Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 107 (2022) 9–14

www.elsevier.com/locate/procedia

55th CIRP Conference on Manufacturing Systems

Supply Chain Management 4.0: Looking Backward, Looking Forward

M.D. Khan, D. Schaefer.*[b], J Milisavljevic-Syed*

[a]Systems Realization Laboratory, School of Engineering, University of Liverpool, Brownlow Hill, Liverpool L69 3GH, United Kingdom

*[b]School of Engineering, University of Lincoln, Brayford Pool, Lincoln, LN6 7TS, United Kingdom.

* Corresponding author. Tel.: +44 151 795 7362. *E-mail address:* j.milisavljevic-syed@liverpool.ac.uk

Abstract

About ten years ago, a bold vision with a prospect of largely autonomous factories of the future with digitized processes, data-driven smart applications, and seamlessly integrated supply chains was born and quickly became known as Industry 4.0 or aka the 4th Industrial Revolution. A true game-changer, Industry 4.0 has revolutionized the possibilities of advanced manufacturing across the manufacturing sector at large. However, the advancement of supply chains and supply chain management that are essential elements of the wider production engineering process has not yet reached the same level of maturity. The purpose of this paper is to review the state-of-art of supply chain management within the context of Industry 4, from both an academic and industry perspective. The authors will discuss the key elements of typical supply chains in terms of what has already been achieved and identify important research challenges to be addressed over the course of the next 5-10 years. The content obtained was done through a combination of a supply chain management workshop at the University of Liverpool in 2020 and an extensive literature review. The unique contribution of this work is finding how each identified supply chain management element e.g., procurement has progressed within the context of I4 in both academia and industry, focusing on State-of-Art and future challenges.

Keywords: Industry 4.0; Supply Chain 4.0; Smart Manufacturing; Factories of the Future

1. Introduction

About ten years ago emerged a need for disruptive change in the manufacturing sector driven by increasing demand to meet customers' individual preferences in a more timely and cost-effective manner that triggered the initial vision of Industry 4.0 (I4). This vision first appeared in Germany in 2011[5], where German chancellor Angela Merkel gave one of the first I4 definitions "The comprehensive transformation of the whole sphere of industrial production through the merging of digital technology and the internet with conventional industry."[5]. However, from an engineering perspective I4 includes elements such as smart data processing for more competitive manufacturing, virtualisation of processes, a shift from manual data processing and decision-making to automated and increasingly autonomous computer-based decision-making in near real-time and supported by artificial intelligence and smart actions. This is in addition to new data-driven business models[6], as well as a range of activities aimed at democratising innovation, design, and manufacture[7-9].

Within Industry 4.0, there is a need to track manufacturing processes in real time and adjust or optimize manufacturing systems accordingly to changing customer and market conditions[10]. In addition, supply chains must be able to cope with demand fluctuations, uncertainty, and external disturbances by working towards a "digital" or "smart" supply chain which integrates Supply Chain Management (SCM) elements with Industry 4. However, within SCM there are multiple elements e.g., manufacturing, warehousing, procurement etc. Therefore, an analysis must be done on the current state of each element in terms of what has already been achieved in industry and academia as well as the current challenges that need to be overcome. The methodology used is a combination of content from a Supply Chain Management 4.0 workshop at the University of Liverpool in 2020, in which keynote speakers were invited to fulfil the aim of the workshop on identifying key research challenges within their supply chain management domain and future research directions for the next 5-10 years. This workshop was supplemented by an extensive literature review to not become outdated on SCM 4.0.

10.1016/j.procir.2022.04.002

The overarching aim of this paper is to provide a clear vision on how supply chain management may change in the context of I4, a review of the state-of-the-art, and the identification of research and industry issues to be addressed to achieve the outlined vision. The organization of the paper is as follows. In Section 2, the building blocks of SCM are presented followed by a state-of-art review of each SCM element in the context of I4 enabling technologies in both academia and industry. In Section 3, major research challenges for each supply chain element are identified. The implications for managers, researchers and public bodies are presented in Section 4. Lastly, conclusions drawn from this review along with directions for future work are presented in Section 5.

