Emerald Benchmarking: an International Journal

Industry 4.0: Reopening the Research Agenda

Journal:	*Benchmarking: an International Journal*
Manuscript ID	Draft
Manuscript Type:	Original Article
Keywords:	Industry 4.0, smart factory, meta-analysis, real-time factory, digital factory

1. Introduction

Industry 4.0, the so-called smart factory or the real-time factory are concepts related to new trends in manufacturing disciplines. In the present time, managers work on the implementation of automatized industrial processes to increase productivity and different associations are created in order to develop new platforms for industrial technological advances. Even sustainability requirements and circular economy are relevant reasons for joining industry 4.0. Factories of the future are focused on more intelligent, flexible, sustainable and dynamic production through the application of sensors and autonomous systems. Additionally, countries and regions are creating their own plans to support the industrial strategies connected with the automation: the "High-Tech Strategy 2020 Action Plan" of the German government, the "Industrial Internet" from USA, or the "Internet +" of China are illustrations of these initiatives.

From an academic perspective, recent research has focused on the impact of automation in labor markets, industry and employment (David, 2015; Espí-Beltrán et al, 2017; Frey, and Osborne, 2017; Leitão et al, 2015; or Dorn and Hanson, 2015).

Nevertheless, Industry 4.0 is not a new issue. Mark Weiser coined the term *ubiquitous computing* referring to a vision of the smart environment in 1991. This approach is transferred to manufacturing issues. Furthermore, the recommendations of the German government to increase German companies´ productivity date from 2005. Also, in 2005, a non-profit association was established to develop the Industry 4.0 framework. It was named "Technology Initiative SmartFactory". Furthermore, the principal ideas of Industry 4.0 were first published by Kagermann in 2011.

Despite these experiences, future work on Industry 4.0 is required. The smart factory will face global challenges, and automation represents the most important goal of factories for the next decades. With the existing technologies, most applications are available, but they should be implemented in a progressive way in real companies.

Industry 4.0 is perceived as the new competitive advantage of a nation. In 1998, Porter described the elements that made a region competitive, and suggested a model to develop successful clusters in a territory. In the present, automation of processes increases the productivity of a company, reduces energy requirements and helps a company to respond to a growing demand for customer-specific products. In conclusion, smart factories could be seen as the future competitive advantage of a region. Faller and Feldmüller (2015) described the initiative of a region around small cities (Velbert and Heiilgenhaus) to support knowledge to develop those skills related to demanding technologies of Industry 4.0. This idea supports the relevance of studying the automation of industries, and signaling future fields for the research in this area. The analysis will be focused on the relationship between management and Industry 4.0, and, consequently, technological research will be omitted.

In this context, an updated review of previous research is presented and a new research agenda is proposed. These are the principal contributions of this research paper that focuses on helping future academics in the study of this issue.

This paper is organized as follows. Section 2 shows the methodology followed in the review. Theoretical research focuses on operational issues, decision-making questions, case-study papers, human resources challenges and management goals are presented in section 3. Section 4 proposes a new research agenda. Finally, some conclusions are presented.

2. Design, methodology and approach

This article is focused primarily on the theoretical discussions, practical experiences and key areas of development in Industry 4.0. In our view, meta-analysis is an effective research strategy to analyze the experiences, problems and principal debates related to Industry 4.0 (Gunasekaran & Ngai, 2012; Franklin & Tripodi, 2009; Torraco, 2005; Tranfield et al, 2003; Webster & Watson, 2002). In fact, meta-analysis is a well-founded research technique which allows one to address the characteristics of technology-based interventions and the main debates that arise within our field of knowledge (Lundahl & Yaffe, 2007; Ramsey & Montgomery, 2014; Soni et al, 2013). To this end, this review examines articles related to Industry 4.0.

Concretely, the articles were published in 33 journals from which 100 papers dating from 2005 to 2018 have been selected. The databases from which the articles were retrieved are Academica-e, ASSIA, the Citation Index, Dialnet, ISOC, Scopus, the Social Sciences Citation Index, Social Services Abstracts and the Web of Science.

The initial search aimed to find all articles which specifically included the term “Industry 4.0” in their abstracts or keywords, or those which included “Smart industry”, “industrie 4.0”, “automation”, “smart production”, “smart plan”, “business 4.0”, “learning factory” or “smart factory” in their titles. The exclusion criteria assumed that if none of these terms appeared in any of these fields of an article, it was likely that Industry 4.0 did not occupy a core position in the article and it could therefore be excluded.

On the other hand, technological papers were omitted, as this article is focused on the implementation of Industry 4.0 and its consequences in management and organizations. Articles that develop a specific technology or that are dedicated to technical and technological solutions were not included in the review.

Human resources articles were searched in order to complete the database, as the implementation of smart factories mainly affects employees. Terms such as “digitization” are added to the initial examination to search these articles.

The searches were conducted in June 2017 and updated in September 2018. A manual search of papers published was performed in the selected journals. The studies were coded by reading the abstracts and full texts of the papers. All of the selected articles were collected, classified and analyzed in Microsoft Excel as a reference database. A summary of this database is included in the Appendix of this article.

Finally, bibliometric review is omitted in this analysis, as the paper focused on the smart industry concepts, trends and areas of research.

3. **Purpose**

Examining previous research about Industry 4.0 is not new. Ghobakhloo (2018) conducted a review of the ongoing research on the Industry 4.0 phenomenon. Similarly, Lu (2017) published a research paper about an overview of the research on Industry 4.0, by an examination of previous literature, though the analysis of 88 papers related to Industry 4.0 that were studied and grouped into five categories.

Nevertheless, an actualization of their work is needed as industry 4.0 is a new trend and several papers have been published in recent years. In particular, most of the papers included in this review were published in 2015 and 2016.

This paper is based on the research conducted by Lu (2017) and Ghobakhloo (2018). Their work will be expanded as previous literature about this topic will be completed. Additionally, a research agenda was identified from the proposals of previous papers and from the experience of practitioners.

The next chapter identifies fields of research in industry 4.0. Operational issues, decision-making questions, case-studies, human resources challenges and management practices regarding the smart industry will be studied below.

3.1 Operational issues

Operations automation has interested practitioners for several years. The integration of electronic components such us sensors or microchips has enabled new developments in manufacturing plants (Lucke, et al, 2008) and supported production automation. Roblek et al (2016) defined the new manufacturing process as a procedure with the capacity of achieving more complex and qualified standards and requirements of products.

Reducing emissions and saving energy are other approaches to introduce industry 4.0 in companies (Bressanelli et al, 2018; Müller et al, 2018).

To achieve these goals, several "Factories-in-a-Lab" and specific projects have been created. The iFactory in the Intelligent Manufacturing Systems Centre at the University of Windsor, in Canada (ElMaraghy et al, 2011), the iFactory established at the University of

Sttugart (Wiendahl et al, 2015), the Smart FactoryKL in Kaiserslaurtern, or the Intelligent Networked Manufacturing System (Lucke et al., 2008) are just some of these initiatives.

3.1 *Decision-making questions*

Real-time adopted production sustains more "informed" decisions. Big data solutions, cloud computing and data analysis support this decision-making process. Automation is mostly close to real time information, and technologies such as collaborative robots or ERPs. This real time information is an important support for decisions, as it offers the best evidence to adopt a particular choice.

Most research papers that work on mechanization analyze the role of automation in the decision-making process. For instance, the e-business model proposed by Al-Mudimigh for Citibank automates bank services and several business decisions. Aviation systems are a traditional case of automatic decisions (Wiener & Curry, 1980; Wiener, 1988; Mundra, 1989; Sarter & Woods, 1992; Billings & Woods, 1994; Hilburn et al, 1997; Dornheim, 1998; Bliss, 2003; Wickens et al, 1978, 1998, 2000, 2005, 2008; Metzger & Parasuraman, 2005; Dixon & Wickens, 2006; Allendoerfer et al, 2007).

Trentham & Scholl (2008) revised automation techniques in the public and private sector, concluding that these techniques improve productivity and efficiency in organizations. Parasuraman & Wickens (2008) identified the optimal levels and stages of automation.

Skitka, Mosier, & Burdick (2000) showed the responsibility of errors in automated devices. They proposed measures to reduce the "automation bias" that provokes these errors. These scholars also analyzed "Automation bias" in decision-making contexts.

Huber (1988) designed a theory of the effects that computer-assisted communication and decision-aiding technologies have on organizational design, intelligence, and decision-making.

Cummings & Bruni (2009) developed a model to assign decisions to humans or computers. They define three roles in the decision process: the moderator, generator, and decider, and illustrated their model though a case-study example.

Finally, even theoretical models are defined in order to design the most effective decision-making process, considering automation. For instance, Parasuraman (2000) outlined a model with different levels of automation.

3.3 Companies case study

Several case studies have been described regarding automation practices. Automation in buildings, referring to the automation of lighting and energy savings, or the evaluation of automation practices in the construction sector are some of these case-studies (Ippolito et al, 2014; Aghemo et al, 2014). The automotive industry presents different experiences in this field (Bhamu et al, 2013; Rybicka et al, 2016; Villareal, Garza-Reyes et al, 2017). Most of these cases present a relationship with the Lean method. In general, the manufacturing sector develops many examples of automation in the operational process and most analysis focuses on the advantages of automation and the effects of the elimination of time-consuming and tedious tasks (Wang et al, 2013). Even abstract models to support an industrial firm evolution in automation are defined (Legat et al, 2013) and automation is perceived as one of the most important industrial trends, with the Internet of Things and cyber-physical system (Wollschlaeger et al, 2017). Obviously, there is a close relationship between automation and industry 4.0.

