procedia Manufacturing	4	Benchmarking: An International Journal	1
Proceedings of the 10th ICERI	1	COMPUT IND ENG	1
ACM International Conference Proceeding Series	1	Economy of Region	1
8th IFKAD 2013	1	EKSPLOAT NIEZAWODN	1
IOP Conference Series: Earth and Environmental Science	1	INDECS	1
Lecture Notes in Mechanical Engineering	1	International Journal of Quality and Service Sciences	1
Proceedings of METAL 2016	1	International Journal of Technology Management	1
Procedia Computer Science	1	Journal of Organisational Transformation and Social Change	1
Procedia Engineering	1	Kasetsart Journal of Social Sciences	1
Procedia Social and Behavioral Sciences	1	The Learning Organization	1
Proceedings 2015 IEEE	1		
Proceedings of the 13th ECMLG	1		
Proceedings of the 14th ICICKM	1		
Proceedings of the 30th IBIMA 2017	1		
Proceedings of the 45th SEFI	1		

5.2. Topic Mining

In order to detect the most frequent topics found in abstracts, we used the phrase extraction process and cluster analysis functions provided by the Wordstat Provalis software. Table 2 presents the following most frequently used phrases (frequency of occurrence ≥ 4). Listed from most frequently used to least frequently used, these phrases include industrial revolution, knowledge management, smart factory, business models, engineering education, facility management, relational capabilities, big data analytics, cyber physical systems, and digital competency.

Column Frequency-Inverse Document Frequency (TF-IDF) shows the importance of each phrase within the collection of papers. A phrase that has higher TF-IDF values is of higher importance. Phrases that are most important in the whole collection of papers are facility management (TF-IDF value 9.7), relational capabilities (9.7), learning cultures (8.1), and personnel development (8.1).

Table 2. Most frequent phrases in papers related to future competences at a smart factory (frequency 4+).

Extracted Phrases	Frequency	No. of Cases	% Case	Length	TF ● IDF
industrial revolution	8	7	16.67%	2	6.2
knowledge management	8	5	11.90%	2	7.4
smart factory	7	4	9.52%	2	7.1
business models	6	5	11.90%	2	5.5
engineering education	6	3	7.14%	2	6.9
facility management	6	1	2.38%	2	9.7
relational capabilities	6	1	2.38%	2	9.7
big data analytics	5	2	4.76%	3	6.6
cyber physical systems	5	4	9.52%	3	5.1
digital competency	5	3	7.14%	2	5.7
learning cultures	5	1	2.38%	2	8.1
manufacturing industry	5	5	11.90%	2	4.6
personnel development	5	1	2.38%	2	8.1
augmented reality	4	3	7.14%	2	4.6
human resource	4	2	4.76%	2	5.3
internet of things	4	3	7.14%	3	4.6
level of digital	4	2	4.76%	3	5.3
managerial education	4	1	2.38%	2	6.5
manufacturing companies	4	4	9.52%	2	4.1
manufacturing enterprises	4	2	4.76%	2	5.3
physical objects	4	2	4.76%	2	5.3

The cluster analysis identified five topics regarding future competences at smart factories (see Figures 2 and 3):

- Cluster 1 includes abstracts with the co-occurring phrases: augmented reality, cyber physical systems, internet of things, and physical objects.
- Cluster 2 includes abstracts with the co-occurring phrases: engineering education and industrial revolution.
- Cluster 3 includes abstracts with the co-occurring phrases: human resources and knowledge management.

