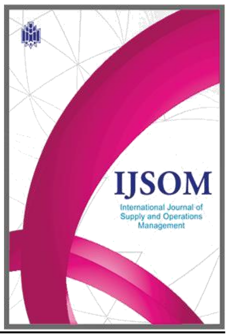
International Journal of Supply and Operations Management

IJSOM

August 2018, Volume 5, Issue 3, pp. 256-265
ISSN-Print: 2383-1359
ISSN-Online: 2383-2525
www.ijsom.com



Challenges and Benefits of Industry 4.0: An overview

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Abstract
The aim of this article is to provide an overview of industry 4.0. Our goal is to give a perspective of what Industry 4.0 is, its challenges in today's context, and present how we have to design and implement future business organizations. Numerous researchers have mentioned that implementing industry 4.0 is a response to the current challenges in fast changing environments. Indeed, in order to improve flexibility, reduce costs and offer customized products, companies must redesign their production processes appropriately. After an introduction to the new context phenomenon of “Industry 4.0”, we provide a comprehensive definition of this new concept and explain the research methodology. Then we present several points of view about challenges and issues of Industry 4.0, and most benefits of this new industrial paradigm are also described. Finally, we end this paper by drawing conclusions and suggesting future research.

Keywords: Industry 4.0; Benefits; Implementation; Challenges.

1. Introduction

Since the 1800s when new manufacturing processes have transformed the industrial landscape, the industrialization technological changes have driven paradigm shifts that are called “industrial (re)evolutions” (Lasi et al., 2014). Currently, industry represents the part of the economy that carries out the production of materials and goods, which are highly mechanized and automatized. Nowadays, the industrial production has reached the edge of a new industrial revolution and the factory of the future has been pictured.

The modern manufacturing systems must be flexible/agile, reactive, integrated and cost-effective simultaneously to enable industrial companies to stay competitive in an international competition. To develop and run such complex systems, manufacturing enterprises need to design and engineer their production processes appropriately and in a systematic way following structured approaches based on sound principles and supported by efficient tools and methods (Schelechtendal et al., 2015).

Recently, the Industry 4.0 concept (as the fourth industrial revolution) has become an increasingly important issue, being discussed and researched by academics, consultants and companies. However, despite the increasing interest in the Industry 4.0 topic, it is still a non-consensual concept. There are still some vague ideas about this new manufacturing paradigm, regarding its implications and consequences. Also, most companies and factories are not aware of the challenges they may face when they want to implement the Industry 4.0 background. Nevertheless, it has been assumed that there is still a misunderstanding in Industry 4.0 about this topic, especially about what involves Industry 4.0 and its meaning and vision. This new production system allows companies to take actions to prepare for this change, defining the most suitable manufacturing model and planning the target roadmaps in order to address the new industrial paradigm’s challenges (MacDougall, 2014).

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Previous studies were conducted to discuss most features of the mutations of globalized market as market demand for individual and specialized products, shorter life-cycles; need of high flexibility and adaptability of product. To find a solution for that in order to be competitive, the industrial work production systems require a new manufacturing process. Automated mass production might become less economically viable.

The purpose of this paper is to provide a comprehensive understanding of the Industry 4.0 concept, with the aim of investigating the challenges, issues, components, benefits, progress and relevance of Industry 4.0 implementation. After this introduction about the new context phenomenon of "Industry 4.0", we present a comprehensive definition of this new concept and explain the research methodology. Then we present several points of view about challenges and issues of Industry 4.0, and most benefits of this new industrial paradigm are also described. Finally, we end this paper by drawing a conclusion and suggesting future research.

2. Research method

A systematic review of the literature was conducted to explore the meaning, challenges, and benefits of Industry 4.0. The research described in this paper has largely been carried out via mobilizing various types of literature review considering the following electronic databases: Elsevier (Science Direct), Scopus, Emerald Insight and Springer, over the 2011-2018 timeframe period, including scientific papers, journals, articles, magazines, newspapers, government reports, EU reports, business reports from companies, and consultants' reports. Throughout the development of this paper, the main purpose is to understand the scope of Industry 4.0 definitions, benefits and challenges.