2. Supply Chain Management Elements

To explore the State-Of-Art of SCM in the context of I4, the building blocks of SCM must be presented. According to Chartered Institute of Procurement and Supply (CIPS) [11] there are six components which form the traditional SCM system: Planning, Sourcing (Procurement), Demand and Inventory (Warehousing), Manufacturing, Delivery and Logistics, and Returning. The Returning element will not be analysed in this paper due to the lack of industry data and current academic literature. The supply chain workforce is also included in this review as they are involved in each of the SCM elements. This section will provide a State-of-Art review on each component.

2.1 Planning

With a dynamic and ever-changing world, supply chain planning systems must be able to cope with complexities it faces. With the introduction of I4 technologies, it should be the case that planning becomes easier. However, most businesses still rely on outdated manual systems as seen in Figure 1. According to [3] nearly 75% of supply chain functions still use spreadsheets and 53% use SAP, which will stop its support in 2027. From the survey, 60% of executives plan to implement AI based methods in the future.

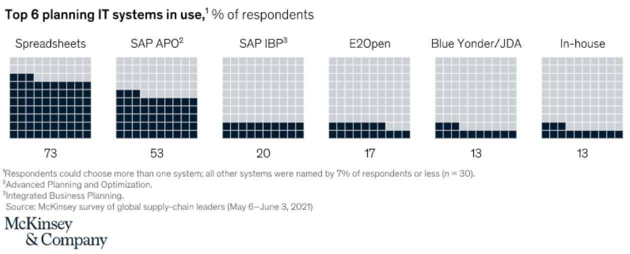

Figure 1-Top 6 planning IT systems in use, % of respondents [3]

2.2 Sourcing (Procurement)

Procurement is a major part of the supply chain process and aims to change the way materials are sourced, improve collaboration with suppliers, become more active in supplier risk management and improve the planning process through digital technologies[12]. According to a survey conducted by Bienhaus, 2018 [13], the results point out that procurement is focused on strategic decisions and is extended on collecting, analysing, and processing the data within its environment to support the organisation and supply chain in its efficiency and effectiveness. At present, the level of Procurement 4.0 implementation varies widely across the industry. From a survey conducted by Forrester, 2019 [14] with 417 procurement leaders nearly two-thirds (65%) of organization's have self-assessed their procurement maturity as advanced. However, using the Forrester maturity framework it is found that only 12% have truly become advanced, leaving the vast majority at risk of lagging behind their competitors who are more effective in the procurement process.

2.3 Demand and Inventory (Warehousing)

With the ever-fluctuating customer demand, the supply chain must accurately forecast future demand and strike a balance between inventory levels and meeting customer needs without creating a surplus. COVID-19 has heightened the importance of managing consumer demand [15]. With the advancements in Artificial Intelligence (AI), it is possible to predict real time demand which allows for efficient inventory control. Most of the publications relating to demand management focus on using AI methods such as deep learning. [16] evaluate and compare artificial neural network (ANN), convolutional neural network (CNN) and long short-term memory (LSTM) for forecasting sales in Ecuador. [17] use ARIMAX and neural networking to significantly improve inventory performance through demand prediction improvement. Thomassey [18] also uses advanced methods such as fuzzy logic, neural network, and data mining for predicting clothing demand. [19] use a multivariate approach where combining both ARIMAX and ML based models give greater confidence in demand prediction within the assembly industry. When comparing with traditional methods, AI methods can remove data set defects e.g., lack of historical data and provide most accurate demand predictions [20].

Warehousing is undergoing rapid changes due to two main trends. Firstly, customer expectations and service requirements are fueling a demand for warehouses or distribution centers to be agile and responsive[2]. Secondly with the advent of emerging technologies e.g., Augmented Reality (AR), autonomous vehicles, IoT, collaborative robots etc. there is a need to integrate both entities. Hence, more work is needed for management systems involving other I4 technologies that are predicted to be greatly adopted over the coming years as seen in Figure 2.