- Cluster 4 includes abstracts with the co-occurring phrases: big data analytics, manufacturing industry, business models, and relational capabilities.
- Cluster 5 includes abstracts with the co-occurring phrases: learning cultures, personnel development, manufacturing companies, and smart factory.
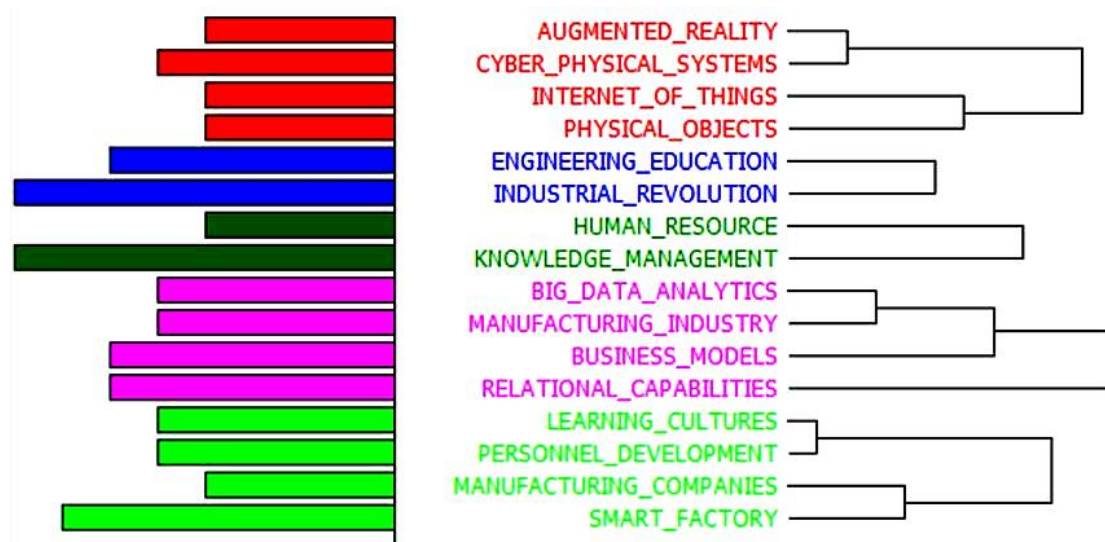

Figure 2. Cluster analysis of phrases related to future competences at a smart factory.
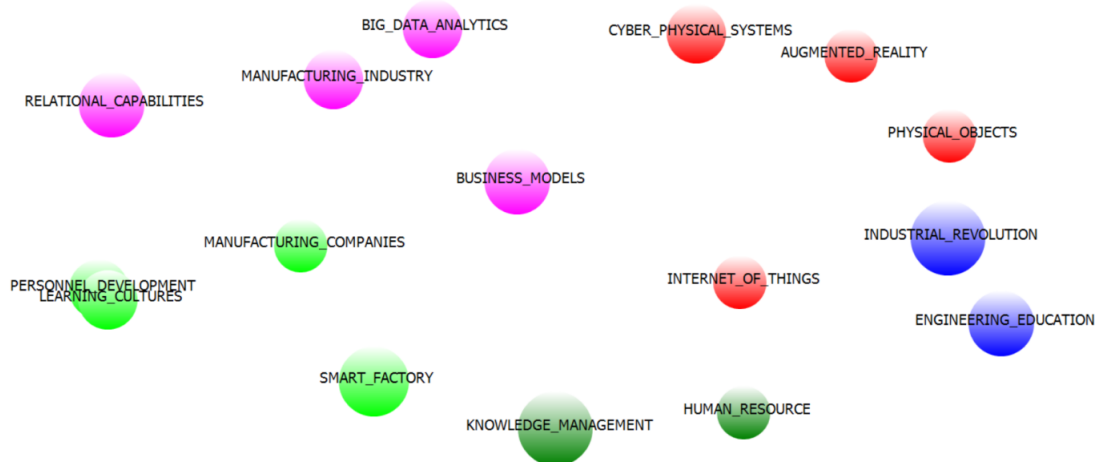

Figure 3. Mapping of clusters.

We did additional analysis due to the reason that the dendrogram determines only the temporal order of the branching sequence, i.e., the connections between phrases. We used proximity plots in order to detect phrases that tend to frequently appear near specific phrases, i.e., industrial revolution, knowledge management, business models, and manufacturing industry. The phrases that occur most often with the phrase industrial revolution are business models, cyber-physical systems, engineering education, Internet of things, knowledge management, and physical object. The phrases that occur most often with the phrase knowledge management are human resources, industrial revolution, Internet of things, and smart factory. The phrases that occur most often with the phrase business models are big data analytics, industrial revolution, Internet of things, manufacturing companies, manufacturing industry, and smart factory. The phrase manufacturing industry occurs the most often with the phrases big data analytics, business models, cyber-physical systems, human resources, manufacturing companies, and relational capabilities.

