Industry 4.0 Technologies in Supply Chain Management

Subjects: Engineering, Industrial
Contributor: Abirami Raja Santhi, Padmakumar Muthuswamy

The supply chain ecosystem is becoming fragile and difficult to manage due to the complexities in its interlinked functions such as planning, procurement, production, logistics, distribution, and sales. Organizations have started embarking on "Industry 4.0 technologies", a name used to denote transformative modern-day technologies such as Artificial Intelligence, Machine Learning, automation and robotics, Internet of Things, Big Data Analytics, Blockchain, and so on to make faster decisions, optimize current practices, provide end-to-end transparency, increased collaboration, and superior warehouse management, which can collectively make it an "Intelligent supply chain".

Keywords: Industry 4.0 ; supply chain 4.0 ; artificial intelligence ; blockchain ; big data analytics ; additive manufacturing ; supply chain challenges

1. Introduction

The transformation of industrial practices into new techniques dominated by the technologies available at that time is the Industrial Revolution. The world has so far witnessed three industrial revolutions. The first industrial revolution began in the middle of the 18th century when steam-powered engines and mechanization were introduced, which made the people leave their villages and migrate to nearby cities to work in factories. The mechanization of agriculture, textile industries, railroads, machinery, internal combustion engines, and electric power were the technologies behind the second industrial revolution that started in the middle of the 19th century. The third industrial revolution began in the 1950s and was driven by the invention of transistors and microprocessors that also introduced computers and electronic devices into the factories. Currently, we are living to see the fourth industrial revolution, or Industry 4.0, slowly unfolding around us. This revolution can be called the computerization of manufacturing, in which advanced digital technologies are married to industrial machines and processes to achieve operational efficiency, productivity, and automation to the highest possible extent. The foundation of Industry 4.0 was built over four important modern technologies as Networking, data, and computational (Smart sensors, IoT, Blockchain, and cloud computing), Analytics and Intelligence (Artificial Intelligence, Machine Learning, and Big Data Analytics), Human-machine interaction (Automation, Robotics, COBOTS, and Drones), and Advanced manufacturing (Additive manufacturing) as shown in **Figure 1**. Given that the fourth industrial revolution would radically change the entire production process, it is also expected that supply chain and logistics functions would undergo a drastic transformation [1].

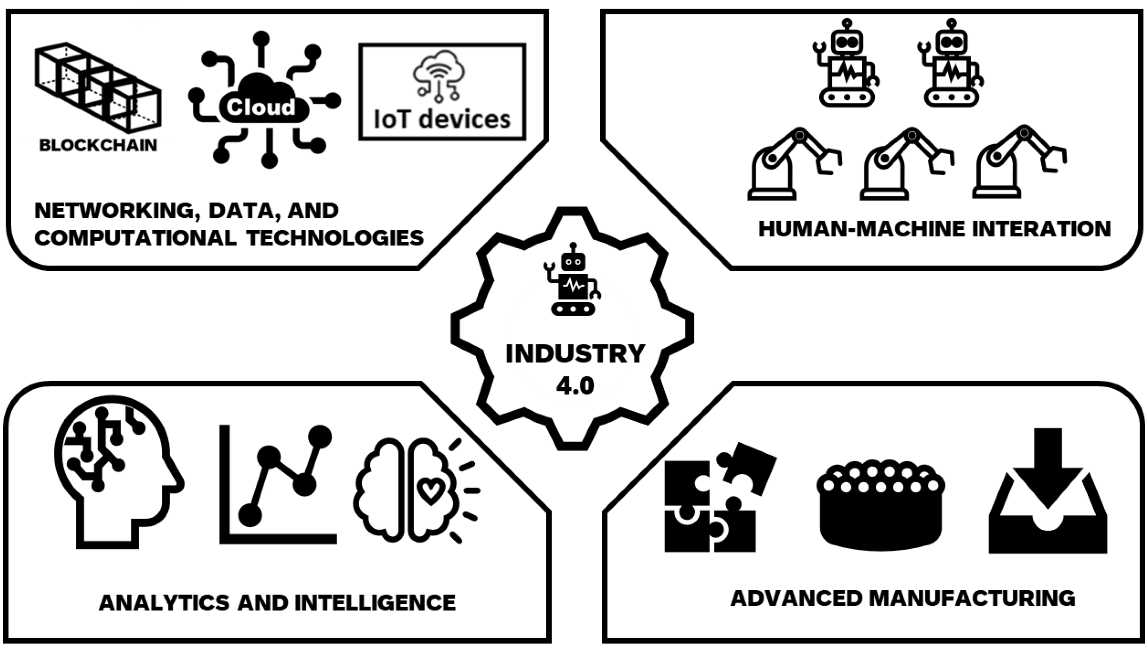

Figure 1. Foundation of Industry 4.0 technologies.