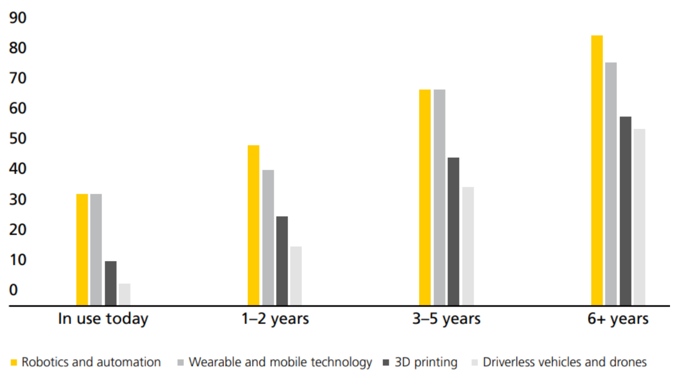

Figure 2-Planned Adoption Rates for Warehouse Technologies [2]

With the increase in demand for storage space in warehouses, an increase in the use of smart technologies e.g., (AR) using smart glasses to locate items for workers, is being implemented [21] and already has shown to increase a worker's performance by 34% on first usage[22]. The use of autonomous systems is also increasing in warehouses, however autonomous machines transporting goods within a warehouse must also cope with unexpected occurrences as they normally have a predefined route e.g., a blockage occurs on the route with an item in the way. Developing AI using deep learning, to train the machine with a range of unexpected environmental to make decisions without the use of a human, is being developed[23] and will be expanded to most companies into the future. Dark Warehousing is also a recent concept in which material handling and all warehousing activities are fully automated, hence removing all human labor [24]. However, in industry, there is a lack of implementation with only Ocado and Walmart being the most prominent examples of implementing a near fully automated warehouse [24].

2.4. Smart Factory/Manufacturing

Smart Factory relates to a highly digitalized and networked manufacturing facility[25]. The pressure on lower cost and higher quality, high demand and so on, are the driving forces that are changing the landscape of the manufacturing systems and creating the need for better process plans, quality control, and energy optimization. Smart manufacturing is on the digital roadmap connecting and exchanging information between manufacturing monitoring and execution with process planning for manufacturing resulting with better quality and function of product, shorter lead time, and energy label as seen in Figure 3.

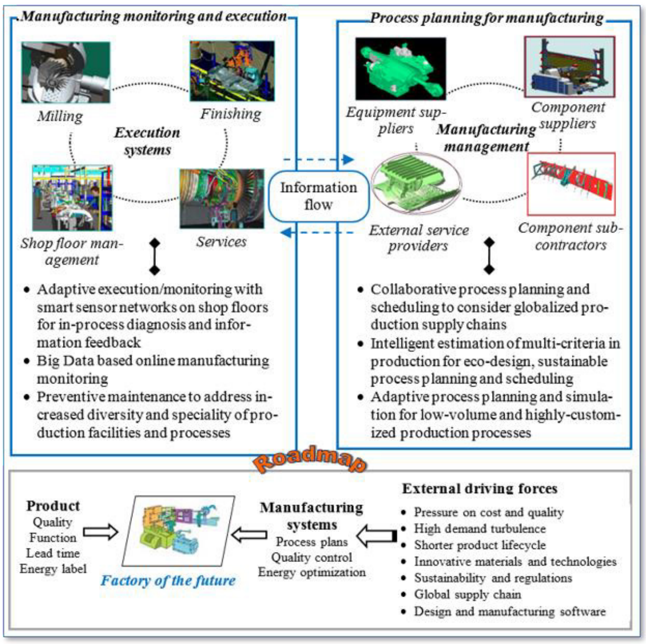

Figure 3-Smart manufacturing roadmap[1]

Based on a survey by Deloitte, 2019 [26], in which more than 40 interviews are conducted with manufacturing leaders in diverse industries e.g., chemical, paper, aerospace etc. emerged several themes on how to transform from a traditional factory to a smart factory. Gartner,2021 [27] also reported from a global survey in 2020 that change management along with technology and people are key drivers of transitioning to a smart factory. This is confirmed by 83% of respondents, in agreement that their leadership understand more investment into smart manufacturing is needed. The same study by Deloitte, 2019 [26] revealed that only 5% of USA manufacturers surveyed have fully converted to a "smart factory" status, with 30% in the process of transitioning to a smart structure. This leaves nearly two out of every three reporting no progress at all. In addition, a study done by Deloitte, 2019 [28] revealed that in the United States alone 86% of manufacturers state that smart factories will be the main driver of competition by 2025 and 83% of manufacturers also state the way products are made will be transformed by 2025. The following sub-sections content result from the talks given at the Supply Chain Management workshop at University of Liverpool in March 2020.