Results that indicate which phrases co-occurred most often within each of the clusters are presented in Figure 4.
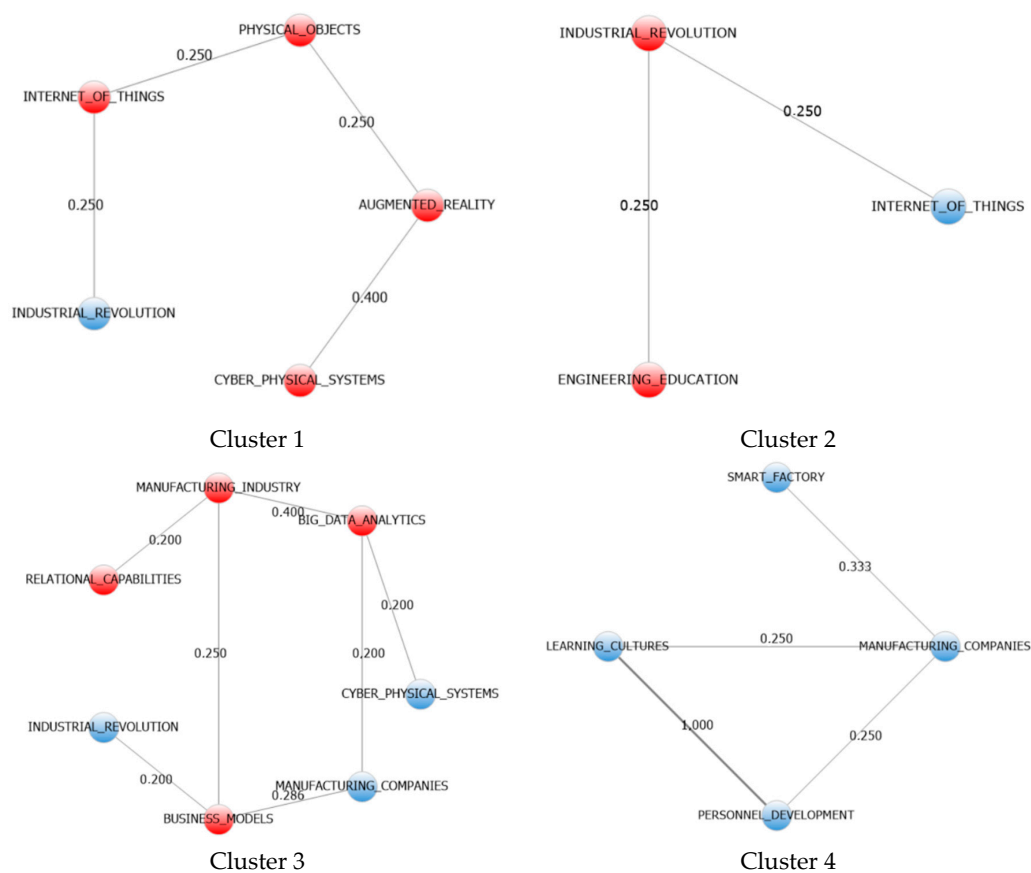

Figure 4. Proximity plots of phrases in clusters.

Analysis retrieved four main topics, i.e., (1) personnel development in learning organizations [32–38], (2) training techniques for personnel [39–41], (3) future engineering profile and engineering education [42–44], and (4) relational capabilities [45–47]. Although the total number of papers was 44, the cluster algorithm included 7 papers in Cluster 1 and 3 papers for the remaining clusters, since the topics of other papers were highly specific, and could not be assigned to any of the developed clusters. The retrieved papers were analysed according to the clusters identified by the topic mining.