Gone are the days when supply chain and logistics management were considered a network of functions that worked to convert raw materials and deliver a finished product to the end user or customer. The scope of the modern supply chain has grown beyond conventional boundaries and is pounded every day with new challenges which strive to improve business competitiveness and growth. The entire supply chain is tangled with numerous internal and external factors which put an enormous amount of pressure on the everyday functioning of a business. For instance, more than 70% of the survey participants from 17 countries that were a part of the Geodis supply chain survey 2017 have responded that their supply chain is either 'very' or 'extremely' complex, and achieving extended visibility is one of the major objectives to efficiently manage it, which nicely sums up the complexity involved in supply chain management [2] and the need for digital technologies. The extended supply chain visibility and transparency can be categorized into six major parts. They are visibility in procurement and inventory management, operations, logistics finance, quality control, sales, and customer service [3].

However, in the coming years, the various Industry 4.0 technologies are believed to act as the main driving force in supply chain management, such as supply planning, logistics, performance management, order management, stakeholder relationship, and strategic supply chain. They can provide multidirectional communication across the supply chain network and bring a transformation in service, cost, capital, and agility to a traditional supply chain. The various enabling technologies and their application are discussed in the following sections. Although there are numerous advanced digital, computing, and networking technologies developed in the last decade that can bring a transformation and help address contemporary supply chain challenges, only the most popular technologies are discussed.

2. Artificial Intelligence

Artificial Intelligence (AI) is an algorithm-based intelligence fed to machines to provide problem-solving abilities and decision-making skills and perform human-like assignments. In other words, the technique makes machines think and behave like humans. It is a combination of several digital and software technologies that acts as the driving force of Industry 4.0 [4]. Although the origin of the technology can be traced back to the 1940s [5], with numerous incremental advancements, it has gained widespread acceptance and implementation in the past decade in almost all sectors. Implementing the technique in supply chain management can provide an integrated end-to-end solution from purchasing to sales to increase efficiency and productivity. The ability of AI to analyze a huge volume of data in a shorter time, provide granular level visibility to data, reduction in cycle time, improve operational efficiency, continuous process improvement, and data-driven decision-making capabilities would help in the complete transformation of the function.

Although many different AI techniques were applied by scholars to address the supply chain-related challenges, studies have shown that Artificial Neural Networks (ANN), Fuzzy Logic (FL), Multi-Agent and Agent-Based Systems (MAS and ABS), and Genetic Algorithm (GA) are the most used techniques. In addition, data mining, case-based reasoning, swarm intelligence, support vector machines, decision trees, k-means clustering, and Bayesian networks are a few other techniques used by scholars [6]. Mobarakeh et al. [7] have applied a bootstrapping method to address unpredictable and irregular demand forecasting challenges of a business aircraft supply chain and concluded that the technique can result in significant cost savings. An IoT-based risk monitoring system and fuzzy logic approach was successfully applied by Tsang et al. [8] to control the quality of product and reduce safety-related issues in a cold supply chain. Similarly, Ignaciuk and Wieczorek [9] have applied a Genetic Algorithm for inventory control strategies and optimizing the goods flow process in logistic networks and proved that the technique is highly effective even in scenarios that have high analytical and computational complexities. An agent-based simulation framework was successfully applied by Ferreira and Borenstein [10] for supply chain production planning problems, which can also be used for inventory control. The major challenges faced by organizations across the globe during unpredicted events such as the COVID-19 include suppliers not meeting delivery obligations, fluctuations in customer demands, and the spike in demand due to panic buying. However, AI can be used to identify and mitigate risks, enable sustainable supply chain processes and logistics, and provide supply chain resilience, risk management, data-driven supply chain, decision model, technology management, network design, and optimization algorithms to improve supply chain efficiency [11]. **Table 1** shows the different studies from the literature that have applied different AI techniques for various supply chain and logistics-related challenges, as reported by Toorajipour et al. [6].

Table 1. Application of AI techniques in various functions.