Nevertheless, it is not just the industrial sector that is involved in automation, as several initiatives have been taken in the service sector. For example, Kassem et al (2015) described a strategy to promote automation in the University. They showed how this university moved from a manual process of information to an automated one. Even the health sector is following this tendency (Qureshi & Syed, 2014), and great opportunities could appear in the implementation of automation practices in the public sector (Bin Taher et al, 2015). Likewise, Bin Taher et al (2015) research proposed a ten-step change management framework to guide managers on business process re-engineering and automation in a public sector context.

3.4 *Human resources challenges*

The role of employees in this new context, the effects of Industry 4.0 on employment and the requirements of digital competences have attracted the attention of scholars in the last few years. Romero et al (2016) defined the figure of the "Operator 4.0" as a smart and skilled operator who performs 'work aided' by machines if and as needed.

The implementation of Industry 4.0 is, according to Roblek et al (2016), an integrated process that involves human and machine. Furthermore, the behavior of employees is essential to achieve the goals of Industry 4.0.In this context, Lasi et al (2014) affirmed that new manufacturing systems should respond to human needs and not the reverse.

Nevertheless, new training is required in order to facilitate the useful knowledge to work in this new environment. Data science concepts, mathematics knowledge, programming… are needed for this new industrial era. The so-called "digital natives" already have these digital abilities to compete in the new economic environment.

Several papers from the analysis carried out focused on digitization and on the effects of industry 4.0 on employees. New skills should be included in workers´ curriculums and scholars should help to define these technological competences.

3.5 *Management*

Industry 4.0 affects the organization of work. Changes in management are required in order to achieve the goals of Industry 4.0, and to implement a smart factory. Traditional methodology should be adapted in order to satisfy the requirements of Industry 4.0. For instance, Flatscher & Riel (2016) proposed a new strategic production planning process. They described the implementation of Industry 4.0 in a TIER1 company, and the long-term strategic planning needed to invest in robots, in new machinery, and, in fact, in the transformation of company professionals to exploit the potential of a smart factory.

Narkhede (2015) showed competitive priorities and the role of implications of organizational knowledge on manufacturing advanced industry.

Research regarding the interoperability of a company and the creation of networked organizations were included in the area of management (Ruggaber, 2006). New networks have been implemented to include more relevant relationships like Supply Chains or even dynamic networks like virtual organizations.

According to Decker (2014), human resources management must integrate the so-called "generation y" and human resources managers should understand the motivations of this generation.

Finally, Müller et al (2016) detected, though a qualitative study based on interviews, several actions for the implementation of a new and useful management in smart factories.

4 Findings. Reopening the research agenda. Emerging issues for further research

Industry 4.0 is considered as a new trend in the future of manufacturing, as can be concluded from the number of publications on Industry 4.0 in the last few years (Bauernhansl et al, 2014).

The database of the literature review was structured by the contents of the papers included. 100 articles were classified in eleven areas: operational issues, decision-making questions, case-studies, human resources management, management, terminology, levels of implementation, stages of development, Lean, organization and sustainability.

Figure 1 shows results from this analysis.

Most papers from the review included operational issues: 27 out of 100 articles. Case-studies were also found in the analysis: 25 out of 100 papers described specific case-studies on the implementation of industry 4.0. Human resources and terminology are relevant: 21 and 17 papers respectively.

The fact that several case-studies were found and that terminology questions are important describes the state of the art of Industry 4.0. In particular, research on industry 4.0 can be characterized as being at its early stages. Theory is built from case-studies, and they are mostly studied previously to conclude with new models and theoretical frameworks.

INSERT FIGURE 1 HERE

On the other hand, several of these areas will be included as future areas of research. In fact, these circumstances confirm the importance of the elaboration of a new research agenda that could help the development of this future research.

From the analysis of the previous literature, several fields of research can be suggested. From the necessity of a generally accepted terminology, to the analysis of the real implementation of industry 4.0 or the effects of the smart factory on employees, several fields of research are proposed.

From the analysis conducted, there is a need to improve the theory in six areas:

i. *Creating a common terminology*. As was observed by Bauer (2014) and reminded by Hermann et al (2016), there is not even a generally accepted definition of the term Industry 4.0. At least, a generally accepted understanding of the concept Industry 4.0 has not been published. Providing the systematization of knowledge requires time, although terminology should be a priority for further developments in a scientific field of research.

Discussing the terminology on an academic level is difficult, but it is needed for academics to be able to further investigate the topic. As was noted by Hermann, Pentek & Otto (2016), discussing the topic of Industry 4.0 from an academic perspective is quite difficult. To solve those problems, they propose the implementation of Industry 4.0 scenarios. By doing so, they identify the design principles of Industry 4.0. This perspective may help future developments in this field.

Likewise, standards must emerge to assure coordination and communication between plants (Zuehlke, 2010; Weyer et al, 2015). There is a lack of regulation, which is essential for process control applications.

Although Hermann et al. (2016) conducted a literature review to establish the foundation of a design theory for Industry 4.0, more research should be undertaken in this area.

ii. Levels of implementation of Industry 4.0. As the smart factory is a trend in the business world, most managers affirm they are carrying out actions for implementing the Industry 4.0 in their factories. Nevertheless, most companies are not a trustful automatized industry. Such, Industry 4.0 should be differentiated from real Industry 4.0 practices. In this line, the elaboration of a model that describes the diverse scenarios could be an interesting field for future research.

iii. Stages for the development of Industry 4.0. A framework could be proposed to go through the different stages of the automation and data-in-real-time development. For instance, a plant needs to automatize production firstly, and to adopt information systems or cloud-computing projects secondly, in order to become a smart factory.

iv. Industry 4.0, *sustainability and Lean*: The Lean method has been identified as a useful strategy to change cultural values of a company and to improve the way the work is done. In this context, Lean could support the development of Industry 4.0 in a company. According to Sanders et al (2016), Lean manufacturing is needed to implement Industry 4.0. They analyzed the link between Lean and smart factories. In this way, Biao et al (2016) examined the relationship between lean production and intelligent manufacturing, and proposed a lean intelligent production system (LIPS) to improve production quality and efficiency and to reduce costs (in particular, energy saving and waste reduction) in Industry 4.0. Furthermore, they proposed the concept of the lean intelligent production system (LIPS). Similarly, Kolberg & Zühlke (2014) studied the relationship between automation technologies and Lean production, and analyzed the concept Lean Automation. From these proposals, further studies that implement this production system could become a new are of research.

v. *Human resources effects*. At present time, there is a discussion about the effects of Industry 4.0 on the labor market. For instance, according to Christofides et al (2007) the introduction of training related to advanced networking technologies and sensor networks will be essential for chemical engineers to implement Industry 4.0. Moreover, most engineering studies should include these new skills in their curriculum. In fact, it is generally accepted that jobs will change, and new qualifications will be required, but there is not a consensus about the estimations of the number of new jobs created and job destruction from Industry 4.0 implementation. Employee motivation, the manager 4.0 and its competences or the skills required for this new framework could be an exciting area for academics focused on Industry 4.0.

vi. *Industry 4.0 and organization*. The new Industry 4.0 framework affects the company´s organization. Traditional organizational charts are not useful for this situation. New relationships are required, and a new way of organizing the company is needed. Virtual organizations and redarchy are examples of these new charts where interactions occur between different professionals and departments.

Finally, figure 2 presents the six areas presented above.

INSERT FIGURE 2 HERE

5. Conclusions

Since Mark Weiser coined the term *ubiquous computing* in 1991, Industry 4.0 has focused the attention of researchers and practitioners, and it is widely recognized as one of the main trends in future manufacturing. Moreover, Industry 4.0 could be defined as the most important goal of the manufacturing sector in the following years. Factories will move from a traditional framework to a digital one. Information in real time, automation of processes and data processing to support decision-making will characterize this new context.

In this situation, research focused on smart factories could support these changes and help companies in this transformation.

Previous literature has been collected and classified into theoretical –operational issues and decision-making research- or empirical research –case-studies, human resources and management issues-, complementing the work developed by Lu in 2017.

A research agenda has been defined to guide future research. Creating a common terminology, defining the levels of implementation of Industry 4.0, identifying the stages for the development of Industry 4.0, describing a Lean method for these factories, focused on sustainability implications, analyzing human resources effects and studying the effects of the Smart Factory in the organization are the six topics identified in this research agenda.

Creating a common terminology implies not only the definition of the concept Industry 4.0, but also the generation of standards that support control. Standards definition may help to develop rules and new legislation in the field of industry 4.0.

Defining the levels of implementation of Industry 4.0 and the stages for the development of Industry 4.0 would help the identification of best practices in this process.

The Lean method emerges as a useful strategy to change the organizational culture in the advance of Industry 4.0 and facilitates the introducion of the benefits of industry 4.0 for waste reduction and energy savings.

Finally, human resources effects of Industry 4.0 on the labor market and organizational and managerial consequences are identified as a specific field for future research.

Researchers are encouraged to develop further research in the mentioned areas to help practitioners in the transition from the traditional manufacturing plant to the smart factory. Employees´ adaptation to this new environment should be prioritized in order to achieve a successful advance in Industry 4.0.

6. Originality and value

After examining previous research, this article proposes a research agenda in Industry 4.0 issues.

Creating a common terminology, defining the levels of implementation of Industry 4.0, identifying the stages for the development of Industry 4.0, describing a Lean method for these factories, focused on sustainability implications, analyzing human resources effects and studying the effects of the Smart Factory in the organization are the six topics identified in this research agenda.

This research agenda should guide future investigation in the smart industry.