Figure 5 shows the distribution of papers across clusters over time. In 2012, papers were only written on the topic of personnel training techniques (Cluster 2). In 2013, the topics of future engineering profiles and engineering education were added to Cluster 2. In 2015, papers were written on topics found in Cluster 1 (personnel development in learning organizations) and Cluster 4 (relational capabilities). From the year 2016 to 2018 the topics covered almost all of the clusters, with the exception of Cluster 2 (training techniques of personnel) in 2017. For 2019, papers on the topic of relational capabilities are expected for publication (Cluster 4).
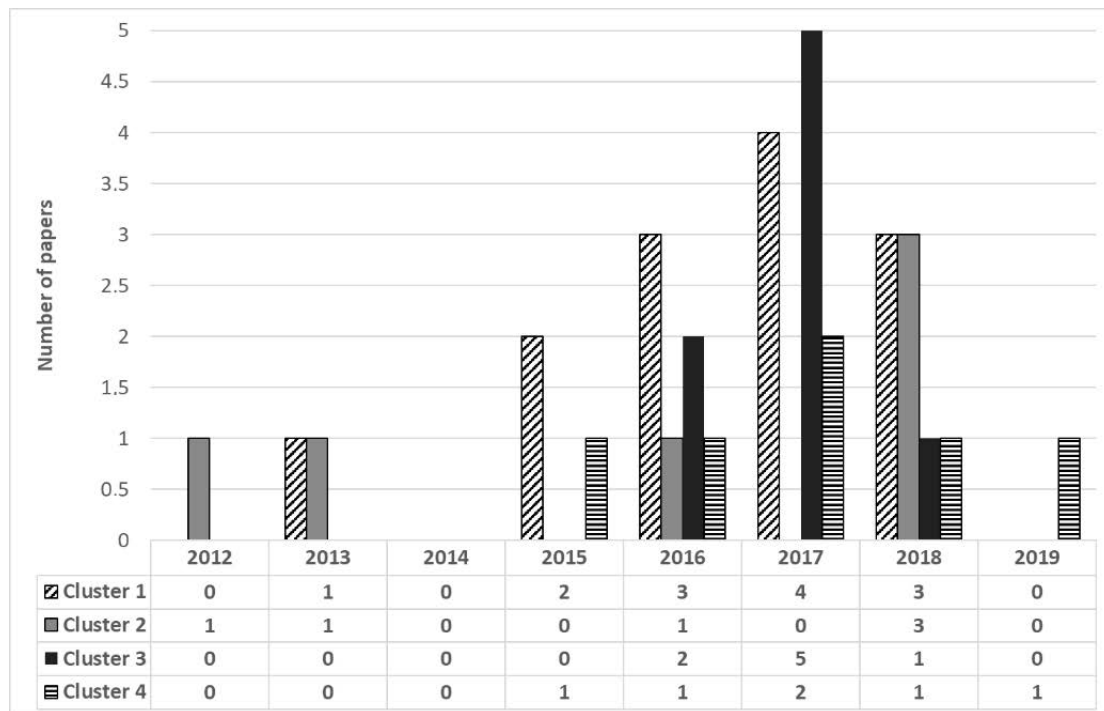
Figure 5. Distribution of papers across clusters over time.

	2012	2013	2014	2015	2016	2017	2018	2019
Cluster 1	0	1	0	2	3	4	3	0
Cluster 2	1	1	0	0	1	0	3	0
Cluster 3	0	0	0	0	2	5	1	0
Cluster 4	0	0	0	1	1	2	1	1

5.3. Content Analysis

Authors Pecina and Sladek [48] found that one of the key issues to be considered within Industry 4.0 and smart factories is the analysis of workers' competences. Similarly, Imran and Kantola [49] consider it crucial to determine the competences for new job profiles at factories. So far, the technical aspect of development has been discussed in the subject of Industry 4.0 as well as smart factories. The aspect of so called "soft factors" is neglected in the field of scientific research but is increasingly dealt with in reports by leading consultants like McKinsey, Deloitte, Accenture, and the Boston Consulting Group [50]. For this reason, the main purpose of this study is to review the topic of future competences at smart factories.

For the content analysis, we used 43 articles that dealt with employee competences. By conducting cluster analysis, we have identified 4 clusters:

- Cluster 1, which includes papers on the topic personnel development,
- Cluster 2, which includes papers about training techniques for personnel,
- Cluster 3, which includes papers about future engineering profile, and
- Cluster 4, which includes papers about relational capabilities.

Most of the papers dealing with personnel development (Cluster 1) are quite new (written after 2015) and are about lifelong learning and future employee competences. Since the focus of the study was on the future competences, we present them in Table 3 and in the discussion below it.

Analysis of selected papers showed that there are three papers focused on personnel training techniques (Cluster 2). Papers that are presented have been written within a period of two years, which includes training to gather digital knowledge [39,41] and training updated with techniques and ideas coming from the industry world [40].

There are three papers focused on future engineering profile and engineering education (Cluster 3). A review of the empirical results of the studies were discussed by Richert et al. [44], which was carried out to investigate the competences needed for the engineering job profile, for example, virtual collaboration between human and robot. Boronina et al. [42] identified the contradictions and problems in formation and development of professional potential for future engineers. The results of their study showed that there is a gap between the desired and available competences.

Table 3. The classification of competences.