Field of Research	Subfield and Related Literature
Marketing	Sales forecasting [12], Sales management [13], Sales promotions [14], Pricing models [15], Market segmentation [16], Customer segmentation [17], Marketing decision support [18], Direct marketing [19], and Industrial marketing [20]
Product design	Design specifications of new products [21] and Product life-cycle management [22]
Logistics	Container terminal management [23], General logistics [24], Inbound logistics processes [25], Logistics systems automation [26], Lot-sizing [27], and Logistics workflow [28]
Production	Assembly line balancing [29], Assembly automation [30], Production monitoring [31], Production forecasting [32], Production systems [33], Production planning and scheduling [34], Production data management [35], Integrated production management [36], General production management [37], Flexible manufacturing systems [38], Decision support systems [39], Manufacturing problem solving [40], Quality control and improvement [41], Quality monitoring [42], Product line optimization [43], Workflow management [44], Product-driven control [45], and Low-volume production [46]
Supply chain	Demand forecasting [47], Facility location [48], Supplier selection [49], Supply chain network design [50], Supply chain risk management [8], Inventory replenishment [51], Crisis management [52], Global value chains [53], Supply chain process management [54], General supply chain management [55], Supply chain integration [56], Supply chain planning [57], Maintenance systems [58], and Sustainable supply chain [59]

3. Internet of Things (IoT)

The modern supply chain function is bombarded with a myriad of challenges due to varieties of reasons, such as the presence in multiple geographical locations, which makes it vulnerable to regional issues, ever-changing customer demands, product customization, price competitiveness, increase in product complexities, adaptation to changing technological advancements, fluctuations in socio-economic and political factors, and natural calamities [60]. In recent years, technologies such as the Internet of Things (IoT) have been seen as a critical enabler for efficient and flexible supply chain management and support smart factory ecosystems or Industry 4.0 [61]. It is a system of interconnected machines, artificial intelligence utilities, or people [62]. While the aim of Industry 4.0 is to transform industrial production to the next level, the objective can be fully realized only when the supply chain and logistics become data-driven and fully digitized using technologies such as IoT. The typical data flow from various supply chain sources collected using IoT devices to a secure cloud server is shown in **Figure 2**.

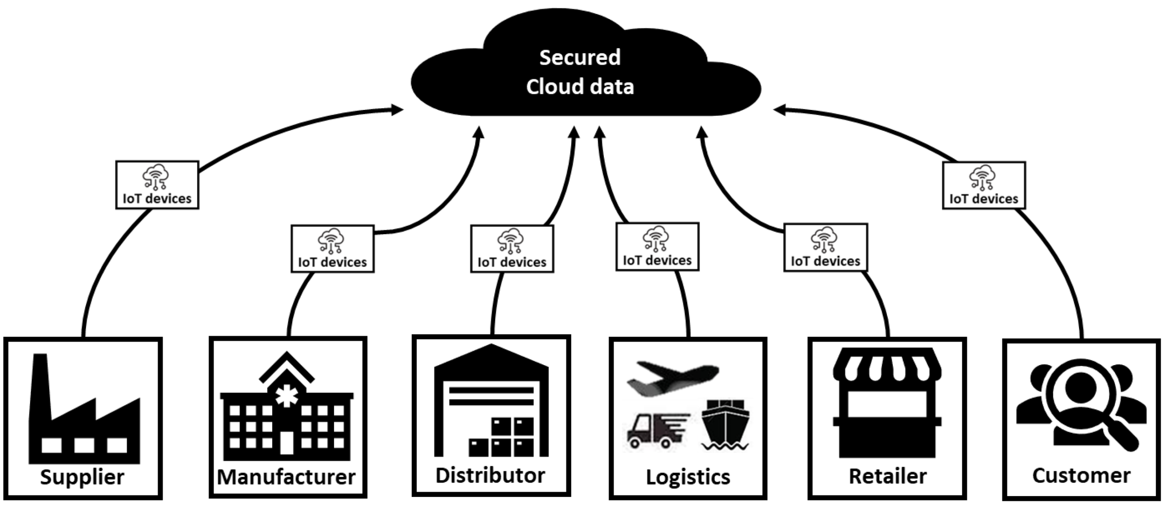

Figure 2. Data flow from various supply chain sources to the cloud using IoT devices.