7. Limitations

This review has some limitations. Firstly, some gray literature, such as reports from non-governmental organizations and front-line practitioners' reflections, were not included.

Secondly, only research studies in English and Spanish were reviewed. In spite of these limitations, this study has covered the leading journals and represents a very significant sample set of this literature.

Bibliography

Aghemo, C., Blaso, L., & Pellegrino, A. (2014). "Building automation and control systems: A case study to evaluate the energy and environmental performances of a lighting control system in offices". *Automation in Construction*, 43, pp. 10-22.

Allendoerfer, K., Friedman-Berg, F., & Pai, S. (2007*). Human factors analysis of safety alerts in air traffic control*. Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center.

Bartodziej, C. J. (2016). *The concept industry 4.0: an empirical analysis of technologies and applications in production logistics*. Springer.

Bauer, W., Hämmerle, M., Schlund, S., & Vocke, C. (2015). "Transforming to a hyper-connected society and economy–towards an "Industry 4.0"". *Procedia Manufacturing*, 3, pp. 417-424.

Bauernhansl, T., Ten Hompel, M., & Vogel-Heuser, B. (2014). *Industrie 4.0 in produktion, automatisierung und logistik: anwendung, technologien und migration*. Wiesbaden: Springer Vieweg.

Benson, A. D., Johnson, S. D., & Kuchinke, K. P. (2002). "The use of technology in the digital workplace: A framework for human resource development". *Advances in Developing Human Resources,* 4(4), pp. 392-404.

Bhamu, J., Khandelwal, A., & Sangwan, K. S. (2013). "Lean manufacturing implementation in an automated production line: a case study". *International Journal of Services and Operations Management*, 15(4), pp. 411-429.

Bhimani, A., & Willcocks, L. (2014). "Digitisation, 'Big data' and the transformation of accounting information". Accounting and Business Research, 44(4), pp. 469-490.

Biao, W. A. N. G., Zhao, J. Y., Wan, Z. G., Hong, L. I., & Jian, M. A. (2016). "Lean Intelligent Production System and Value Stream Practice". *DEStech Transactions on Economics and Management*, (ICEM).

Billings, C.E., & Woods, D.D. (1994). “Concerns about adaptive automation in aviation systems”. *Human performance in automated systems: Current research and trends*, pp. 24-29.

Bin Taher, N. A., Krotov, V., & Silva, L. (2015). “A framework for leading change in the UAE public sector”. *International Journal of Organizational Analysis*, 23(3), pp. 348-363.

Bliss, J. (2003). “An investigation of alarm related accidents and incidents in aviation. International”. *Journal of Aviation Psychology*, 13, pp. 249-268.

Boothroyd, G. (2005). *Assembly automation and product design*. CRC Press.

Bressanelli, G., Adrodegari, M.P. & Saccani, N. (2018), “Exploring How Usage-Focused Business Models Enable Circular Economy through Digital Technologies”, *Sustainability* 10.3: pp. 639.

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (2014). “How virtualization, decentralization and network building change the manufacturing landscape: An Industry 4.0 Perspective”. *International Journal of Mechanical, Industrial Science and Engineering*, 8(1), pp. 37-44.

Cadavid, J., Alférez, M., Gérard, S., & Tessier, P. (2015). “Conceiving the model-driven smart factory”, in *Proceedings of the 2015 International Conference on Software and System Process*, pp. 72-76, ACM.

Carlsson, B. (Ed.). (2012). “Technological systems and economic performance: the case of factory automation”. *Springer Science & Business Media* (5).

Chen, F., Deng, P., Wan, J., Zhang, D., Vasilakos, A. V., & Rong, X. (2015). “Data mining for the internet of things: literature review and challenges.” *International Journal of Distributed Sensor Networks*, 11(8), 431047.

Cheng, G. J., Liu, L. T., Qiang, X. J., & Liu, Y. (2016). “Industry 4.0 development and application of intelligent manufacturing”, in International Conference, IEEE, *Information System and Artificial Intelligence (ISAI)*, pp. 407-410.

Chen, B., Wan, J., Shu, L., Li, P., Mukherjee, M., & Yin, B. (2018). “Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges”. *IEEE Access*, 6, pp. 6505-6519.

Christofides, P. D., Davis, J. F., El-Farra, N. H., Clark, D., Harris, K. R., & Gipson, J. N. (2007). “Smart plant operations: Vision, progress and challenges”. *AiChE journal*, 53(11), 2734-2741.

Cummings, M. L., & Bruni, S. (2009). *Collaborative human–automation decision making*. Springer Handbook of Automation, pp. 437-447.

Davis, J., Edgar, T., Porter, J., Bernaden, J., & Sarli, M. (2012). “Smart manufacturing, manufacturing intelligence and demand-dynamic performance”. *Computers & Chemical Engineering*, 47, pp. 145-156.

David, H. (2015). “Why are there still so many jobs? The history and future of workplace automation”. *Journal of Economic Perspectives 29*.3: pp. 3-30.

Decker, J. (2016). “Business 4.0 and Generation Y/Z: Challenges and Opportunities for Human Resources Management”. *Theory and Applications in the Knowledge Economy*, 770.

Dixon, S., & Wickens, C.D. (2006). “Automation reliability in unmanned aerial vehicle flight control: A reliance-compliance model of automation dependence in high workload”. *Human Factors*, 48, pp. 474-486.

Dorn, D., and Gordon H. H. (2015). “Untangling trade and technology: Evidence from local labour markets”. *Economic Journal* 125.584: pp. 621-46.

Dornheim, M. (1999). “Apache tests power of new cockpit tool”. *Aviation Week and Space Technology*, pp. 46-49

Drath, R., & Horch, A. (2014). “Industrie 4.0: Hit or hype?” *IEEE industrial electronics magazine*, 8(2), pp. 56-58.

ElMaraghy, H., AlGeddawy, T., Azab, A., & ElMaraghy, W. (2012). “Change in manufacturing–research and industrial challenges”. *Enabling Manufacturing Competitiveness and Economic Sustainability*, pp. 2-9.

Erol, S., Schumacher, A., & Sihn, W. (2016). “Strategic guidance towards Industry 4.0–a three-stage process model.” In *International conference on competitive manufacturing* (9), pp. 495-501.

Espí-Beltrán, J. V., Gilart-Iglesias, V. and Ruiz-Fernandez, D. (2017). “Enabling distributed manufacturing resources through SOA: The REST approach”. *Robotics and Computer-Integrated Manufacturing* 46: pp. 156-165.

European Factories of the Future Research Association (EFFRA). Roadmap 2020.

Faller, C., and Feldmüller, D. (2015). “Industry 4.0 learning factory for regional SMEs”. *Procedia CIRP* 32: pp. 88-91.

Fidler, D., & Gorbis, M. (2013). “New skills that every worker needs”. *Rotman Magazine*, (3), pp. 40-45.

Flatscher, M., & Riel, A. (2016). “Stakeholder integration for the successful product–process co-design for next-generation manufacturing technologies”. *CIRP Annals-Manufacturing Technology*, 65(1), pp. 181-184.

Franklin, C., & Tripodi, S. (2009). “A meta-analysis of published school social work practice studies”. *Research on Social Work Practice*, 19(6), pp. 667-677.

Ghobakhloo, M. (2018). “The future of manufacturing industry: a strategic roadmap toward Industry 4.0.” *Journal of Manufacturing Technology Management,* 29(6), pp. 910-936.

Gilchrist, A. (2016). *Industry 4.0: the industrial internet of things.* Apress.

Glas, A. H., & Kleemann, F. C. (2016). “The impact of industry 4.0 on procurement and supply management: A conceptual and qualitative analysis”. *International Journal of Business and Management Invention*, 5(6), pp. 55-66.

Gorecky, D., Schmitt, M., Loskyll, M., & Zühlke, D. (2014). “Human-machine-interaction in the industry 4.0 era”. In *Industrial Informatics (INDIN),* 12th IEEE International Conference on, pp. 289-294. IEEE.

Grangel-González, I., Halilaj, L., Coskun, G., Auer, S., Collarana, D., & Hoffmeister, M. (2016), in IEEE Tenth International Conference. “Towards a semantic administrative shell for industry 4.0 components”. Semantic Computing (ICSC), pp. 230-237.

Groover, M. P. (2007). *Automation, production systems, and computer-integrated manufacturing*. Prentice Hall Press.

Gubán, M., & Kovács, G. (2017). “Industry 4.0 Conception”. *Acta Technica Corviniensis-Bulletin of Engineering*, 10(1), pp. 111.

Gunasekaran, A., & Ngai, E. W. (2012). “The future of operations management: an outlook and analysis”. *International Journal of Production Economics*, 135(2), pp. 687-701

Habraken, M., & Bondarouk, T. (2017). “Smart industry research in the field of HRM: Resetting job design as an example of upcoming challenges”. *Electronic HRM in the smart era*, pp. 221-259.

Hecklau, F., Galeitzke, M., Flachs, S., & Kohl, H. (2016). “Holistic approach for human resource management in Industry 4.0”. *Procedia CIRP*, 54, pp. 1-6.

Hermann, M., Pentek, T., and Otto, B. (2016). "Design principles for industrie 4.0 scenarios”,in 49th Hawaii International Conference on *System Sciences (HICSS)*.

Hilburn, B., Jorna, P.G., Byrne, E.A., & Parasuraman, R. (1997). “The effect of adaptive air traffic control (ATC) decision aiding on controller mental workload”. *Human-automation interaction: Research and practice*, pp. 84-91.

Hozdić, E. (2015). “Smart factory for industry 4.0: A review”. *International Journal of Modern Manufacturing Technologies*, 7(1), pp. 28-35.