This methodology enabled us to achieve an overall understanding of the field and current developments and practices described in multiple studies. The first step of the literature review process was the scoping and planning of search terms, in which the keywords "challenges" "opportunities" and "benefits" were searched in combination with the keywords "industry 4.0*", "manufacturing", and "production" in the scientific databases recognized by high quality research hosting. Based on this process, a subset of 45 articles was selected, composing the corpus of papers to be read in full and analysed. The aim is to provide an overview as shown in various tables below.

3. Industry 4.0: a glimpse

Our current business environment is radically changing, and the increasingly demanding and rapidly changing customer needs are the underlying reason that has driven industrial revolutions at different periods. These revolutions have brought to the world drastic changes in diverse areas, posed huge challenges for industries and manufacturers, led to massive innovations and transformations, and remarkably affected people's way of life (Huang, 2017).

Currently, the need for flexibility and real time response to the changes in the market is becoming an essential issue (Schlötzer, 2015). Thus, many companies have adjusted their manufacturing process in order to focus on individualised products in a proper time. As we can observe it, the digitalization and virtualization process ensures and procures several opportunities for manufacturers to create new values and drive innovation to achieve more competitive success in their business. Nowadays, all companies must incorporate innovation in their manufacturing process and in order to sustain in the context of globalization and guarantee more perfection production systems which are characterised by flexibility, adaptability, agility, proactivity and so on. The manufacturing automation (called Industry 4.0 or smart factory) is the ultimate path to this. Therefore, the smart factory plays the main role of optimising the movement of goods by providing the necessary information for the proper operator in the proper moment (Schlötzer, 2015).

The core of this Industry 4.0 is Internet of things which allows connection of machines, products, systems and people. In short, the term Industry 4.0 appeared published for the first time in November 2011 by the German government that resulted from an initiative regarding high-tech strategy for 2020 and since then this concept is used across Europe. In the United States and more generally the English speaking world, terms such as "The Internet of Things" or the "Internet of Everything" are also used (Deloitte, 2014). It can be defined as the embedding of smart products into digital and physical processes. Digital and physical processes interact with each other and with cross-geographical and organizational boundaries (Schmidt et al., 2015). In order to understand Industry 4.0 accurately, some recent definitions are presented including an overview as shown in Table1.

According to Surah et al. (2018), Industry 4.0 as the fourth industrial revolution is characterised by a combination of new technical components and main principles to design and form this concept, in order to get a horizontal and vertical integration or value networks (Schmidt et al., 2015).

Table1. Industry 4.0 definitions

Authors	Industry 4.0 …
Koch et al. (2014)	"The term Industry 4.0 stands for the fourth industrial revolution and is best understood as a new level of organization and control over the entire value chain of the life cycle of products, it is geared towards increasingly individualized customer requirements".
MacDougall (2014)	"Industry 4.0 or Smart industry refers to the technological evolution from embedded systems to cyber-physical systems. It connects embedded system production technologies and smart production processes to pave the way to a new technological age which will radically transform industry and production value chains and business models".
McKinsey Digital (2015)	"Industry 4.0 seen as a digitization of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous cyber physical systems, and analysis of all relevant data".
Deloitte AG (2015)	"The term Industry 4.0 refers to a further development stage in the organization and management of the entire value chain process involved in manufacturing industry"
Geissbauer et al. (2016)	"Industry 4.0 - the fourth industrial revolution, focuses on the end-to-end digitization of all physical assets and integration into digital ecosystems with value chain partners".
Pfohl et al. (2015)	"Industry 4.0 is the sum of all disruptive innovations derived and implemented in a value chain to address the trends of digitalization, automization, transparency, mobility, modularization, network collaboration and socializing of products and processes".
Hermann et al. (2015)	"Industrie 4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industrie 4.0, CPS monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT, CPS communicate and cooperate with each other and humans in real time. Via the IoS, both internal and cross organizational services are offered and utilized by participants of the value chain".

*Adapted from (Huang, 2017)

The main components that form the concept of Industry 4.0 are:

1- Identification (RFID systems): The first step is the identification of the processing good.

2- Locating (RTLS): Identification used to be associated with locating or recording the place of identification; in order to locate it, real time locating systems (RTLS) are used.

3- Sensing or Cyber-physical system (CPS): It is the term that describes the unification of digital (cyber) with real (physical) workflows. In manufacturing, this means that the physical production steps are accompanied by computed-based processes, using the concept ubiquitous computing. A CPS includes sensors and actuators by which it can collect and send data. Sensing provides the function of the right condition for the logistics system.