2.4.1 Data Driven Smart Manufacturing (DDSM)

Data Driven Smart Manufacturing (DDSM) is used to leverage digital and intelligent technologies to facilitate decision making during manufacturing lifecycles. Enabling technologies include Industrial IoT (IIoT), Cyber-Physical System (CPS), deep learning algorithms and Big Data analytics[1]. Data-driven modelling (DDM), as inhibitor, can be used for smart manufacturing applications such as feature/pattern recognition, regression, classification, clustering, and optimisation. The benefits of using DDM are more flexible and adaptive for customised and dynamic manufacturing processes, and less experiences required for complex problem solving[1].

2.4.2. Quality Control in Additive Manufacturing

The ability of additive manufacturing (AM) to fabricate geometrically complex and light-weight parts has increased end-users' demand for AM-based products. However, a lack of process robustness, stability and repeatability of laser-based AM technologies is a barrier to meeting the quality certification constraints imposed by the leading industrial sectors (e.g., aerospace and bio-medical). Thus, quality control in AM is a major issue which demands feasible solutions. Furthermore, due to the layer-wise nature of the process, the defects will not always be visible once the part production is completed. Photodiode based in-process quality control is one of techniques that enables the part quality can be monitored during the build[29]. At a later stage, it may even enable the implementation of automatic in-process corrective actions to increase the robustness of the build process. The application of photodiode based in-process quality control in AM are numerous, such as RAS for healthcare, construction and hazardous environments, biomechanics, and soft robotics.

2.4.3. Right-First Time and Zero-defect Manufacturing

I4 enablers, such as CPS, IoT, Big data, Cloud computing, AI, Robotics leads to Digital Lifecycle Management (DLM), a closed-loop in-process quality improvement for right-first time and near zero-defects in lifecycle[30, 31]. DLM as a transformative framework is used to create precise digital twins with capabilities to integrate data from interconnected systems with multidisciplinary simulation of products and manufacturing processes. Furthermore, DLM is used to achieve resilient performance in production systems such as predicting the behavior of process machinery, to either optimize existing equipment for increased productivity/quality or introduce new equipment into an assembly line with minimum disruption [32]. DLM benefits are numerous but most important are shorten lead time, rump-up time, and improved quality. Shorten lead time is achieved by increasing right-first-time, rapid deployment of new process technologies, and reduction of installation and commissioning time and cost. DLM has application in automotive, aerospace, and consumer goods industry.

2.4.4 Cloud-based Design and Manufacturing (CBDM)

Design has been a major beneficiary of cloud-based tools which enable collaborative work regardless of location and time, establishing dynamics of geographically distributed work team, and particularly benefit in COVID-19 crises. One of such is Cloud-based Design and Manufacturing (CBDM)[33, 34]. "CBDM refers to a service-oriented networked product development model in which service consumers are enabled to configure, select and utilize customized product realization services ranging from computer-aided engineering software to reconfigurable manufacturing systems."[33]. From a business perspective, CBDM involves new business models and how design and manufacturing services can be delivered (e.g., IaaS, PaaS, HaaS, and SaaS), how services can be deployed (e.g., private cloud, public cloud and hybrid cloud), and how services can be paid for (i.e., pay-per-use). CBDM benefits are numerous, such as ubiquities access to design and manufacturing resources; on-demand scalability, multi-tenancy; increased resource utilization; reduced capital cost and complexity; reduced maintenance cost; accelerated time-to-market; attractive pay-as-you-go pricing etc.[35].

2.5 Smart Logistics and Delivery

Currently there is no universally accepted definition of Smart logistics in literature[36]. However, it can be seen as the integration of emerging digital technologies with logistical processes to enable products moving forward in the supply chain more quickly and efficiently to meet customer demands without an increase in costs[37].

There is a need to devising a framework for smart logistics. A conceptual framework, with a systematic review on Logistics 4.0 is introduced by Winkelhaus,2020[37]. It is seen that external changes e.g., politics and social trends, triggers the increased attention into Logistics 4.0 research. The huge amounts of data being generated is challenging to process and extract insights. Human involvement is also seen as a major contributor to Logistics 4.0. The application of drone technology within logistics has gained recent popularity with major logistics companies. A report by [38] estimates that by 2027, drone logistics market would reach $29.06 billion. There are already a few major logistics companies e.g., Amazon, UPS and others who are already starting to adopt this technology. A list of major adopters of drones in logistics and SCM around the globe is shown in [39]. There are however still barriers to major adoption with regulatory and threat to privacy and security the major barriers [40].