Technical Competences	Methodological Competences	Social Competences	Personal Competences
understanding IT security	creativity	seeing the big picture (overview competence, integration competence)	commitment to lifelong learning
coding capabilities	problem solving	the ability to lead	personal flexibility
understanding of processes	creative problem-solving competence	the ability to communicate effectively in complex situations	motivation for learning
technical capabilities	conflict resolution	network competence	adaptability
understanding the analogies of the operation of new technologies	the ability to act as mediators in decision-making processes	the ability to participate and work in a team	ability to work in stressful situations
the ability to solve complex challenges	analytical skills	language skills	social responsibility
	research skills	the ability to transfer knowledge to others	the successful determination of the dividing line between important and less important information

We have identified three papers that are focused on relational capabilities, identifying relational capabilities, which are used for new knowledge identification and access. These are: "frequent meetings with customers; frequent meetings with suppliers; dialogue with government to influence policy that encourages research and technology transfer; partnership actions for the commercialization of products and services; active membership with sector associations; immersion in science and technological parks; intentionally establishing links with entrepreneurship-supporting entities; human resources development by technical training institutions; and systematic links with the universities" [46]. For the future manufacturing, "interdisciplinary competences from engineering, information technology, and computer science are required" [47].

In the literature, there are several ways to classify competences. After carefully reviewing the full texts of articles, we determined that the classifications of competences are linked to a specific type of competences. For example, Kinkel et al. [34] classified competences into four clusters: network competence, creative problem-solving competence, overview competence, and integration competence, but the classification is used for innovation competences. Nyikes [39] classified competences into ethical, cognitive, and technological competences, but this classification is used for digital competences. In our research, we used the classification of competences by Hecklau et al. [32], because, in our judgment, it is a general classification of competences, and competences of the individual (employee) can be best classified by this classification. This is similar to the classification of competences by Erpenbeck and Von Rosenstiel [31] and Janjua et al. [51]. Highlighted similarities are that all of them classify competences into personal and competences and define them equally. For rested classes, Erpenbeck and Von Rosenstiel [31] mention action and domain-related competences, Janjua et al. [51] functional, generic management, and cognitive skills, and Hecklau et al. [32] technical and methodological competences. Domain-related competences are related to methodological competences and functional competences, while methodological competences also include competences from the list of action competences and cognitive skills. Generic management competences are more common for management-related jobs, while Hecklau et al. [32] also included technical competences, which are essential for jobs in smart factories.

Table 3 shows classification of future competences of Cluster 1 articles' content analysis [32–38]. Under technical competences of the future, we list IT security, coding capabilities, understanding of processes, technical capabilities, understanding the analogies of the operation of new technologies, and the ability to solve complex challenges. In regards to methodological competences, we list creativity, problem solving, conflict resolution, analytical skills, and research skills. Under social competences, we include seeing the big picture, the ability to lead, the ability to communicate effectively, network competence, the ability to work in a team, language skills, and the ability to transfer knowledge to others. Finally, for personal competences, we include commitment to lifelong learning, personal flexibility, motivation for learning, adaptability, ability to work in stressful situations,

social responsibility, and the successful determination of the dividing line between important and less important information.

6. Conclusions

In this paper, we focus on future competences at smart factories. We conducted bibliometric analysis and data mining using Statistica Data Miner analysis. Using cluster analysis, we segmented peer-reviewed journal articles and conference papers, published in Web of Science and Scopus databases, into four sections: (1) personnel development in learning organizations, (2) training techniques for personnel, (3) future engineering profiles and engineering education, and (4) relational capabilities. We have made an in-depth look for Cluster 1, specifically future competences and classified them into four categories, as suggested by Hecklau et al. [32], i.e., technical competences, methodological competences, social competences, and personal competences. We found out that future competences are, for example, the ability to solve complex challenges, creative problem-solving, seeing the big picture, and commitment to lifelong learning.

Our findings provide practical implications for managers concerned with human resource management activities. The key theoretical contributions are to be found in the list of future competences that are under-researched, especially in the field of smart manufacturing. Therefore, the identification of those is an important theoretical contribution of this study.

While we believe our study has an important contribution, it has some limitations. The main limitation is that we only looked at articles from the databases of Web of Science and Scopus. The searching was limited only to peer-reviewed literature written in English.

Future studies on competences at smart factories should look at other databases and literature in other languages in order to determine which articles were potentially missed by our study. Job profiles and required competences will change in many jobs. This means that in the future research, measures for transformation and adaptation in the field of education and development of employees will be important.