4- Networking or Internet of things (IoT): With IoT, enterprises can supervise their every product in real time and manage their logistics architecture. IoT is part of the CPS that enables the communication with other CPS and between the CPS and users.

5- Data collection and analysis (Big Data and Data Mining): Logistics 4.0 implies a huge increase of variety, volume and velocity of data creation. The types and amount of collected data have increased because of the advances in sensor technology and the products containing computed capacities.

6- Business Service or Internet of services (IoS): This enables service vendors to offer their services via Internet. It consists of participants, infrastructure for services, business models and the services themselves.

The main implementation principles as reviewed in several researches (L. Domingo, 2016; Obitko and Jirkovsky, 2015) and recognised by The German Commission for Electrical, Electronic & Information Technologies of DIN and VDE (2013) are:

1- Interoperability, where standardization and semantic descriptions are important, since it means that companies, humans and CPS are connected by IoT and IoS.

2- Virtualization, over the CPS, the physical world can be linked to the virtual. In other words, the data from sensors are linked to virtual and simulation models. Thus, a virtual copy of the physical world is created and enables the CPS to monitor physical processes.

3- Real time capability, a continuous data analysis is needed to react to any changes in the environment in real time, such as routing or handling failures.

4- Decentralization, that means giving autonomy, resources and responsibility to lower levels of the organizational hierarchy. Individual agents have to make decisions on their own and delegate the decisions to higher levels in the event of failures or complex situations.

5- Service orientation. Service-orientated architecture (SOA), an architectural pattern in computer software design in which application components provide services to other components via a communication protocol, typically over network, allows encapsulation of various services to combine them and to facilitate their utilization.

6- Security of information and its privacy shall be emphasized in the data exchange using ICT technologies.

In short, industry 4.0, as the fourth industrial revolution, has a mission to emphasize the end-to-end digitization of all physical assets and integration into digital ecosystems with value chain partners; it refers to an extra development step in the organization and management of the entire value chain process involved in the manufacturing industry. This new concept means a combination of technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industry 4.0, the CPS monitors physical processes, creates a virtual copy of the physical world and makes decentralized decisions. Over the IoT, the CPSs communicate and cooperate with each other and with humans in real time. Via the IoS, both internal and cross organizational services are offered and utilized by participants of the value chain for increasingly individualized customer requirements and products (Koch et al., 2014).

4. Challenges and Issues of implementing industry 4.0

According to Pereira et al. (2017), the quest of applying Industry 4.0 brings diverse technological challenges, with high influences on many dimensions in today’s manufacturing industry. Thus, it is essential to develop a strategy for all the actors involved in the entire value chain, to reach a consensus on security issues and the relevant architecture before implementation begins (Wan, and Zhou, 2016). Moreover, numerous authors state that implementing Industry 4.0 is a hard mission and it is likely to take ten or more years to be realized. Adopting this new manufacturing process involves many aspects, and faces many types of difficulties and challenges, including scientific, technological, and economic challenges, social problems as well as political issues.

The most challenging aspects for the organizations that wish to adopt this new approach are touch skills and qualifications of their workers concerning e.g. problem-solving skills, failure analysis, the ability to deal with constant changes and completely new tasks. Indeed, they should be able to trial with specific Industry 4.0 technologies with new complexity tasks: the collection, processing and visualization of manufacturing process data (Hendrik Unger et al., 2017). As we know at this moment there are few studies in the field of engineering and management teaching and needs of students and of the industrial workforce are changing (Barbara Motyl et al., 2017). Industry 4.0 will lead to potential deep changes in several domains that go beyond the industrial sector and allow the creation of new business models (Carvalho et al., 2018).