2.6 Supply Chain Workforce

Supply chain management in the context of I4 bring many advantages and certain fear that digitization would lead to a significant reduction of manufacturing jobs. The fear is justified because the technology themes surrounding I4 are not mapping onto the skillsets of the industry workforce[7]. Manufacturing businesses have a growing need for a new type of engineers with digital skill sets. There is a discrepancy between workforce qualifications sought by employers and workforce qualification delivered by mainstream education institutions[41]. According to Mckinsey, 2030 [4] by 2030 in the US and Western Europe there will be a 58% increase in the amount of time spent on technological activities as seen in Figure 4.

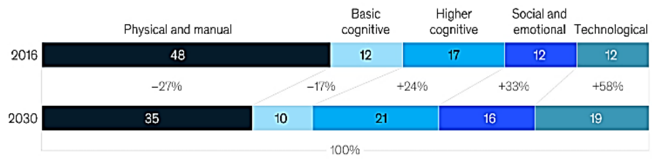

Figure 4-Skill shift in US and Western Europe, % of time spent [4]

In addition, demand for high level social and emotional skills e.g., initiative taking, leadership is also to rise by 33%. In industry there is an emphasis on upskilling the existing workforce to cope with future technological advances as well as new processes to follow[4, 42]. McKinsey, 2017 stated that by 2030, automation will replace nearly 800 million workers globally and nearly 50% of companies envision that automation will decrease full time workers. However, with the right skill set, over 25% of companies predict automation will lead to new roles emerging[43].

COVID-19 has impacted the workplace with an emphasis now on working online from home. In a Deloitte 2020 study [44], CEOs stated that nearly a third of their workforce will be working from home on a full-time basis by 2022. As data monitoring and processing becomes more evident on the shopfloor, managers and shop floor technicians will become more involved in data management of machines. This changes the nature of traditional work for most of the supply chain workforce with 32% of companies replacing full time workers with a contingent workforce for cost saving measures as stated by Gartner, 2021 [27].

3. Supply Chain Management 4.0 Challenges

In this section, the challenges are addressed in relation to the state of the art in Section 2 as presented in Table 1.

Table 1- Challenges of I4 technologies in Supply Chain Management

Eleme nts	Key Challenges
Plan ning	• Upgrading to newer planning systems requires huge financial resources and time [3]

Data-driven smart manufacturi	• Expensive data collection process - due to the vast number of smart sensors, RFID, and other expensive equipment • Low efficiency of data transmission over Industrial internet - data is continuously flowing from different machines, systems, and human operators. Interfacing software between these entities is not always apparent.
Quality control in additive manufacturing	• Sensing associated with for powder bed fusion processes, • Determining what can be sensed (optical, laser, thermal melt pool, etc.) and what the results mean, • Correlating sensor data to machine process parameters, • Correlating sensor data to defects (determining what causes defects, and when defects appear), and • Understanding the physics behind the AM processes to build simulations to generate data on which to base design decision(s).
Right-first time and zero-defect manufacturing	• Real-time data gathering and optimization- The vast quantity of data being sent to and from needs to be collected and processed for optimization which is costly and takes a long time. • Physical-digital integration- Modelling of physical machines into digital identities (Digital Twin) and integrating them is difficult • Framework implementation in industry
Cloud-based Design and Manufacturing (CBDM)	• Rapid scalability in cloud manufacturing to understand how to realize rapid scalability (elasticity) in cyber-physical production environments (cloud manufacturing) • Smart cloud-based digital design-to-manufacture analysis to computationally determine feasibility of part fabrication given 3D geometry in STL file, 3D-printer specification and process (cloud-based on-demand DFM for Digital Fabrication) • Interoperability and IT/OT-Convergence in Industry where IT/OT convergence is a crucial step in building Cloud-Based Cyber-Physical Product Creation and Production Engineering Systems (Cloud-Based Design & Manufacturing)[45].
Procuremen t 4.0	• Shift to I4 will require supply chains limited to physical goods become experts at buying digital supplies and services e.g., software maintenance, developers. • Employees do not have required resources and capacities to maintain new roles in a Procurement 4.0 environment [13]
Smart Warehousing	▪ The need for highly trained workforce is needed as automation increases, in order to operate robots and machinery[46]. ▪ Design of system architecture within warehouse needs to be interoperable between machines and systems.[46]. Security of warehouse data is often at risk due to outdated encryption methods which are insufficient for satisfactory level of security [21].
Smart Logisti cs	• Lack of roadmap/frameworks for transitioning into a smart logistics system. • Very high cost of using autonomous vehicles/drone technology.
Supply Chain Workforce	• Lack of advanced tech skills e.g., ML, AI for current workforce who need to upskill [4]. • Post-COVID nature of work shifting to online working which complicates employment contracts [44] • Knowledge and Information exchanges between academia and industry needs to be firmly established through schemes and government support [41].