References

1. Möller, D.P. Digital manufacturing/Industry 4.0. In *Guide to Computing Fundamentals in Cyber-Physical Systems*, 1st ed.; Möller, D.P., Ed.; Springer: Cham, Switzerland, 2016; pp. 307–375, ISBN 978-3-319-25178-3.
2. Roblek, V.; Meško, M.; Krapež, A. A complex view of Industry 4.0. *SAGE Open* **2016**, *6*, 1–11. [CrossRef]
3. Crnjac, M.; Veža, I.; Banduka, N. From concept to the introduction of Industry 4.0. *Int. J. Eng. Manag.* **2017**, *8*, 21–30.
4. Flynn, J.; Dance, S.; Schaefer, D. Industry 4.0 and its potential impact on employment demographics in the UK. *Adv. Transdiscipl. Eng.* **2017**, *6*, 239–244. [CrossRef]
5. Posada, J.; Toro, C.; Barandiaran, I.; Oyarzun, D.; Stricker, D.; De Amicis, R.; Vallarino, I. Visual computing as a key enabling technology for Industrie 4.0 and industrial internet. *IEEE Comput. Graph. Appl.* **2015**, *35*, 26–40. [CrossRef] [PubMed]
6. Mabkhot, M.M.; Al-Ahmari, A.M.; Salah, B.; Alkhalefah, H. Requirements of the Smart Factory System: A Survey and Perspective. *Machines* **2018**, *6*, 23. [CrossRef]
7. Dombrowski, U.; Wagner, T. Mental strain as field of action in the 4th industrial revolution. *Procedia CIRP* **2014**, *17*, 100–105. [CrossRef]
8. Morlock, F.; Wienbruch, T.; Leineweber, S.; Kreimeier, D.; Kuhlenkoetter, B. Industry transformation of manufacturing companies—Maturity based migration to cyber-physical-manufacturing system. *ZWF Z. Wirtsch. Fabr.* **2016**, *111*, 306–309. [CrossRef]

9. Herzog, S.; Sanders, A.; Redlich, T.; Wulfsberg, J. Mitarbeiterqualifikation in der Smart Factory: Ansatzpunkte zum Qualifizierungsbedarf der Mitarbeiter ausgehend von neuartigen Geschäftsmodellen einer Smart Factory. *ZWF Z. Wirtsch. Fabr.* **2016**, *111*, 653–657. (In German) [CrossRef]

10. Achenhagen, C.; Zeller, B. Zukünftige Qualifikationsanforderungen im "Internet der Dinge" in der Industriellen Produktion. 2011. Available online: http://www.frequenz.net/uploads/tx_freqprojerg/Summary_indProd_final.pdf (accessed on 6 May 2018).

11. Hecklau, F.; Galeitzke, M.; Flachs, S.; Kohl, H. Holistic approach for human resource management in Industry 4.0. *Procedia CIRP* **2016**, *54*, 1–6. [CrossRef]

12. Kremer, D. Prozess-szenarien für Die Industrie 4.0. 2014. Available online: https://www.iao.fraunhofer.de/images/iao-news/iao-news_oktober_2014.pdf (accessed on 13 May 2018).

13. Zhang, J.; Yao, X.; Zhou, J.; Jiang, J.; Chen, X. Self-organizing manufacturing: Current status and prospect for Industry 4.0. In Proceedings of the 2017 5th International Conference on Entrerprise Systems: Industrial Digitalization by Entrerprise Systems, Barcelona, Spain, 14–15 October 2017.

14. Bertoncel, T.; Erenda, I.; Meško, M. Managerial Early Warning system as best Practice for Project Selection at a Smart Factory. *Amfiteatru Econ.* **2018**, *20*, 805–819. [CrossRef]

15. Kane, G.C.; Palmer, D.; Phillips, A.N.; Kiron, D. Is your business ready for a digital future? *MIT Sloan Manag. Rev.* **2015**, *56*, 37–44.

16. Macurova, P.; Ludvik, L.; Žwakova, M. The driving factors, risks and barriers of the Industry 4.0 concept. *J. Appl. Econ. Sci.* **2017**, *12*, 2003–2011.

17. Wang, S.; Wan, J.; Li, D.; Zhang, C. Implementing smart factory of Industry 4.0: An outlook. *Int. J. Distrib. Sens. Netw.* **2016**, *12*, 3159805. [CrossRef]

18. Radziwon, A.; Bilberg, A.; Bogers, M.; Madsen, E.S. The smart factory: Exploring adaptive and flexible manufacturing solutions. *Procedia Eng.* **2014**, *69*, 1184–1190. [CrossRef]

19. Ivanov, D.; Dolgui, A.; Sokolov, B.; Werner, F.; Ivanova, M. A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory Industry 4.0. *Int. J. Prod. Res.* **2016**, *54*, 386–402. [CrossRef]

20. Lucke, D.; Constantinescu, C.; Westkämper, E. Smart factory-a step towards the next generation of manufacturing. In Proceedings of the 41st CIRP Conference on Manufacturing Systems, Tokyo, Japan, 26–28 May 2008; Springer: London, UK, 2008; pp. 115–118.