Other challenges and issues of firms are related to innovation, technological components, digital transformation advancements and the rising interconnectivity developments which play an important role in every organization. As mentioned above, Industry 4.0 which consists of providing a new way of manufacturing is closely associated with the end-to-end digitization of all physical assets and with the integration into digital ecosystems of all value chain partners. Though, according to a McKinsey and company study (2015), the majority of companies, especially the small and medium-sized enterprises in the industry, seem rather unwilling to start the digital transformation process and the hesitation has to do with a number of implementation barriers faced by manufacturers with no/limited progress in Industry 4.0 (D, Kü sters et al., 2017). Iyer (2018) indicates that manufacturing is now bringing about both opportunities and challenges, so neither business leaders nor policy makers can rely on old responses in the new manufacturing environment. Thus, a serious challenge of manufacturers will be to address decision-making based on a number of factors: wages, inventory, requirements, logistics etc. to name a few. The result could very well be a new kind of global manufacturing company—a networked enterprise that uses “big data” and analytics to respond quickly and decisively to changing conditions and can also pursue long-term opportunities. “Even though we have all the enablers to make Industry 4.0 feasible such as connectivity technology, affordable IoT hardware, standardized communication protocol, collecting meaningful data and analyzing for implications are still the biggest challenges to driving the impact from Industry 4.0.” (McKinsey and company, 2015; p. 45). In short, Table 2 provides an overview of the main challenges and issues of implementing Industry 4.0.

Table 2. Challenges and Issues of implementing industry 4.0

Authors	Industry 4.0: challenges and issues
Dennis Kü sters et al. (2017)	– Uncertainties about financial benefits due to a lack of demonstrated business cases justifying investments – No strategy to coordinate actions across different organizational units – Missing talent and capabilities, e.g. data scientists – A lack of courage to push through radical transformation – Cybersecurity concerns with third-party providers
Samuel Nilsen and Eric Nyberg (2016)	– Horizontal integration through value networks – Vertical integration – Life cycle management and end-to-end engineering – The human being as a conductor for added value
T. Stock and G. Seliger (2016)	– The manufacturing equipment will be characterized by the application of highly automated machine tools and robots. The equipment will be able to flexibly adapt to changes in the other value creation factors, e.g. the robots will be working together collaboratively with the workers on joint tasks. – The current jobs in manufacturing are facing a high risk for being automated to a large extent. The numbers of workers will thus decrease. The remaining manufacturing jobs will contain more knowledge work as well as more short-term and hard-to-plan tasks. The workers increasingly have to monitor the automated equipment, are being integrated in decentralized decision-making, and are participating in engineering activities as part of the end-to-end engineering. – The increasing organizational complexity in the manufacturing system cannot be managed by a central instance from a certain point on. Decision making will thus be shifted away from a central instance towards decentralized instances. The decentralized instances will autonomously consider local information for the decision making. The decision itself will be taken by the workers or by the equipment using methods from the field of artificial intelligence. – Additive manufacturing technologies also known as 3D printing will be increasingly deployed in value creation processes, since the costs of additive manufacturing have been rapidly dropping during the last years by simultaneously increasing in terms of speed and precision. This allows designing more complex, stronger, and more lightweight geometries as well as the application of additive manufacturing to higher quantities and larger scales of the product.
Wan et al. (2016)	– Intelligent Decision-Making and Negotiation Mechanism: In smart manufacturing system needs more autonomy and sociality capabilities as key factors of self-organized systems whereas the today's system have 3C Capabilities i.e. lack of autonomy in the systems . – High Speed IWN Protocols: The IWN network used today can't provide enough bandwidth for heavy communication and transfer of high volume of data but it is superior to the weird network in manufacturing environment. – System Modeling and Analysis: In system modeling, to reduce dynamical equations and conclude appropriate control model, systems should be modelled as self-organized manufacturing system. The research is still going on for complex system. – Modularized and Flexible Physical Artifacts: When processing a product, Equipment for machining or testing should be grouped and worked together for distributed decision making. So there is a need of creating modularized and smart conveying unit that can dynamically reconfigure the production routes.
Saurabh Vaidya et al. / Procedia Manufacturing 20 (2018) and Laura Doming (2016)	– Cyber Security: With the increased connectivity and use of standard communications protocols that come with Industry 4.0, the need to protect critical industrial systems and manufacturing lines and system data from cyber security threats increases dramatically. – Manufacturing Specific Big Data and Analytics: It is a challenge to ensure high quality and integrity of the data recorded from manufacturing system. The annotations of the data entities are very diverse and it is an increasing challenge to incorporate diverse data repositories with different semantics for advanced data analytics. – Investment Issues: Investment issue is rather general issue for most of new technology based initiatives in manufacturing. The significant investment is required for implementing industry 4.0 is an SME initially. The implementation of all the pillar of industry 4.0 requires huge amount of investment for an industry. – Reduction of the development and innovation periods. High innovation capability is turning into an essential success factor for many companies – Individualization sales. Over the time, the buyers have gained the chance to define the conditions of the trade. This trend leads to an increasing individualization of products. It is called "batch size one" – Flexibility. Due to the characteristics of the markets is essential flexibility in the production – Decentralization. To deal with the new framework requirements, faster decision making procedures will be necessary. This is why organizational hierarchies need to be reduced – More sustainability. The aim is an economic and ecological efficiency in the production, due to the increase of the prices for resources as well as the social change in ecological aspects