4. Implications for Researchers and Managers

This section will provide the specific implications for managers and researchers as well as governmental bodies. Firstly, with the advancements in I4 technology in each SCM element, a focus on creating standards and roadmaps needs to be conducted. Within smart warehousing Currently the management systems for warehouses needs to be developed further. Migrating to new and improved management systems involving I4 technologies has been looked at, however most consider only a single I4 technology e.g., IoT[21]. This is similar to sourcing (procurement) where studies related to I4 implementation in the procurement process is scarce [47, 48]due to the nature of procurement which involves cooperation of the organisation with a network of suppliers. This calls for more research into creating a framework/roadmap for businesses looking to transition into smart procurement.

Secondly, researchers must focus on creating interoperable systems which allows seamless data exchange and communication between different supply chain actors. Data collection and processing is a common issue with the vast amount of data being generated which takes time and costs money. Future work can look at new ways of collecting and analysing the data from sensors needs to be investigated. Allowing different systems to communicate seamlessly in the manufacturing environment needs further investigating. Thirdly, conducting studies on how governmental policies affect logistics and procurement systems needs to be investigated. A logistics system which can automatically adjust its processes to comply with new policies will vastly reduce logistical lead times.

Finally, More joint efforts between academia and industry are required[41]. Education should be more focused and intensive, with shorter degree programs so that the knowledge of students will not be outdated by the time they graduate. New means of delivering education online are needed as well as accessibility and reduce cost of provision at the same time. On the other hand, industrial strategy needs to go beyond the traditional view and invest into talent, foster the creativity, empathy, and cognitive learning of employees may lead to new and innovative business strategies[7].

5. Conclusions

This paper has addressed the issue of supply chain management within the context of I4 starting with state-of-art of each supply chain management element which then leads to the challenges. Finally, implications for researchers, industry and public bodies are presented. The review is as a result of a Supply Chain Management workshop at University of Liverpool, 2020 where keynote speakers on certain topics were invited to give a talk on current and future trends. This was backed up with an extensive literature review to make sure the content was not outdated. The contribution of this work is in the form of providing a readable, bitesize summary of each SCM element within the context of I4 as well as challenges that need to be addressed for the future.

With the advent of COVID-19 and sustainability becoming an important agenda, the management of supply chains has become even more important. This is exaggerated by the introduction of emerging digital technologies which places an emphasis on businesses to integrate them in their supply chain processes. Within each SCM element analyzed, it is seen that digital technologies are being utilized at a greater extent now e.g., AI in smart warehousing, drone technology in logistics etc. However, research on creating frameworks/roadmaps for supply chain businesses to use still needs further development. In addition, creating strong relationships between stakeholders in the supply chain network and improved communication channels will help to improve the overall supply chain resiliency against external disturbances such as COVID-19.

CRediT author statement

Mohammed Khan: Investigation, Writing - Original Draft, Writing - Review & Editing. **Dirk Schaefer**: Investigation, Writing - Original Draft, Writing - Review & Editing, Supervision. **Jelena Milisavljevic-Syed**: Investigation, Writing - Review & Editing, Writing - Original Draft, Supervision

Acknowledgement

The authors would like acknowledge support from EPSRC through a DTA scholarship for this project. They further would like to thank the participants of a Supply Chain Management Workshop held at the University of Liverpool in spring 2020.