21. Yoon, J.S.; Shin, S.J.; Suh, S.H. A conceptual framework for the ubiquitous factory. *Int. J. Prod. Res.* **2012**, *50*, 2174–2189. [CrossRef]

22. Ghobakhloo, M. The future of manufacturing industry: A strategic roadmap toward Industry 4.0. *J. Manuf. Technol. Manag.* **2018**, *29*, 910–936. [CrossRef]

23. Yao, X.; Zhou, J.; Zhang, J.; Boër, C.R. From intelligent manufacturing to smart manufacturing for Industry 4.0 driven by next generation artificial intelligence and further on. In Proceedings of the 2017 5th International Conference on Enterprise Systems (ES), Beijing, China, 22–24 September 2017; pp. 311–318.

24. Gruber, F.E. Industry 4.0: A best practice project of the automotive industry. In *Digital Product and Process Development Systems*; Kovács, G.L., Kochan, D., Eds.; Springer: Berlin/Heidelberg, Germany, 2013; pp. 36–40, ISBN 978-3-642-41329-2.

25. Mulder, M.; Gulikers, J.; Biemans, H.; Wesselink, R. The new competence concept in higher education: Error or enrichment? *J. Eur. Ind. Train.* **2009**, *33*, 755–770. [CrossRef]

26. Boyatizs, R.E. *The Competent Manager: A Model for Effective Performance*; John Wiley and Sons: New York, NY, USA, 1982.

27. Roberts, G. *Recruitment and Selection: A Competency Approach*; Chartered Institute of Personnel and Development: London, UK, 1997.

28. Torres, M.V.T.; Cardelle-Elawar, M.; Mena, M.J.B.; Sanchez, A.M.M. Social background, gender and self-reported social competence in 11- and 12-year-old Andalusian children. *Electron. J. Res. Educ. Psychol.* **2003**, *1*, 38–56.

29. Spencer, L.M.; Spencer, S.M. *Competence at Work: Models for Superior Performance*; Wiley: New York, NY, USA, 1993; ISSN 978-0471548096.

30. Erpenbeck, J.; Von Rosenstiel, L. Handbuch Kompetenzmessung: Erkennen, verstehen und bewerten von Kompetenzen in der betrieblichen, pädagogischen und psychologischen Praxis. In *Research Challenges of Industry 4.0 for Quality Management*; Foidl, H., Felderer, M., Eds.; Schäffer-Poeschel: Stuttgart, Germany, 2016; pp. 121–137. (In German)

31. Erol, S.; Jäger, A.; Hold, P.; Ott, K.; Sihn, W. Tangible Industry 4.0: A scenario-based approach to learning for the future of production. *Procedia CIRP* **2016**, *54*, 13–18. [CrossRef]

32. Hecklau, F.; Orth, R.; Kidschun, F.; Kohl, H. Human resources management: Meta-study-analysis of future competences in Industry 4.0. In Proceedings of the 13th European Conference on Management, Leadership and Governance: ECMLG 2017, Utrecht, The Netherlands, 18–19 October 2017; Academic Conferences and Publishing Limited: Utrecht, The Netherlands, 2017; p. 163.

33. Plumanns, L.; Printz, S.; Vossen, R.; Jeschke, S. Strategic management of personnel development in the Industry 4.0. In Proceedings of the 14th International Conference on Intellectual Capital and Knowledge Management and Organisational Learning, Honk Kong, China, 7–8 December 2017; Academic Conferences International Limited: Oxfordshire, UK, 2017; pp. 179–186.

34. Kinkel, S.; Schemmann, B.; Lichtner, R. Critical competencies for the innovativeness of value creation champions: Identifying challenges and work-integrated solutions. *Procedia Manuf.* **2017**, *9*, 323–330. [CrossRef]

35. Prinz, C.; Morlock, F.; Freith, S.; Kreggenfeld, N.; Kreimeier, D.; Kuhlenkötter, B. Learning factory modules for smart factories in Industrie 4.0. *Procedia CIRP* **2016**, *54*, 113–118. [CrossRef]

36. Noehring, F.; Woestmann, R.; Wienzek, T.; Deuse, J. Socio-technical capability assessment to support implementation of cyber-physical production systems in line with people and organization. In Proceedings of the International Conference on Applied Human Factors and Ergonomics, Orlando, FL, USA, 21–25 July 2018; Springer: Cham, Switzerland, 2018; pp. 299–311.