In order to boost companies which are moving towards Industry 4.0 and to their digital transformation, several studies (Yasanur Kayikci, 2018; Lopes Nunes et al., 2017) show opportunities and focus on benefits of the new manufacturing process. Thus, the new market landscape and the future industrial sector including the smart process represent several opportunities regarding profitability and growth, enhancing the competitiveness of organizations. Furthermore, starting to invest in the smart factory means deep changes, in every aspect of organizations value chain, such as product development processes, marketing, manufacturing, logistics, after-sales services and security (Lopes Nunes et al., 2017).

5. Benefits of Industry 4.0

As mentioned before, the smart products integration with smart production, smart logistics and smart networks and Internet of Things result in the transformation of current value chains and the emergence of new and innovative business models, making the smart factory the key element of future smart infrastructures. From this new infrastructure perspective, several benefits and profits will arise (C Vila et al., 2017). In fact, virtual and augmented prototyping provides a full understanding of product features and benefits, facilitating the interactive exploration of the all products functionalities between every stakeholder. Industry 4.0 provides a new way of doing business and a new source of creating value, especially for traditional manufacturing companies. … One of the biggest disruptions of Industry 4.0 is the ever-increasing value and importance of data. Companies need to think about data as a precious raw material. Therefore, companies will need to change the way they think about and manage large amounts of data and information. This will be one of the biggest challenges for traditional manufacturing companies" (McKinsey and company; 2015, P 45). Employing dynamically programmable production technology in combination with increased flexibility of the machine itself (e.g., flexible grip hooks) has multiple benefits, among which are individualized customization, more dynamic allocation of resources/capacity, shorter changeover times, and reduced production complexity with fewer constraints. This allows for faster, cheaper, easier, and more diverse production processes. Industry 4.0 has many benefits for firms in different dimensions. Table 3 summarizes some of the most important benefits and opportunities. As we can observe from the table above, Industry 4.0 provides numerous benefits, for example the reduction of labour costs, the simplification of business processes and the reduction of inventory inaccuracies, as well as more transparency in logistics processes (Logistics cost ; Delivery time; Transport delay Changes in amount of delayed shipment; Inventory reduction ; Loss/damage ; Frequency of service ; Forecast accuracy ; Reliability ;Flexibility ;Transport volumes ; Applications and so on). All of these are keys to increased productivity and revenue which can, hence, stimulate economic growth (Carl Jan du Plessis, 2017).

6. Conclusion and future work

The main aim of this paper was to provide an overview of Industry 4.0 meaning, challenges and benefits of implementing Industry 4.0. We tried to present the review for the current and future features of the concept of Industry 4.0 which exhibited that the connection of humans, objects and systems that forms dynamic, real-time optimized and self-organizing, cross-company value creation networks impacts all the processes of the organization when the company decides to adopt this new way of producing. For example, it requires increased data volumes and availability in real time which needs new infrastructures. However, some clear benefits can be identified from the implementation of Industry 4.0 as flexibility, quality standards, efficiency, and so on. Hence, this will allow companies to meet customers' demands, creating values. Nevertheless, the majority of companies are hesitant to begin their digital transformation processes due to serious implementation barriers that include uncertainties about financial benefits and a lack of specialist knowledge.