Reference

[1] Li W, Wang S. Sustainable Manufacturing and Remanufacturing Management: Coventry: Springer; 2018.
[2] Harrington L. WAREHOUSING 4.0: THE AGE OF THE SMART DC. DHL: DHL; 2017.
[3] Destino MF, Julian ;Müllerklein,Daniel ; Trautwein,Vera To improve your supply chain, modernize your supply-chain IT. Mckinsey and Company; 2022.
[4] Gupta RE, Kweilin; Salguero, J. Building the vital skills for the future of work in operations. Mckinsey & Company: Mckinsey & Company; 2020.
[5] Gurria A. Speech by Federal Chancellor Angela Merkel to the OECD Conference. 2014.
[6] Schaefer D, Walker J, Flynn J. A Data-Driven Business Model Framework for Value Capture in Industry 4.02017.
[7] Milisavljevic-Syed J, Themes J, Schaefer D. The Digitization of Design and Manufacturing: A State-of-the-Art Report on the Transition from Strategic Vision to Implementation in Industry. Procedia CIRP. 2020;93:575-80.
[8] Forbes H, Schaefer D. Social Product Development: The Democratization of Design, Manufacture and Innovation. Procedia CIRP. 2017;60:404-9.
[9] Allen J, Commuri S, Jiao J, Milisavljevic-Syed J, Mistree F, Panchal J, et al. Guest Editorial: Design Engineering in the Age of Industry 4.0. J Mech Des. 2021;143:1-4.
[10] Simosko N. Evolving The Supply Chain Into A New Information 'Demand' Chain. Forbes: Forbes; 2020.
[11] CIPS. What Does Supply Chain Management Mean? Chartered Institute of Procurement and Supply2022 [Available from: https://www.cips.org/knowledge/procurement-topics-and-skills/supply-chain-management/.
[12] Schrauf SB, Phillip. How digitization makes the supply chain more efficient, agile, and customer-focused. PwC; 2016.
[13] Bienhaus F, Haddud A. Procurement 4.0: factors influencing the digitisation of procurement and supply chains. Business Process Management Journal. 2018;24.
[14] Consulting F. Executing A Successful Procurement Transformation Forrester's Infrastructure & Operations research group: Forrester Consulting; 2019.
[15] Alicke KB, Ed. How COVID-19 is reshaping supply chains. Mckinsey: Mckinsey; 2021.
[16] Husna A, Hassanzadeh Amin S, Shah B. Demand Forecasting in Supply Chain Management Using Different Deep Learning Methods. 2021. p. 140-70.
[17] Feizabadi J. Machine learning demand forecasting and supply chain performance. International Journal of Logistics Research and Applications. 2020:1-24.
[18] Thomassey S. Sales forecasts in clothing industry: The key success factor of the supply chain management. International Journal of Production Economics. 2010;128:470-83.
[19] Gonçalves J, Cortez P, Carvalho M, Frazão N. A multivariate approach for multi-step demand forecasting in assembly industries: Empirical evidence from an automotive supply chain. Decis Support Syst. 2020;142:113452.
[20] Ni D, Xiao Z, Lim MK. A systematic review of the research trends of machine learning in supply chain management. International Journal of Machine Learning and Cybernetics. 2020.
[21] Buntak K, Kovačić M, Mutavdžija M. Internet of things and smart warehouses as the future of logistics. Tehnički glasnik. 2019;13:248-53.
[22] Annunziata MA, Magid. Augmented Reality IsAlready Improving Worker Performance. Harvard Business Review: Harvard; 2017.
[23] Thamer H, Börold A, Benggolo A, Freitag M. Artificial intelligence in warehouse automation for flexible material handling2018.
[24] Marketing S. Dark Warehouses: Are They in Your Supply Chain's Future? Stord2020 [Available from: https://www.stord.com/blog/dark-warehouses-are-they-in-your-supply-chains-future.
[25] Tomorrow M. What is the Smart Factory and its Impact on Manufacturing? Manufacturing Tomorrow2017 [Available from: https://www.manufacturingtomorrow.com/article/2017/01/what-is-the-smart-factory-and-its-impact-on-manufacturing/9043.