37. Straub, N.; Kaczmarek, S.; Hegmanns, T.; May, D.; Haertel, T.; Möllmann, A.; Zaremba, B. Kompetenzmodell für die operative Logistik in der Arbeitswelt 4.0. *ZWF Zeitschrift Wirtschaftlichen Fabrikbetrieb* **2016**, *111*, 645–649. (In German) [CrossRef]

38. Gitelman, L.; Kozhevnikov, M. Paradigm of managerial education for a technological breakthrough in the economy. *Econ. Reg.* **2018**, *1*, 433–449. [CrossRef]

39. Nyikes, Z. Contemporary digital competency review. *INDECS* **2018**, *16*, 124–131. [CrossRef]

40. Queiruga-Dios, A.; Bullón Pérez, J.; Hernández Encinas, A.; Martín Del Rey, A.; Martín-Vaquero, J. Case study: Engineering education, Industry 4.0, security, and competencies-based assessment. In Proceedings of the 45th SEFI Annual Conference 2017—Education Excellence for Sustainability, Azores, Portugal, 18–21 September 2017; SEFI: Brussels, Belgium, 2017; pp. 1410–1416, ISBN 978-989-98875-7-2.

41. Sangmeister, J.; Winther, E.; Deutscher, V.; Bley, S.; Kreuzer, C.; Weber, S. Designing competence assessment in VET for a digital future. In *Digital Workplace Learning*; Springer: Cham, Switzerland, 2018; pp. 65–92, ISBN 978-3-319-46215-8.

42. Boronina, L.N.; Baliasov, A.A.; Sholina, I.I. Professional potential of future engineers in Russia's old-industrial region: Institutional challenges and risks. In Proceedings of the 10th International Conference of Education, Research and Innovation, Seville, Spain, 16–18 November 2017; pp. 4827–4836.

43. Guidelines Support Companies during Formation of Industry-4.0-Competencies in the Workforce. Available online: https://www.plattform-i40.de/I40/Redaktion/DE/Downloads/Publikation/i40-gestalten.pdf?__blob=publicationFile&v=4 (accessed on 20 July 2018). (In German)

44. Richert, A.; Shehadeh, M.; Plumanns, L.; Groß, K.; Schuster, K.; Jeschke, S. Educating engineers for Industry 4.0: Virtual worlds and human-robot-teams: Empirical studies towards a new educational age. In Proceedings of the Global Engineering Education Conference (EDUCON), Abu Dhabi, United Arab Emirates, 10–13 April 2016; pp. 142–149.

45. Longo, F.; Nicoletti, L.; Padovano, A. Smart operators in Industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. *Comput. Ind. Eng.* **2017**, *113*, 144–159. [CrossRef]

46. Martins, J.T. Relational capabilities to leverage new knowledge: Managing directors' perceptions in UK and Portugal old industrial regions. *Learn. Organ.* **2016**, *23*, 398–414. [CrossRef]

47. Quint, F.; Sebastian, K.; Gorecky, D. A mixed-reality learning environment. *Procedia Comput. Sci.* **2015**, *75*, 43–48. [CrossRef]

48. Pecina, P.; Sladek, P. Fourth industrial revolution and technical education. In Proceedings of the 11th International Conference on Technology, Education and Development (INTED), Valencia, Spain, 6–8 March 2017; pp. 2089–2093.

49. Imran, F.; Kantola, J. Review of Industry 4.0 in the Light of Sociotechnical System Theory and Competence-Based View: A Future Research Agenda for the Evolute Approach. In Proceedings of the International Conference on Applied Human Factors and Ergonomics, Orlando, FL, USA, 21–25 July 2018; Springer: Heidelberg, Germany, 2018; pp. 118–128.
50. Vacek, J. Socio-economic aspects of Industry 4.0. In *Innovation Management, Entrepreneurship and Corporate Sustainability (IMECS 2016)*; Vysoká škola ekonomická v Praze: Praha, Czechia, 2016; pp. 731–741.
51. Janjua, S.Y.; Naeem, M.A.; Kayani, F.N. The competence classification framework a classification model for employee development. *Interdiscip. J. Contemp. Res. Bus.* **2012**, *4*, 396–404.