Huber, G. P. (1990). “A theory of the effects of advanced information technologies on organizational design, intelligence, and decision-making”. *Academy of management review*, 15(1), pp. 47-71.

Ippolito, M. G., Sanseverino, E. R., & Zizzo, G. (2014). “Impact of building automation control systems and technical building management systems on the energy performance class of residential buildings: An Italian case study”. *Energy and Buildings*, 69, pp. 33-40.

Jung, K., Choi, S., Kulvatunyou, B., Cho, H., & Morris, K. C. (2017). “A reference activity model for smart factory design and improvement”. *Production planning & control*, 28(2), pp. 108-122.

Kagermann, H. (2015). “Change through digitization—Value creation in the age of Industry 4.0”. *Management of permanent change*,pp. 23-45.

Kang, H.S., Lee, J.Y., Choi, S., Kim, H., Park, J.H., Son, J.Y., Kim, B.H. and Do Noh, S., (2016). “Smart manufacturing: Past research, present findings, and future directions”. *International Journal of Precision Engineering and Manufacturing-Green Technology,* 3(1), pp. 111-128.

Kassem, M., Kelly, G., Dawood, N., Serginson, M., & Lockley, S. (2015). “BIM in facilities management applications: a case study of a large university complex”. *Built Environment Project and Asset Management*, 5(3), pp. 261-277.

Kolberg, D., & Zühlke, D. (2015). “Lean automation enabled by industry 4.0 technologies”. *IFAC-PapersOnLine*, 48(3), pp.1870-1875.

Landherr, M., Schneider, U., & Bauernhansl, T. (2016). “The Application Center Industrie 4.0-Industry-driven manufacturing, research and development”. *Procedia CIRP*, 57, pp. 26-31.

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). “Industry 4.0”. *Business & Information Systems Engineering*, 6(4), 239.

Lee, J., Bagheri, B., & Kao, H. A. (2015). “A cyber-physical systems architecture for industry 4.0-based manufacturing systems”. *Manufacturing Letters*, 3, pp. 18-23.

Lee, Jay, Hung-An Kao, and Shanhu Yang. (2014). "Service innovation and smart analytics for industry 4.0 and big data environment." *Procedia Cirp* 16:pp. 3-8.

Legat, C., Folmer, J., & Vogel-Heuser, B. (2013). "Evolution in industrial plant automation: A case study". In Industrial Electronics Society, *IECON 2013-39th Annual Conference of the IEEE*, pp. 4386-4391.

Leitão, P., Colombo, A. W., and Karnouskos, S. (2016). "Industrial automation based on cyber-physical systems technologies: Prototype implementations and challenges". *Computers in Industry* 81 (2016): pp. 11-25.

Lu, Y. (2017). "Industry 4.0: A Survey on Technologies, Applications and Open Research Issues". *Journal of Industrial Information Integration*, (6), pp. 1-10.

Lucke, D., Constantinescu, C., & Westkämper, E. (2008). "Smart factory-a step towards the next generation of manufacturing". *Manufacturing systems and technologies for the new frontier*, pp. 115-118.

Lundahl, B., & Yaffe, J. (2007). "Use of meta-analysis in social work and allied disciplines". *Journal of Social Service Research*, 33(3), pp. 1-11.

Metzger, U., & Parasuraman, R. (2005). "Automation in future air traffic management: Effects of decision aid reliability on controller performance and mental workload". *Human Factors*, 47, pp. 35-49.

Müller, J. M., Kiel, D., and Voigt, K. (2018), "What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability", *Sustainability* 10.1: pp. 247.

Müller, S., Willicks, F., Stiehm, S., Richert, A., & Jeschke, S. (2016). "Demography Management in Industry 4.0: First Results of a Qualitative Study". *European Conference on Management, Leadership & Governance*, pp. 199.

Narkhede, B. E. (2017). "Advance manufacturing strategy and firm performance: An empirical study in a developing environment of small-and medium-sized firms". *Benchmarking: An International Journal*, 24(1), 62-101.

Mundra, A. (1989*). A new automation aid for air traffic controllers for improving airport capacity.* McLean, VA: The MITRE Corporation.

Parasuraman, R., & Wickens, C. D. (2008). "Humans: Still vital after all these years of automation. Human Factors". *The Journal of the Human Factors and Ergonomics Society*, 50(3), pp. 511-520.

Paelke, V. (2014). "Augmented reality in the smart factory: Supporting workers in an industry 4.0 environment". *Emerging Technology and Factory Automation (ETFA),* pp. 1-4. IEEE.

Pfeiffer, S. (2016). "Robots, Industry 4.0 and humans, or why assembly work is more than routine work". *Societies*, 6(2), pp. 16.

Porter, M. E. (1998). *Clusters and the new economics of competition*.. Boston: Harvard Business Review.

Prause, G. (2015). "Sustainable business models and structures for Industry 4.0". *Journal of Security & Sustainability Issues*, 5(2).

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, pp. 113-118.

Qin, J., Liu, Y., & Grosvenor, R. (2016). "A categorical framework of manufacturing for industry 4.0 and beyond". *Procedia Cirp*, 52, pp. 173-178.

Qureshi, M. O., & Syed, R. S. (2014). "The impact of robotics on employment and motivation of employees in the service sector, with special reference to health care". *Safety and health at work*, 5(4), pp. 198-202.

Ramsey, A. T., & Montgomery, K. (2014). "Technology-based interventions in social work practice: A systematic review of mental health interventions". *Social work in health care*, 53(9), pp. 883-899.

Radziwon, A., Bilberg, A., Bogers, M., & Madsen, E. S. (2014). "The smart factory: exploring adaptive and flexible manufacturing solutions". *Procedia engineering*, 69, pp. 1184-1190.

Roblek, V., Meško, M., & Krapež, A. (2016). *A Complex View of Industry 4.0.* SAGE Open, 6(2).

Romero, D., Bernus, P., Noran, O., Stahre, J., & Fast-Berglund, Å. (2016). *The Operator 4.0: Human Cyber-Physical Systems & Adaptive Automation towards Human-Automation Symbiosis Work Systems*, in APMS (Advances in Production Management Systems).

Ruggaber, R. (2006). "Athena-Advanced technologies for Interoperability of heterogeneous enterprise networks and their applications". *Interoperability of enterprise software and applications*, pp. 459-460.

Rüttimann, B. G., & Stöckli, M. T. (2016). "Lean and Industry 4.0—twins, partners, or contenders? A due clarification regarding the supposed clash of two production systems". *Journal of Service Science and Management*, 9(06), pp. 485.

Rybicka, J., Tiwari, A., & Enticott, S. (2016). "Testing a Flexible Manufacturing System Facility Production Capacity through Discrete Event Simulation: Automotive Case Study. World Academy of Science, Engineering and Technology". *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, 10(4), pp. 690-694.

Sanders, A., Elangeswaran, C., & Wulfsberg, J. (2016). "Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing". *Journal of Industrial Engineering and Management*, 9(3), pp. 811-833.

Sarter, N., & Woods, D. (1992). "Pilot interaction with cockpit automation: Operational experiences with the Flight Management System". *International Journal of Aviation Psychology*, 2, pp. 303-321

Scheuermann, C., Verclas, S., & Bruegge, B. (2015). "Agile factory-an example of an industry 4.0 manufacturing process", in 3rd International Conference, IEEE, *Cyber-Physical Systems, Networks, and Applications (CPSNA),* pp. 43-47.

Seufert, S., & Meier, C. (2016). "From eLearning to digital transformation: A framework and implications for L&D". *International Journal of Advanced Corporate Learning (iJAC)*, 9(2), pp. 27.

Schuchmann, D., & Seufert, S. (2015). “Corporate learning in times of digital transformation: A conceptual framework and service portfolio for the learning function in banking organisations”. *International Journal of Advanced Corporate Learning* (iJAC), 8(1), pp. 31-39.

Schuh, G., Gartzen, T., Rodenhauser, T., & Marks, A. (2015). “Promoting work-based learning through industry 4.0”. *Procedia CIRP*, 32, pp. 82-87.

Schuster, K., Groß, K., Vossen, R., Richert, A., & Jeschke, S. (2016). “Preparing for industry 4.0–collaborative virtual learning environments in engineering education”. *Engineering Education 4.0*, pp. 477-487.

Shen, W., Hao, Q., Yoon, H. J., & Norrie, D. H. (2006). “Applications of agent-based systems in intelligent manufacturing: An updated review”. *Advanced engineering INFORMATICS*, 20(4), pp. 415-431.

Shrouf, F., Ordieres, J., & Miragliotta, G. (2014). “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), IEEE International Conference.

Skitka, L. J., Mosier, K. L., & Burdick, M. (1999). “Does automation bias decision-making?” *International Journal of Human-Computer Studies*, 51(5), pp. 991-1006.

Skitka, L. J., Mosier, K., & Burdick, M. D. (2000). “Accountability and automation bias”. International *Journal of Human-Computer Studies*, 52(4), pp. 701-717.

Smith, B. Q. (2006). “Outsourcing and digitized work spaces: Some implications of the intersections of globalization, development, and work practices”. *Journal of Adolescent & Adult Literacy*, 49(7), pp. 596-607.

Soni, G., & Kodali, R. (2013). “A critical review of supply chain management frameworks: proposed framework”. *Benchmarking: an international journal*, 20(2), 263-298.

Stock, T., & Seliger, G. (2016). “Opportunities of sustainable manufacturing in industry 4.0”. *Procedia Cirp,* 40, pp. 536-541.