The Radio-Frequency Identification tag (RFID) that was previously used to read, identify, and track products is seen as the precursor to IoT technology. It can provide an unprecedented level of visibility to the supply chain by connecting and creating a network of “things” (physical objects) that are a part of the supply chain. In other words, it integrates physical objects with the digital world through various advanced sensing, networking, and computing technologies. This enables the physical objects to communicate with each other using the “internet” (hence the name Internet of Things), and the real-time data collected from them can be used for the predictive and preventive analysis of various supply chain situations that requires immediate actions that in turn improves supply chain efficiency. It also allows remote management of supply chain operations, improved coordination between the partners, and provides accurate data for effective decision making. End-to-end visibility of data is critical in achieving a transparent supply chain that can withstand a massive disruption such as the COVID-19 pandemic or war. The recent increase in the penetration of IoT sensors is creating a massive network that can communicate with each other while generating an unprecedented volume of data that can be used for real-time monitoring and information gathering. Especially the food and perishable goods supply chain has already started realizing the true potential of IoT technology in their supply chain and logistics which provides insight into information such as real-time production planning and inventory management, temperature, pressure, and humidity inside shipping containers, tracking the exact location of goods at various stages with tamper-proof time stamping, and delivery tracking. By tracking a system’s utilization details, the technology can also help in improving the overall operational efficiency of the system. Developing suitable algorithms and inventory management mathematical models can help in reducing wastage and shortage of such products [63][64].

The SCOR model (Supply Chain Operations Reference model) is a standard framework developed and endorsed by the Supply-Chain Council to improve supply chain processes in various organizations. To translate the business strategies into execution plans and policies, it has divided the supply chain management into various stages such as Plan, Source, Make, Deliver, Return, and Enable [65]. Accordingly, the various research studies based on using IoT in these supply chain processes, as summarized by Ben-Daya [60], are shown in **Table 2**.

Table 2. IoT in supply chain management.

Process	Role of IoT	Relevant Literature
Source	• Connect with suppliers to improve supply chain visibility. • Track activities in real time and obtain inspection details from suppliers to improve product quality. • Supply chain data collection for strategic planning.	Verdouw et al. [66], Ng et al. [67], Yu et al. [68].
Make	• Transparency on the status of parts and raw materials to minimize lead time and cost. • Combine product and after-sales service to reduce cost. • Real-time quality and maintenance data from the customer to improve product design. • Remote preventive maintenance to increase product life and customer satisfaction.	Wang et al. [69], Rymaszewska et al. [70], Putnik et al. [71], Ondemir et al. [72], Chukwuekwe et al. [73].

Process	Role of IoT	Relevant Literature
Deliver	• Inventory tracking to reduce logistics time. • Information sharing and joint ordering for collaborative warehousing, on-time delivery, and inventory accuracy. • Autonomous decision making to reduce time and cost. • Quality monitoring and quality-controlled logistics to eliminate waste and improve quality.	Reaidy et al. [74], Qiu et al. [75], Choy et al. [76], Kong et al. [77], Yao [78], Mathaba et al. [79].
Return	• Ease reverse logistics to reduce cost and lead time. • Enable traceability to improve visibility and reduce cost. • Monitoring product data while in use to improve customer satisfaction.	Gu and Liu [80], Parry et al. [81], Thürer et al. [82].

Such studies show that the availability of the right data at the right time would enable the supply chain participants to make an improved and timely decision that can enhance the operational efficiency of organizations [83][84].

4. Big Data Analytics (BDA)

The enormous amount of data generated from various devices is big data, and big data analytics is the process of analyzing the data to reveal information such as hidden patterns, correlations, market trends, and customer preferences, which can be used by organizations to make data-driven decisions. It is not just the amount of data that is generated and collected using various advanced technologies such as smart sensors and IoT, but it is also critical to use appropriate techniques to use data as a strategic tool to drive changes and make the right decisions. Usually, the data can be either structured, semi-structured, or unstructured in the form of numbers, texts, images, audio files, or social media feeds that are collected from various sources such as radio-frequency identification (RFID), global positioning system (GPS), point-of-sale (POS), smart sensors, IoT devices, instant messengers, or social media. Although data analytics is a combination of mathematics and statistical techniques, BDA is a technique used to analyze a huge volume of data to obtain meaningful insights and turn them into business intelligence [85].