Table 3. Benefits of Industry 4.0

	Industry 4.0 benefits
Ekaterina Uglovskaia (2017)	– Advanced planning and controlling with relevant, real-time data – Rapid reaction to changes in demand, stock level, errors – Sustainable manufacturing/ resources efficiency (materials, energy, people) – Higher quality, flexible production – Increased productivity – Ad-hoc reaction to market changes – Personalization of products – New level of customer satisfaction – Increase in competitive advantage by the successful digital business model implementation and technology creation – Costs and wastes reduction – Safer work conditions – New work places – Work-life balance – Increase in revenue – Innovative company's image

Table 3. Continued

	Industry 4.0 benefits
M.W. Waibel et al. (2018)	– Reduction of overproduction and waste – Reduction of energy consumption as energy intensive tasks can be done when there is overproduction. Use of energy recovery for the whole system. – Reduction of waste especially in the product development phase – Reduction of transportation and travel effort – Saving of natural resources – Contribute to the environmental dimension of existing manufacturing plants
T. Pereira et al. (2017)	– Decentralized and digitalized production, where the production elements are able to autonomously control themselves – The products will become more modular and configurable, promoting mass customization in order to meet specific customer requirements – New innovative business models :, value chains are becoming more responsive, increasing competitiveness through the elimination of barriers between information and physical structures – Digitization consists in convergence between physical and virtual worlds and will have a widespread impact in every economic sector. – The main driver for innovation, which will play a critical role in productivity and competitiveness. – Transforming jobs and required skills : avoid what is known as technological unemployment, redefining current jobs and taking measures to adapt the workforce for the new jobs that will be created – New competencies and it is necessary to create opportunities for the acquisition of the required skills through high quality training
Hugo Karre et al. (2017)	– Workers will have a much greater share of doing complex and indirect tasks such as collaborating with machines in their daily work; – Workers will have to (1) solve unstructured problems, (2) work with new information, and (3) carry out a number of non-routine manual tasks. – Reinforcing physical abilities such as strength or fine motor skills and lowering the physical work related strain by using exoskeletons, positioning devices, robots or automation of monotonous tasks ; Lowering the required short-term memory effort by visualizing detailed and on demand information (users obtain relevant information when he/she needs it and in a form that he/she can comprehend it) ; Reducing the number of errors made on the shop floor by real-time observation of the process and skill- /ability based work instructions
Yasanur Kayikci / (2018)	– Logistics cost : Changes in logistics cost savings in terms of transport, warehousing, inventory carrying and administration costs – Delivery time : Changes in delivery improvements, cycle time, lead time – Transport delay Changes in amount of delayed shipment – Inventory reduction : Changes in inventory volume – Loss/damage : Changes in amount of lost and/or damaged goods from damage, theft and accidents – Frequency of service : Changes in utilization rate (load factor), frequent intervals – Forecast accuracy : Changes in demand uncertainties – Reliability : Changes in logistics quality in terms of transport, inventory and warehousing e.g. perfect order, scheduled time deliveries – Flexibility : Changes in planning conditions e.g. percentage of non-programmed shipments executed without undue delay – Transport volumes : Changes in total transported freight volume – Applications : Suitable applications for digitization in logistics processes
McKinsey and Company (2015)	– Large increase in all operational efficiencies with the use of data levering to improve processes – Industry 4.0 is seen as one of the major drivers for the growth of revenue levels, even as its implementation will also require significant investments by businesses. – logistics and statistics are generated and collected in an automated manner, so responses are faster – the growth it stimulates will lead to a 6% increase in employment over the next ten years
BCG study (2015)	– Increased productivity : The automotive industry alone, productivity is expected to increases by 10–20%, once Industry 4.0 is fully implemented – the growth it stimulates will lead to a 6% increase in employment over the next ten years
Koch et al. (2014)	– Increased productivity: operational efficiencies will increase by an average of 3.3% annually for the following five years leading to an average annual reduction in costs of 2.6%. – Revenue will increase faster and higher than the costs incurred to automate or digitise the manufacturing process in terms of Industry 4.0. – with Industry 4.0 concepts and methods applied, logistics and statistics are generated and collected in an automated manner, so responses are faster

References

Almada-Lobo, F. (2016). The Industry 4.0 Revolution and the Future of Manufacturing Execution Systems (MES). *Journal of Innovation Management*, Vol. 3(4), pp. 16–21.

Andersson, P., and Mattsson, G. L. (2015). Service Innovations Enabled by the Internet of Things. *IMP Journal*, Vol. 9(1), pp. 85–106.

Andrea B., and Jiří T. (2017). Requirements for Education and Qualification of People in Industry 4.0. *27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017, Modena, Italy*, pp. 2195 – 2202

Arroyo, L., Murillo, D., and Val, E. (2017). *Trustful and Trustworthy: Manufacturing Trust in the Digital Era. Barcelona: ESADE Roman Llull University Institute for Social Innovation; EY Fundación Espana*. Campus barcelona sant cugat Barcelona (Spain) 2017.