[26] Laaper SD, Ben; Cotteleer, Mark; Sniderman, Brenna; . Implementing the smart factory-New perspectives for driving value. Deloitte: Deloitte 2019.
[27] Baker M. 9 Future of Work Trends Post-COVID-192021. Available from: https://www.gartner.com/smarterwithgartner/9-future-of-work-trends-post-covid-19.
[28] Wellener PS, Steve; Dollar, Ben; Laaper, Stephen; Manolian, Heather; Beckoff, David. 2019 Deloitte and MAPI Smart Factory Study. Delloite; 2019.
[29] Jayasinghe S, Paoletti P, Sutcliffe C, Dardis J, Jones N, Green PL. Automatic quality assessments of laser powder bed fusion builds from photodiode sensor measurements. Progress in Additive Manufacturing. 2021.
[30] Babu M, Franciosa P, Ceglarek D. Spatio-Temporal Adaptive Sampling for effective coverage measurement planning during quality inspection of free form surfaces using robotic 3D optical scanner. Journal of Manufacturing Systems. 2019;53:93-108.
[31] Franciosa P, Serino A, Al Botros R. Closed-loop gap bridging control for remote laser welding of aluminum components based on first principle energy and mass balance. Journal of Laser Applications. 2019;31:022416.
[32] Franciosa P, Sokolov M, Sinha S, Sun T, Ceglarek D. Deep learning enhanced digital twin for Closed-Loop In-Process quality improvement. CIRP Annals. 2020;69(1):369-72.
[33] Wu D, Rosen D, Wang L, Schaefer D. Cloud-Based Design and Manufacturing: A New Paradigm in Digital Manufacturing and Design Innovation. Computer-Aided Design. 2015;59.
[34] Schaefer D. Cloud-Based Design and Manufacturing (CBDM). - A Service-Oriented Product Development Paradigm for the 21st Century2014.
[35] Wu D, Greer MJ, Rosen DW, Schaefer D. Cloud manufacturing: Strategic vision and state-of-the-art. Journal of Manufacturing Systems. 2013;32(4):564-79.
[36] Douaioui K, Fri M, Mabrouki C, Semma E. Smart port: Design and perspectives. 2018:1-6.
[37] Winkelhaus S, Grosse E. Logistics 4.0: a systematic review towards a new logistics system. International Journal of Production Research. 2020;58:18-43.
[38] MarketsAndMarkets. Drone Logistics and Transportation Market by Solution 2020 [Available from: https://www.marketsandmarkets.com/Market-Reports/drone-logistic-transportation-market-132496700.html.
[39] Rejeb A, Rejeb K, Simske S, Treiblmaier H. Drones for supply chain management and logistics: a review and research agenda. International Journal of Logistics Research and Applications. 2021:1-24.
[40] Sah B, Gupta R, Bani-Hani D. Analysis of barriers to implement drone logistics. International Journal of Logistics Research and Applications. 2020;24:1-20.
[41] Flynn J, Dance S, Schaefer D. Industry 4.0 and ts Potential Impact on Employment Demographics in the UK2017.
[42] Manyika JL, Susan; Chui, Michael; Bughin, Jacques; Woetzel, Jonathan; Batra, Parul; Ko, Ryan; Sanghvi, Saurabh Jobs lost, jobs gained: What the future of work will mean for jobs, skills, and wages. Mckinsey and Co; 2017.
[43] Fourm WE. The Future of Jobs Report. World Economic Forum: World Economic Forum
2018.
[44] Bergstrom JG, Patrick; Stewart, Ian. Looking beyond the horizon - Preparing today's supply chains to thrive in uncertainty. Deloitte: Deloitte; 2020.
[45] Mourad MH, Nassehi A, Schaefer D, Newman ST. Assessment of interoperability in cloud manufacturing. Robot Comput-Integr Manuf. 2020;61:101832.
[46] Taliaferro A. Industry 4.0 and distribution centers. Deloitte Insights; 2016.
[47] Jegan J, Saxena D, Sonwaney V, Foropon C. Procurement 4.0 to the rescue: Catalysing its adoption by modelling the challenges. Benchmarking An International Journal. 2021;ahead-of-print.
[48] Nicoletti B. Procurement 4.0 and the fourth Industrial Revolution2020.