Historically, supply chain managers and scholars have applied statistical and operational research approaches to manage and solve supply chain challenges [86]. However, the recent progress in digital and computing technologies such as BDA has opened a new avenue in approaching and solving the challenges using data-driven techniques. The BDA techniques used in the supply chain are also termed Supply Chain Analytics, and they are used for descriptive, predictive, preventive, and prescriptive analytics with little or no human intervention [87]. Unscheduled machine maintenance can lead to reduced Overall Equipment Effectiveness (OEE), which leads to reduced machine utilization and operation losses [88]. Richey et al. [89] have performed a systematic investigation on deploying Big Data across all the supply chain partners and studied its influence on the performance of the supply chain along with their obstacles. Literature studies have shown that data collection, improved interconnection and collaboration across various functions, agile inventory and warehouse management, manufacturing automation, predictive analytics, process control, data-driven decision making at various functions, and superior financial and manufacturing management are a few other potential applications of BDA [90]. However, the four important requirements to enable BDA in an organizational supply chain are developing data generation capabilities at every source, integration of data across all supply chain functions and participants, developing appropriate analytics capabilities, and management accepting data as a decision-making tool and implementing data-driven culture [91].

5. Blockchain

A blockchain is a digitally managed, distributed, and decentralized ledger used to record transactions in an immutable format. It is a combination of various technologies such as computing, networking, cryptography, and mathematics [92]. The unique characteristics and features of the technology, such as immutability, decentralization, distributed ledger, and consensus mechanisms, make it attractive for all applications in which a transaction is performed. Studies have shown that the technology can be used to manage upstream, operational, downstream, and external supply chain complexities [93]. The application of blockchain technology in various supply chain and logistics functions, as discussed by Santhi et al. [93], is shown in **Figure 3**.