Strange, R., & Zucchella, A. (2017). "Industry 4.0, global value chains and international business". *Multinational Business Review*, 25(3), pp. 174-184.

Tamás, P., Illés, B., & Dobos, P. (2016). "Waste reduction possibilities for manufacturing systems in the industry 4.0". *IOP Conference Series: Materials Science and Engineering,* 161, (1), pp. 012074.

Tonelli, F., Demartini, M., Loleo, A., & Testa, C. (2016). "A novel methodology for manufacturing firms value modeling and mapping to improve operational performance in the industry 4.0 era". *Procedia CIRP*, 57, pp. 122-127.

Torraco, R. J. (2005). "Writing integrative literature reviews: Guidelines and examples". *Human Resource Development Review*, 4(3), pp. 356-367.

Toygar, A., Tapie Rohm C.E., & Zhu, J. (2013). "A new asset type: Digital assets". *Journal of International Technology and Information Management*, 22(4), pp. 113.

Tranfield, D., Denyer, D. & Smart, P. (2003). "Towards a methodology for developing evidence-informed management knowledge by means of systematic review". *British Journal of Management*, Vol. 14, pp.207-22.

Trentham, G., & Scholl, H. J. (2008). "Current practices in field force automation: decision support and information management for the field force", in Hawaii International Conference on System Sciences, *Proceedings of the 41st Annual*, pp. 197-197.

Villarreal, B., Garza-Reyes, J. A., Kumar, V., & Lim, M. K. (2017). "Improving road transport operations through lean thinking: a case study". *International Journal of Logistics Research and Applications*, 20(2), pp. 163-180.

Wang, S., Gotlieb, A., Ali, S., & Liaaen, M. (2013). "Automated test case selection using feature model: an industrial case study", in International Conference on Model Driven Engineering Languages and Systems, pp. 237-253. Heidelberg.

Wang, S., Wan, J., Li, D., & Zhang, C. (2016). "Implementing smart factory of industrie 4.0: an outlook". *International Journal of Distributed Sensor Networks*.

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, pp. 158-168.

Wagner, U., AlGeddawy, T., ElMaraghy, H., & Müller, E. (2012). "The state-of-the-art and prospects of learning factories". *Procedia CiRP*, 3, pp. 109-114.

Webster, J., & Watson, R. T. (2002). "Analyzing the past to prepare for the future: Writing a literature review". *MIS Quarterly*, xiii-xxiii.

Weyer, S., Schmitt, M., Ohmer, M., & Gorecky, D. (2015). "Towards Industry 4.0-Standardization as the crucial challenge for highly modular, multi-vendor production systems". *Ifac-Papersonline*, 48(3), pp. 579-584.

Wickens, C.D., & Kessel, C. (1979). "The effect of participatory mode and task workload on the detection of dynamic system failures". *IEEE Transactions on Systems, Man, and Cybernetics*, SMC- 9, pp. 21-31.

Wickens, C.D., Mavor, A., Parasuraman, R., & McGee, J. (1998). *The future of air traffic control: Human operators and automation*. Washington, DC: National Academy Press.

Wickens, C.D., Gempler, K., & Morphew, M.E. (2000). "Workload and reliability of predictor displays in aircraft traffic avoidance". *Transportation Human Factors*, 2, pp. 99-126.

Wickens, C.D., Dixon, S., Goh, J., & Hammer, B. (2005). "Pilot dependence on imperfect diagnostic automation in simulated UAV flights: An attentional visual scanning analysis", in 13th International Symposium on Aviation Psychology, April 18-21, Oklahoma City.

Wickens, C.D., Dixon, S.R., Leiden, K., Keller, D., Bagnall, T., Clayton, K.. (2008). *Addressing the alert problem in air traffic control.* Las Cruces: New Mexico State University.

Wickens, C.D., Rice, S.R., & Levinthal, B. (in press). "Imperfect reliability in unmanned airvehicle supervision and control". *Human-robotics interaction in future military systems*. A.W. Evans (Ed.) Brookfield, VT: Ashgate.

Wiendahl, H. P., Reichardt, J., & Nyhuis, P. (2015). *Handbook factory planning and design*. Springer.

Wiener, E.L., & Curry, R.E. (1980). "Flight-deck automation: Promises and problems". *Ergonomics*, 23, pp. 995-1011.

Wiener, E.L. (1988). "Cockpit automation". *Human factors in aviation*, pp. 433-461.

Wiesner, S., Freitag, M., Westphal, I., & Thoben, K. D. (2015). "Interactions between service and product lifecycle management". *Procedia CIRP*, 30, pp. 36-41.

Witkowski, K. (2017). "Internet of things, big data, industry 4.0–Innovative solutions in logistics and supply chains management". *Procedia Engineering*, 182, pp. 763-769.

Wollschlaeger, M., Sauter, T., & Jasperneite, J. (2017). "The Future of Industrial Communication: Automation Networks in the Era of the Internet of Things and Industry 4.0". *IEEE Industrial Electronics Magazine*, 11(1), pp. 17-27.

Xu, X., (2012). "From cloud computing to cloud manufacturing". *Robotics and computer-integrated manufacturing*, 28(1), pp.75-86.

Zezulka, F., Marcon, P., Vesely, I., & Sajdl, O. (2016). "Industry 4.0–An Introduction in the phenomenon". *IFAC-PapersOnLine*, 49(25), pp. 8-12.

Zhou, K., Liu, T., & Zhou, L. (2015). "Industry 4.0: Towards future industrial opportunities and challenges". *Fuzzy Systems and Knowledge Discovery (FSKD)*, 12th International Conference on, 2147-2152. IEEE.

Zuehlke, D. (2010). "SmartFactory—Towards a factory-of-things". *Annual Reviews in Control*, 34(1), pp. 129-138.

INSERT TABLE 1 (APPENDIX) HERE

Figure 1. Spider chart representation from the literature review

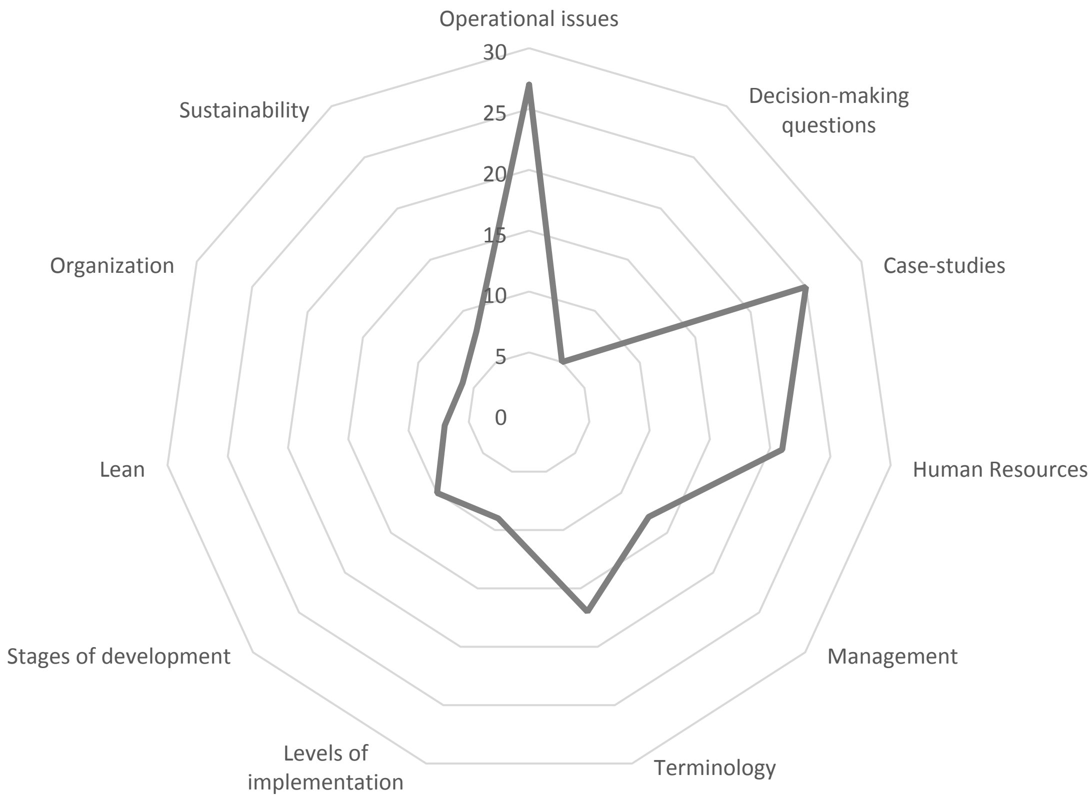
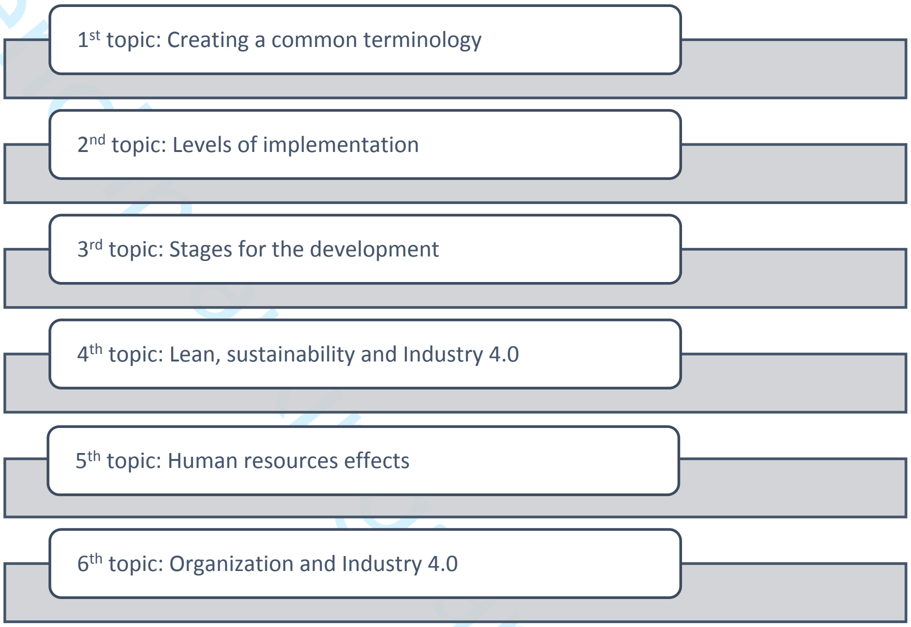