Baena, F., Guarin, A., Mora, J., Sauza, J., and Retat, S. (2017). Learning factory: The path to ındustry 4.0. *Procedia Manufacturing*, Vol. 9, pp. 73–80.

Barbara M., Gabriele B., Stefano U., Domenico S., Stefano F. (2017). How will change the future engineers' skills in the Industry 4.0 framework? A questionnaire survey. *27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017, Modena, Italy,* pp. 1501-1509.

Cordes, F., and Stacey, N. (2017). *Is UK Industry Ready for the Fourth Industrial Revolution? Boston, MA:* The Boston Consulting Group. Boston, MA, USA, 2017.

Deloitte. (2015). Industry 4.0. *Challenges and solutions for the digital transformation and use of exponential technologies*. 45774A Deloitte Zurich Switzerland 2015.

Dennis K., Nicolina P., and Yves-Simon G. (2017). Textile Learning Factory 4.0 – Preparing Germany's Textile Industry for the Digital Future. *7th Conference on Learning Factories, CLF 2017* Procedia Manufacturing, Vol. 9, pp 214 – 221

Fabian S. (2015). The Dynamics of the Digitalization and its implications for companies' future Enterprise Risk Management systems and organizational structures. MSc. in Business, Language and Culture: Leadership and Management Studies Copenhagen Business School, 2015.

Foidl H. and Felderer M. (2016). Research Challenges of Industry 4.0 for Quality Management. in Innovations in Enterprise Information Systems Management and Engineering, Springer, pp. 121–137.

Hans-Christian Pfohl, Burak Yahsi and Ta. (2015). The Impact of Industry 4.0 on the Supply Chain. Proceedings of the Hamburg Inter Innovations and Strategies for Logistics, Vol 20 (2015) pp. 30 – 58.

Hendrik U., Frank B., Egon M. (2017). Context related information provision in Industry 4.0 environments. *27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017, Modena, Italy*, pp.796-805

Hermann, M., Pentek, T. and Otto, B. (2015). Design principles for Industrie 4.0 scenarios: A literature review. HICSS '16 Proceedings of the 2016 49th Hawaii International Conference on System Sciences Vol. 49 (2016), pp 3928-3937.

Hofmann, E., and Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry,* Vol. 89, pp. 23-34.

Roeder I., Wang W.M., Muschard B. (2017). In: R. Stark, G. Seliger, J. Bonvoisin (Eds.), "*Sustain. Manuf. Challenges, Solut. Implement. Perspect*". Springer International Publishing, Cham, pp. 255–276.

Iyer, A. (2018). Moving from Industry 2.0 to Industry 4.0: A case study from India in leapfrogging. "Smart manufacturing" *15th Global Conference on Sustainable Manufacturing / Procedia Manufacturing,* Vol.21 (2018), pp. 663–670

Ríos J., Mas F., Marcos M., Vila C., Ugarte D., and Chevrot T. (2016). Accelerating the adoption of Industry 4.0 supporting technologies in manufacturing engineering courses. *Congreso Universitario de Innovación Educativa en las Enseñanzas Técnicas,* Vol.24 (2016), pp. 100-111

Zhou K., Liu T., and Zhou L. (2016). Industry 4.0: Towards Future Industrial Opportunities and Challenges. *in International Conference on Fuzzy Systems and Knowledge Discovery*, Vol.2016 (12), pp. 2147–2152

Thoben K.D., Wiesner S., and Wuest T., (2017). Industrie 4.0 and Smart Manufacturing- A Review of Research Issues and Application Examples. *International Journal of Automation and Technology,* Vol.11 (1), pp. 4-16.

Koch, V., Kuge, S., Geissbauer, R. and Schrauf, S. (2014). Industry 4.0: Opportunities and challenges of the industrial internet. Tech. Rep. TR 2014-2, PWC Strategy GmbH, United States, New York City, New York (NY).

Gehrke L., Kühn A., Rule D., Moore P., Bellmann C., and Siemens S. (2015). A Discussion of Qualifications and Skills in the Factory of the Future: A German and American Perspective. VDI The Association of German Engineers, Düsseldorf, Germany.

Lee, J., Bagheri, B., and Kao, H. A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters*, Vol. 3, pp. 18-23.