Figure 2: A research agenda



Appendice:

Table 1. Take-home messages from the papers analyzed

ID	Journal title	Year	Take-home message	Authors
1	Industry 4.0: A survey on technologies, applications and open research issues	2017	Through a systematic review, a conceptual framework of interoperability regarding Industry 4.0 is proposed in this article.	Lu, Y.
2	Implementing Smart Factory of Industries 4.0: An Outlook	2016	A flexible and reconfigurable smart industry is defined focused on vertical integration.	Wang, S., Wan, J., Li, D., & Zhang, C.
3	The State-of-the-Art and Prospects of Learning Factories	2012	This article shows the results of a survey of existing learning factories and their characteristics. Their use in research, teaching and industrial projects is analyzed.	Wagner, U., AlGeddawy, T., ElMaraghy, H., & Müller, E.
4	Smart Factory - A Step towards the Next Generation of Manufacturing	2008	This paper presents the Smart Factory developed at the Universität Stuttgart	Lucke, D., Constantinescu, C., & Westkämper, E.
5	SmartFactory—Towards a factory-of-things	2010	Changes and challenges of Smart Factory are described and the experience gained to date in the Smart Factory is presented.	Zuehlke, D.
6	Industry 4.0	2014	This study concludes that a change from product to service-orientation in Industry 4.0 is expected. New types of enterprises appear within the industry.	Lasi, H., Fettke, P., Feld, T., & Hoffman, M.
7	Industry 4.0 Learning Factory for regional SMEs	2015	Small and medium sized enterprises have more difficulties in engaging Industry 4.0. The case of a region where specific support is designed for those companies is presented.	Faller, C., & Feldmüller, D.
8	Opportunities of Sustainable Manufacturing in Industry 4.0	2016	A case of manufacturing equipment for sustainable manufacturing in Industry 4.0 is presented in this paper.	Stock, T., & Seliger, G.
9	Strategic guidance towards Industry 4.0 –a three-stage process model	2016	In this paper a three-stage process model to systematically guide companies in their Industry 4.0 vision and strategy -finding process is proposed.	Erol, S., Schumacher, A., & Sihn, W.
10	Smart plant operations: Vision, progress and challenges	2007	Factors required to implement Industry 4.0 are presented in this paper.	Christofides, P.D., Davis, J.F, El-Farra, N.H., Clark, D., Harris, K.R.D., & Gipson, J.N.
11	Industrie 4.0: Hit or Hype?	2014	Industry 4.0 is presented as a potential hit, where all contributing parties collaborate to overcome challenges.	Drath, R., & Horch, A.
12	Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination	2016	A smart factory framework that incorporates industrial network, cloud, and supervisory control terminals with smart shop-floor objects such as machines, conveyers, and products is presented in this paper.	Wang, S., Wan, J., Zhang, D., Li, D., & Zhang, C.
13	Towards Industry 4.0 - Standardization as the crucial challenge for highly modular, multi-vendor production systems	2015	Towards Industry 4.0 - Standardization as the crucial challenge for highly modular, multi-vendor production systems	Weyer, S., Schmitt, M., Ohmer, M., & Gorecky, D.

14	Applications of agent-based systems in intelligent manufacturing: An updated review	2006	This paper provides an update review on the recent achievements in these areas, and discusses some key issues in implementing agent-based manufacturing systems such as agent encapsulation, agent organization, agent coordination and negotiation, system dynamics, learning, optimization, security and privacy, tools and standards.	Shen, W., Hao, Q., Jooing Yoon, H., & Norrie, D. H.
15	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	2014	Reviewing and analyzing the current initiatives and related studies of the smart factories/Industry 4.0, this paper presents a reference architecture for IoT-based smart factories, defines the main characteristics of such factories with a focus on the sustainability perspectives.	Shrouf, F., Ordieres, J., & Miragliotta, G.
16	A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems	2015	In this paper, a unified 5-level architecture is proposed as a guideline for implementation of CPS.	Lee, J., Bagheri, B.., & Kao, H.
17	Design Principles for Industrie 4.0 Scenarios	2016	Discussing the topic on an academic level is difficult, and so is implementing Industry 4.0 scenarios. Based on a quantitative text analysis and a qualitative literature review, the paper identifies design principles of Industry 4.0.	Hermann, M., Pentek, T., & Otto, B.
18	Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment	2014	This paper addresses the trends of manufacturing service transformation in a big data environment, as well as the readiness of smart predictive informatics tools to manage big data, thereby achieving transparency and productivity.	Lee, J., Kao, H., & Yang, S.
19	From cloud computing to cloud manufacturing	2011	This paper suggest two types of cloud computing adoptions in the manufacturing sector.	Xu, X.
20	Smart manufacturing, manufacturing intelligence and demand-dynamic performance	2012	This article concludes that IT-enabled Smart factories and supply networks can better respond to national interests and strategic imperatives and can revitalize the industrial sector by facilitating global competitiveness and exports, providing sustainable jobs, radically improving performance, and facilitating manufacturing innovation.	Davis, J., Edgar, T., Porter, J., Bernaden, J., & Sarli, M.
21	Data Mining for the Internet of Things: Literature Review and Challenges	2015	A suggested big data mining system is proposed in this article	Chen, F., Deng, P., Wan, J., Zhang, D., Vasilakos, A., & Rong, X.
22	Building automation and control systems: A case study to evaluate the energy and environmental performances of a lighting control system in offices	2014	An experimental case study with the use of a lighting control system is presented in this article.	Aghemo, C., Blaso, L., & Pellegrino, A.
23	Human Factors Analysis of Safety Alerts in Air Traffic Control	2018	The authors collected automation data from en route, approach control, and tower facilities that show how often alerts occur, how controllers respond to alerts, and when controller actions occur relative to the alerts.	Kenneth, A., Friedman-Berg, H., & Pai, S.

24	Lean manufacturing implementation in an automated production line: a case study.	2013	The paper aims at improving production performance of an automated production line by lean manufacturing implementation. The production performance has been improved in an Indian industry by identifying and eliminating non-value added activities through value stream mapping. An increase in the production rate per day by 10.37%, decrease in production lead time by 10.51%, and reduction of non-value added time by 4.00% was observed.	Bhamu, J., Khandelwal, A., & Sangwan, K. S.
25	Lean Intelligent Production System and Value Stream Practice	2016	This paper makes a brief introduction of the Industry 4.0 and "Made in China 2025" plan and analyzes the relationship between the lean production and intelligent manufacturing. Considering the situation of the manufacture in China, the concept of the lean intelligent production system (LIPS) is proposed.	Biao, W. A. N. G., Zhao, J. Y., Wan, Z. G., Hong, L. I., & Jian, M. A.
26	A framework for leading change in the UAE public sector	2015	The purpose of this paper is to guide managers on business process re-engineering (BPR) and automation projects in the United Arab Emirates (UAE) public sector context.	Bin Taher, N. A., Krotov, V., & Silva, L
27	Exploring How Usage-Focused Business Models Enable Circular Economy through Digital Technologies	2018	This paper develops a conceptual framework, based on the literature and a case study of a company implementing a usage-focused servitized business model in the household appliance industry.	Bressanelli, G., Adrodegari, M.P. & Saccani, N.
28	Collaborative human–automation decision making.	2009	This book presents the human–automation collaboration taxonomy (HACT), which builds on previous research by expanding the Parasuraman information processing model, specifically the decision-making component.	Cummings, M. L., & Bruni, S.
29	Why are there still so many jobs? The history and future of workplace automation	2015	This article states that polarization in the labour market is unlikely to continue very far into future. The author reflects on how recent and future advances in artificial intelligence and robotics should shape our thinking about the likely trajectory of occupational change and employment growth.	David, H.
30	Business 4.0 and Generation Y/Z: Challenges and Opportunities for Human Resources Management	2016	The role of people and organizations in a World 4.0 is analyzed. Several recommendations are addressed in order to improve youths' and managers' skills.	Decker, J.
31	Untangling trade and technology: Evidence from local labour markets	2015	This article juxtaposes the effects of trade and technology on employment in US local labour markets between 1980 and 2007	Dorn, D., and Gordon H. H
32	Change in manufacturing–research and industrial challenges	2012	This paper describes the latest state-of-the art fully reconfigurable "plug & play" changeable and flexible "Factory-in-the-Lab" infrastructure and supporting design innovation and advanced research environment.	ElMaraghy, H., AlGeddawy, T., Azab, A., & ElMaraghy, W.
33	Enabling distributed manufacturing resources through SOA: The REST approach	2017	The Service Oriented Architecture (SOA) is quite established in enterprise environments as a pattern for software integration. The aim is to explore a low developed research area to improve interoperability and flexibility in certain demanding manufacturing scenarios while similar performance of	Espí-Beltrán, J. V., Gilart-Iglesias, V. and Ruiz-Fernandez, D.

			current industrial control standard is achieved.	
34	Stakeholder integration for the successful product–process co-design for next-generation manufacturing technologies	2016	A case-study of a TIER-1 company implementing Industry 4.0 is presented in this article	Flatscher, M., & Riel, A.
35	The future of manufacturing industry: a strategic roadmap toward Industry 4.0	2018	The purpose of this paper is to conduct a state-of-the-art r research on Industry 4.0. It highlights its key design principles and technology trends and offer a strategic roadmap to guide the process of the implementation of Industry 4.0	Ghobakhloo, M.
36	Impact of building automation control systems and technical building management systems on the energy performance class of residential buildings: An Italian case study	2014	The paper focuses on the evaluation of the impact on residential buildings of building automation control (BAC) and technical building management (TBM) systems.	Ippolito, M. G., Sanseverino, E. R., & Zizzo, G.
37	BIM in facilities management applications: a case study of a large university complex	2015	Building information modeling (BIM) in facilities management (FM) applications is an emerging area of research. The purpose of this paper is to investigate the value of BIM and the challenges affecting its adoption in FM applications.	Kassem, M., Kelly, G., Dawood, N., Serginson, M., & Lockley, S.
38	Evolution in industrial plant automation: A case study	2013	This paper presents an abstract model for industrial plant evolution and analyzes it using a detailed case study in the industrial plant automation domain.	Legat, C., Folmer, J., & Vogel-Heuser, B.
39	Industrial automation based on cyber-physical systems technologies: Prototype implementations and challenges	2016	Based on the hands-on experiences gathered from four European innovation projects over the last decade (i.e. SOCRADES, IMC-AESOP, GRACE and ARUM), key challenges have been identified and a prioritization and time-line are suggested with the aim of increasing Technology Readiness Levels and leading to their usage in industrial automation environments.	Leitão, P., Colombo, A. W., and Karnouskos, S
40	What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability	2018	A research model comprising of relevant Industry 4.0-related opportunities and challenges as antecedents for its implementation is hypothesized. In order to test the model, partial least square structural equation modeling is applied for a sample of 746 German manufacturing companies from five industry sectors.	Müller, J. M., Kiel, D., and Voigt, K.
41	Demography Management in Industry 4.0: First Results of a Qualitative Study	2016	In the context of Industry 4.0, a concept of demography management focusing on a holistic life-cycle management is developed in this paper.	Müller, S., Willicks, F., Stiehm, S., Richert, A., & Jeschke, S
42	Humans: Still vital after all these years of automation. Human Factors	2008	The authors discuss empirical studies of human-automation interaction and their implications for automation design.	Parasuraman, R., & Wickens, C. D.

43	The impact of robotics on employment and motivation of employees in the service sector, with special reference to health care	2014	The research studies the impact of robotics, which has both positive and negative impacts on the employment and motivation of employees in the retail sector. So far, there has been no substantial research done into robotics, especially in the health care sector.	Qureshi, M. O., & Syed, R. S.
44	A Complex View of Industry 4.0	2016	This article is focused on the importance and influence of Industry 4.0 and consequently the Internet-connected technologies for the creation of value added for organizations and society. The contribution of the article is mainly conceptual.	Roblek, V., Meško, M., & Krapež, A.
45	The Operator 4.0: Human Cyber-Physical Systems & Adaptive Automation towards Human-Automation Symbiosis Work Systems.	2016	A vision for the Operator 4.0 is presented in this paper in the context of human cyber-physical systems and adaptive automation towards human-automation symbiosis work systems for a socially sustainable manufacturing workforce.	Romero, D., Bernus, P., Noran, O., Stahre, J., & Fast-Berglund, Å.
46	Athena-Advanced technologies for Interoperability of heterogeneous enterprise networks and their applications	2006	The project ATHENA is described in this article as a sophisticated business network to improve collaborations.	Ruggaber, R.
47	Testing a Flexible Manufacturing System Facility Production Capacity through Discrete Event Simulation: Automotive Case Study. World Academy of Science, Engineering and Technology	2016	This paper demonstrates how discrete simulation can address complexity to optimize production line performance	Rybicka, J., Tiwari, A., & Enticott, S
48	Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing	2016	This paper analyzes the incompletely perceived link between Industry 4.0 and lean manufacturing, and investigates whether Industry 4.0 is capable of implementing lean.	Sanders, A., Elangeswaran, C., & Wulfsberg, J.
49	Opportunities of sustainable manufacturing in industry 4.0	2016	This paper will present a state of the art review of Industry 4.0 based on recent developments in research and practice. Subsequently, an overview of different opportunities for sustainable manufacturing in Industry 4.0 will be presented. A use case for the retrofitting of manufacturing equipment as a specific opportunity for sustainable manufacturing in Industry 4.0 is outlined	Stock, T., & Seliger, G.
50	Current practices in field force automation: decision support and information management for the field force	2008	This study seeks to establish a baseline of current FFA practices in field fords and field operations	Trentham, G., & Scholl, H. J.
51	Improving road transport operations through lean thinking: a case study	2017	This paper documents a case study whereby the road transport operations of a leading Mexican brewery were improved through lean thinking and waste reduction.	Villarreal, B., Garza-Reyes, J. A., Kumar, V., & Lim, M. K.
52	Automated test case selection using feature model: an industrial case study	2013	This paper proposes a systematic and automated methodology using a Feature Model for Testing (FM_T) to capture commonalities and variabilities of a product line and a Component Family Model for Testing (CFM_T) to capture	Wang, S., Gotlieb, A., Ali, S., & Liaaen, M.

			the overall structure of test cases in the repository.	
53	Handbook factory planning and design.	2015	This book develops a critical analysis of factory planning.	Wiendahl, H. P., Reichardt, J., & Nyhuis, P.
54	The Future of Industrial Communication: Automation Networks in the Era of the Internet of Things and Industry 4.0	2017	The purpose of this article is to review technological trends and the impact they may have on industrial communication.	Wollschlaeger, M., Sauter, T., & Jasperneite, J.
55	A new asset type: Digital assets	2013	Digital assets are already part of the digital society. These "Digital Assets" are similar to tangible and intangible assets that people want to protect, transfer, sell or inherit. Because of lack of legislation and regulations, the concept of "Digital Asset" causes ambiguity between the digital account service providers and the account users.	Toygar, A., Tapie Rohm C.E., & Zhu, J.
56	Outsourcing and digitized work spaces: Some implications of the intersections of globalization, development, and work practices	2006	The author identifies the tensions and contradictions that the demands for "new" work and new work practices create for communities as they seek access to the benefits of globalization.	Smith, B. Q.
57	The use of technology in the digital workplace: A framework for human resource development	2002	This chapter presents a conceptual framework for thinking about the role of technology in the digital workplace and highlights the challenges faced by HRD professionals in promoting individual and organizational learning and performance improvement.	Benson, A. D., Johnson, S. D., & Kuchinke, K. P.
58	Digitization, 'Big data' and the transformation of accounting information	2014	The article discusses a model for understanding data, information and knowledge relationships. The model is applied to examine developments in strategy, organizational and cost structures, digitization, business analytics, outsourcing, off-shoring and cloud computing.	Bhimani, A., & Willcocks, L.
59	New skills that every worker needs	2013	This article describes ten key skills to cope in a fast-changing environment.	Fidler, D., & Gorbis, M.
60	Corporate learning in times of digital transformation: A conceptual framework and service portfolio for the learning function in banking organizations	2015	This paper follows the research question "how can the learning function foster the enhancement of the banking organization's learning and innovation ability in times of digital transformation?"	Schuchmann, D., & Seufert, S.
61	From eLearning to digital transformation: A framework and implications for L&D	2016	Building on a framework originating in the context of business engineering and applying it to corporate training and human resource development, the article explains what digital transformation implies for the L&D function.	Seufert, S., & Meier, C.
62	How virtualization, decentralization and network building change the manufacturing landscape: An Industry 4.0 Perspective	2014	Eight scientific journals are analyzed though a cluster analysis. These journals were focused on individualized production, end-to-end engineering in a virtual process chain and production networks.	Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M.