Liang, Y. C., Lu, X., Li, W. D., and Wang, S. (2018). Cyber Physical System and Big Data enabled energy efficient machining optimisation. *Journal of Cleaner Production*, Article in Press.

Lu, Y. (2017). Industry 4.0: a survey on technologies, applications and open research issues. *Journal of Industrial Information Integration*, Vol. 6, pp 1-10

Lopes Nunes M, Pereira A.C and Alves A.C. (2017). Smart products development approaches for Industry 4.0. *Manufacturing Engineering Society International Conference 2017, MESIC 2017,* Vigo (Pontevedra), Spain. pp. 1215–1222

McKinsey and Company. (2015). Industry 4.0: How to navigate digitization of the manufacturing sector. Tech. rep., McKinsey and Company, New York City, New York (NY).

Morrar, R., Arman, H., & Mousa, S. (2017). The Fourth Industrial Revolution (Industry 4.0): A Social Innovation Perspective. *Technology Innovation Management Review*, Vol. 7(11), pp. 12–20.

Obitko, M., and Jirkovsky, V. (2015). Big Data Semantics in Industry 4.0. In Industrial Applications of Holonic and Multi-Agent Systems. Springer

Pereira A.C., Romero F., (2017). A review of the meanings and the implications of the Industry 4.0 concept, *Procedia Manufacturing*, Vol.13, pp. 1206-1214.

PwC. (2017). Industry 4.0: The Current State of Play in Flemish Manufacturing. Press Release. PwC, March 31, 2017. Accessed November 1, 2017: https://www.pwc.be/en/news-publications/press/2017/industry4-0-the-current-state-of-play-in-flemish-manufacturing.html.

R¨ussmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P. and Harnisch, M. (2015). Industry 4.0: The future of productivity and growth in manufacturing industries, *https://www.bcg.com/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries.aspx*

Robert D., and Tim C. (2017). Review of socio-technical considerations to ensure successful implementation of Industry 4.0, Alistair Smith *27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017, Modena, Italy*, pp. 1288-1295

Wang S., Wan J., Li D., Zhang C., (2016). Implementing Smart Factory of Industrie 4.0: An Outlook. *International Journal of Distributed Sensor Networks,* Vol. *2016*, pp 1-10.

Saurabh V., Prashant A., and Santosh B. (2018). Industry 4.0 – A Glimpse. *2nd International Conference on Materials Manufacturing and Design Engineering/ Procedia Manufacturing*, Vol. 20, pp. 233–238.

Schmidt, R., Möhring, M., Härting, R.-C., Reichstein, C., Neumaier, P., and Jozinović, P. (2015) "*Industry 4.0-Potentials for creating Smart Products: Empirical Research Results*". Germany: Springer

Schmitt, K. (2017). Top 5 Reasons Why Industry 4.0 Is Real And Important. Digitalist Magazine, Accessed July 26, 2017:https://www.digitalistmag.com/industries/manufacturing-industries/2013/10/15/top-5-reasons-industry-4-0-real-important-0833970

Stock T., and Seliger G. (2016). Decoupling Growth from Resource Use Opportunities of Sustainable Manufacturing in Industry 4.0. *13th Global Conference on Sustainable Manufacturing CIRP*, Vol. 40, pp. 536 – 541.

Huang T. (2017). *Development of Small-scale Intelligent Manufacturing System (SIMS) - A case study at Stella Polaris*. AS UIT Faculty of Engineering Science and Technology the Artic UNIVERSITY OF NORWYA.

Waibel, M. W., Steenkamp, L. P., Moloko, N., and Oosthuizen, G. A. (2017). Investigating the Effects of Smart Production Systems on Sustainability Elements. Procedia Manufacturing, Vol. 8, pp. 731-737.

Wegener, D. (2015). Industry 4.0 - vision and mission at the same time. Industry 4.0- Opportunities and challenges of the industrial internet, in *First International Symposium on Supply Chain 4.0: Trends, Challenges and Opportunities from the 4th Industrial Revolution* August 28-29, 2017, Limeira, Brazil. Vol. 01 (2017), pp. 90-91.

Yasanur K. (2018). Sustainability impact of digitizationin logistics. 15th Global Conference on Sustainable Manufacturing Procedia Manufacturing. Vol. 21(2018), pp. 782–789.