63	Human-machine-interaction in the industry 4.0 era	2014	This paper demonstrates solutions for the technological assistance of workers, which implement the representation of a cyber-physical world and the therein occurring interactions in the form of intelligent user interfaces. Besides technological means, the paper points out the requirement for adequate qualification strategies, which will create the required, inter-disciplinary understanding for Industry 4.0.	Gorecky, D., Schmitt, M., Loskyll, M., & Zühlke, D.
64	Lean automation enabled by industry 4.0 technologies	2015	This paper gives an overview of existing combinations of Lean production and automation technology, also called Lean Automation.	Kolberg, D., & Zühlke, D.
65	A categorical framework of manufacturing for industry 4.0 and beyond	2016	This paper focuses on the fundamental conception of Industry 4.0 and the state of current manufacturing systems. It also identifies the research gaps between current manufacturing systems and Industry 4.0 requirements. The major contribution, an implementation structure of Industry 4.0, consisting of a multi-layered framework is described, and it is shown how it can assist people in understanding and achieving the requirements of Industry 4.0	Qin, J., Liu, Y., & Grosvenor, R.
66	Change through digitization—Value creation in the age of Industry 4.0	2015	This article discusses the impact, challenges and opportunities of digitization and concludes with examples of recommended policy action. The two key instruments for enhanced value creation in the Age of Industry 4.0 are platform-based cooperation and a dual innovation strategy.	Kagermann, H.
67	Industry 4.0: Towards future industrial opportunities and challenges	2015	This paper introduces relevant aspects of Industry 4.0 in relation to strategic planning, key technologies, opportunities, and challenges.	Zhou, K., Liu,Y., & Zhou, L.
68	Industry 4.0: the industrial internet of things	2016	This book explores the potential for the Internet of Things (IoT), Big Data, Cyber-Physical Systems (CPS), and Smart Factory technologies to replace people-based systems of offshore locations.	Gilchrist, A.
69	Industry 4.0–An Introduction in the phenomenon	2016	The goal of the paper is to introduce specialists from industry into the important phenomenon of the recent technology and to explain the cyber–physical and informatics background of the platform Industry 4.0 and basic steps in any design and implementation of the Industry 4.0 systems.	Zezulka, F., Marcon, P., Vesely, I., & Sajdl, O.
70	Augmented reality in the smart factory: Supporting workers in an industry 4.0. environment	2014	This article presents an augmented reality system that supports human workers. By providing spatially registered information on the task directly in the user's field of view the system can guide the user through unfamiliar tasks (eg assembly of new products) and visualize information directly in the spatial context where it is relevant	Paelke, V.
71	Promoting work-based learning through industry 4.0	2015	This paper presents the Demonstration Factory of the RWTH Aachen Campus. It features the real production of marketable products as well as an infrastructure tailored to experiment-based production research.	Schuh, G., Gartzen, T., Rodenhauser, T., & Marks, A.
72	Interactions between service and product lifecycle management	2015	The objective of this paper is to identify the interactions between SLM and PLM in manufacturing firms, based on expert interviews and illustrated in	Wiesner, S., Freitag, M., Westphal, I., & Thoben, K.

			PSS use cases.	D.
73	Transforming to a hyper-connected society and economy–towards an “Industry 4.0”	2015	The study examines initial design approaches in the areas of qualifications, leadership and demography-resistant work architectures.	Bauer, W., Hämmerle, M., Schlund, S., & Vocke, C.
74	Holistic approach for human resource management in Industry 4.0	2016	To cope with knowledge and competence challenges related to new technologies and processes of Industry 4.0 new strategic approaches for holistic human resource management are needed in manufacturing companies. A strategic approach for employee qualification is described in this contribution.	Hecklau, F., Galeitzke, M., Flachs, S., & Kohl, H.
75	Sustainable business models and structures for Industry 4.0	2015	The paper addresses the research question of what new and sustainable business models and structures for Industry 4.0 might look like and in which direction existing traditional business concepts have to be developed to deploy a strong business impact of Industry 4.0.	Prause, G.
76	Towards a semantic administrative shell for industry 4.0 components	2016	The paper presents a concept of a Semantic I4.0 Component which addresses the communication and comprehension challenges in Industry 4.0 scenarios using semantic technologies. The approach is illustrated with a concrete example showing its benefits in a real-world use case.	Grangel-González, I., Halilaj, L., Coskun, G., Auer, S., Collarana, D., & Hoffmeister, M.
77	Internet of things, big data, industry 4.0–Innovative solutions in logistics and supply chains management	2017	The aim of this article is to present some ‘smart’ solutions which could be recognized as innovative solutions in both areas: technology and organization.	Witkowski, K.
78	Agile factory-an example of an industry 4.0 manufacturing process	2015	This paper describes the development of an Agile Factory prototype.	Scheuermann, C., Verclas, S., & Bruegge, B.
79	Industry 4.0 development and application of intelligent manufacturing	2016	This paper introduces the development of Industry 4.0, and the Cyber Physical System is introduced with the example of the Wise Information Technology of 120. Then the application of Industry 4.0 in intelligent manufacturing is put forward through the digital factory to the intelligent factory.	Cheng, G. J., Liu, L. T., Qiang, X. J., & Liu, Y.
80	The concept industry 4.0: an empirical analysis of technologies and applications in production logistics	2016	This book examines by means of an empirical study which potential Industry 4.0 technologies have regarding end-to-end digital integration in production logistics based on their functions.	Bartodziej, C. J.
81	The impact of industry 4.0 on procurement and supply management: A conceptual and qualitative analysis	2016	This paper addresses the consequences and potentials of Industry 4.0 for the procurement, supply and distribution management functions.	Glas, A. H., & Kleemann, F. C.
82	Preparing for industry 4.0–collaborative virtual learning environments in engineering education	2016	Based on the technological concept of cyber-physical systems and the internet of things, this paper explores the vision of the smart factory. Future works require new qualifications that are studied in this article.	Schuster, K., Groß, K., Vossen, R., Richert, A., & Jeschke, S.

83	Smart factory for industry 4.0: A review	2015	General support in defining development strategies and policies of its realization, strategically oriented factors, research institutions and supporting institutions are required to implement smart factories.	Hozdić, E.
84	Robots, Industry 4.0 and humans, or why assembly work is more than routine work	2016	This article condenses the key findings of qualitative studies on assembly work. Empirical results challenge the dominant view of assembly work as routine tasks that could easily be replaced by robotics.	Pfeiffer, S.
85	Industry 4.0 Conception	2017	In this study the logistical tendencies and challenges are introduced with reasons and driving forces. The essence of Industry 4.0 conception is also introduced.	Gubán, M., & Kovács, G.
86	Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges	2018	In this paper, a hierarchical architecture of the smart factory was proposed first, and then the key technologies were analyzed from the aspects of the physical resource layer, the network layer, and the data application layer.	Chen, B., Wan, J., Shu, L., Li, P., Mukherjee, M., & Yin, B.
87	Conceiving the model-driven smart factory	2015	The goal of this paper is to present a research agenda to integrate those techniques in manufacturing processes to achieve the Smart Factory vision.	Cadavid, J., Alférez, M., Gérard, S., & Tessier, P.
88	A reference activity model for smart factory design and improvement	2017	This paper introduces a factory design and improvement (FDI) activity model and illustrates a case study of FDI in an electromechanical component factory.	Jung, K., Choi, S., Kulvatunyou, B., Cho, H., & Morris, K. C.
89	Learning factory modules for smart factories in industrie 4.0	2016	This article presents a variety of learning modules for the smart factory in Industry 4.0. It describes the new job profile of employees in Industry 4.0 and thoroughly discusses the various learning modules with their individual learning targets and mapped scenarios.	Prinz, C., Morlock, F., Freith, S., Kreggenfeld, N., Kreimeier, D., & Kuhlenkötter, B.
90	Smart manufacturing: Past research, present findings, and future directions	2016	This paper surveyed and analyzed various articles related to Smart Manufacturing, identified the past and present levels, and predicted the future. The policies of Germany, the U.S., and Korea that have government-driven leading movements for Smart Manufacturing are presented.	Kang, H.S., Lee, J.Y., Choi, S., Kim, H., Park, J.H., Son, J.Y., Kim, B.H. and Do Noh, S.
91	The smart factory: exploring adaptive and flexible manufacturing solutions	2014	This paper reviews the usage of the adjective “smart” in respect to technology and with a special emphasis on the smart factory concept placement among contemporary studies. Due to a lack of consensus of common understanding of this term unified definition is proposed.	Radziwon, A., Bilberg, A., Bogers, M., & Madsen, E. S.
92	Assembly automation and product design	2005	Highlighting the importance of well-designed products, the book covers design for manual assembly, high-speed automatic and robot assembly, and electronics assembly.	Boothroyd, G.
93	Technological systems and economic performance: the case of factory automation	2012	Technological systems in factory automation are presented in this book. It also contains several examples and equations.	Carlsson, B.
94	Automation, production systems, and computer-integrated manufacturing.	2007	This book provides an overview of the market of the technical and engineering aspects of automated production systems.	Groover, M. P.

95	The Application Center Industry 4.0-Industry-driven manufacturing, research and development	2016	The Application Center Industry 4.0, an advanced platform for the cooperative research and development of innovative cyber-physical production systems between the IFF at the University of Stuttgart, the Fraunhofer IPA and cutting-edge manufacturing companies is described in this article.	Landherr, M., Schneider, U., & Bauernhansl, T.
96	A novel methodology for manufacturing firms value modeling and mapping to improve operational performance in the industry 4.0 era	2016	This paper describes a novel methodology for manufacturing value modeling from strategic level down to operational improvements. The methodology and the related mapping and analysis tools have been co-developed with Siemens MES division within Industry 4.0 context. The Manufacturing Value Modeling Methodology (MVMM) is based on 5 steps: Value Map, Maturity Model, Gap and Process Analysis, Validation and Improvement Areas Definition.	Tonelli, F., Demartini, M., Loleo, A., & Testa, C.
97	Industry 4.0, global value chains and international business	2017	This paper aims to provide an assessment of how the widespread adoption of new digital technologies (i.e. the Internet of things, big data and analytics, robotic systems and additive manufacturing) might affect the location and organization of activities within global value chains (GVCs).	Strange, R., & Zucchella, A.
98	Waste reduction possibilities for manufacturing systems in the industry 4.0	2016	This paper presents in detail the fourth industrial revolutions' more important achievements and tools	Tamás, P., Illés, B., & Dobos, P.
99	Lean and Industry 4.0—twins, partners, or contenders? A due clarification regarding the supposed clash of two production systems	2016	This paper explains what Lean really is and how it has to be considered in the context of the Industry 4.0 initiative.	Rüttimann, B. G., & Stöckli, M. T.
100	Smart Industry Research in the Field of HRM: Resetting Job Design as an Example of Upcoming Challenges	2017	This chapter aims to encourage and guide smart industry HRM-related research by addressing upcoming challenges developed using a job design lens.	Habraken, M ., & Bondarouk, T.