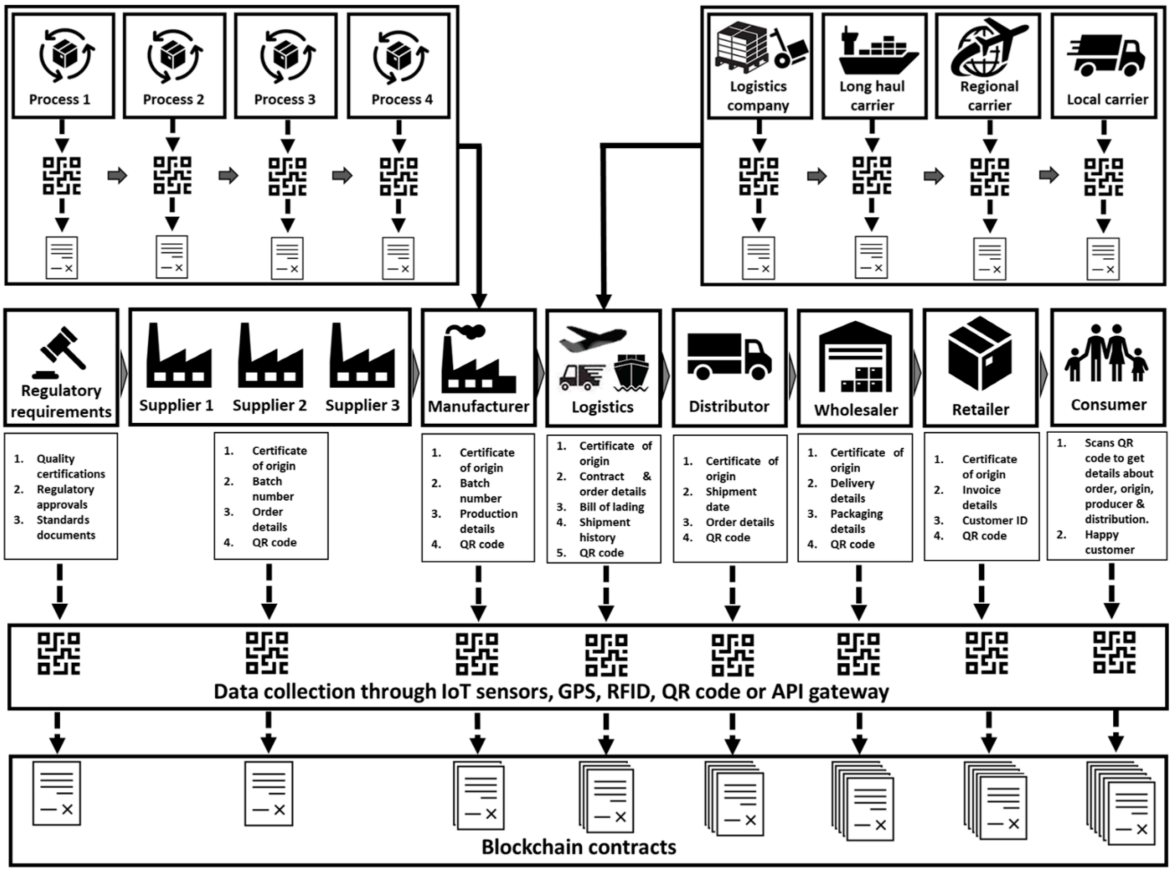

Figure 3. Application of blockchain in supply chain and logistics [93].

At present, most organizations do not have a reliable system to track down the life cycle of a product from the raw material stage till the finished products reach the customers. This is primarily due to the reason that various key functions of the supply chain, such as demand forecasting, scheduling, purchasing, production, quality assurance, inventory management, information management, logistics, and customer service, use conventional standalone technologies that do not communicate or collaborate [94]. In addition, such centralized technologies are prone to hacking and do not provide visibility to data across the entire supply chain participants, which can lead to reduced performance of the supply chain. For example, a large-scale manufacturer having no visibility to data of their supplier network that is spread across the globe can lead to poor planning, delayed production, poor warehousing and inventory management, and inferior performance [95].

However, integrating blockchain technology across all the participants of a supply chain network, such as suppliers, manufacturers, logistics providers, distributors, wholesalers, and retailers, enables the data collection from all the sources that can be stored in one place in a transparent, tamper-proof, and digitally distributed format which can be accessed without any intermediaries. Providing only the required access to the participants can ensure that they can view or add only the information that they are supposed to view or add. The technology also provides the facility to have digital proof of possession of assets which can help avoid counterfeiting and dual contracting [96]. Various systems such as sensors, GPS (Global Positioning System), RFID (Radio Frequency Identification) tags, NFC (Near-Field Communication), bar codes, QR (Quick Response) codes, APIs, and IoT-enabled devices can be used for data collection [97]. Almutairi et al. [98] have shown that Blockchain technology can provide benefits such as trust, transparency and accountability, cooperation, information sharing, financial exchanges, and supply chain integration. Such transparent and immutable data can lead to superior supply chain performance and higher overall customer satisfaction. It also gives prominence to information such as raw material sourcing sites (ensuring minerals are sourced from conflict-free mines), quality (avoiding duplicate parts), and avoiding unethical practices which are currently invisible to customers [99]. In addition, decentralized blockchain technology can be used by organizations to monitor various processes such as workflows, remotely identify and validate connected devices to avoid data tampering, and share legal, proprietary, and compliance data between the participants. Through a case study, Dehshiri et al. [100] have shown that efficiency, coordination, cooperation, information sharing, and cost reduction can be achieved in the automotive supply chain by implementing Blockchain. Other studies have also shown that a private blockchain can provide benefits such as high security, a high degree of trust, low implementation and operational costs, and data privacy. A blockchain-based digital identity enables fool-proof sanctions, thus preventing rogue nations from importing dual-use products or technologies [93].

In summary, improving traceability of products or services, immutability, providing provenance to ensure product source and quality, providing transparency and security to data, simplifying reverse logistics to support a circular economy, ensuring compliance and ethical practices, error-free inventory management, shipping details, and avoiding duplicate payments are few of the benefits of blockchain technology in supply chain management. Asset tracking and self-executable smart contracts that get executed automatically when predefined conditions are met are a few other potential possibilities of the technology that can help multi-organizational enterprises such as supply chain, logistics, and financial units to a greater extent.

6. Automation and Robotics

Although the terms “automation” and “robotics” are often used interchangeably, automation refers to the software program, machine, or technology that is used to carry out a certain task automatically with minimal manual intervention, whereas robotics involves programmable machines that can replace humans from labor-intensive, monotonous, and hazardous environment. In other words, robots are machines that can perform a wide variety of tasks, but automation refers to a special-purpose program, machine, or system that only performs a specific task. Software automation, Robotic Process Automation (RPA), and industrial automation are the three different types of automation, while robots can be categorized into semi-autonomous and autonomous robots. Although it was predicted long ago that robotics would become an integral part of the supply chain until now, they were working only in the production environment to automate certain processes [101]. The various technological and organizational challenges have delayed their implementation in the other functions of a supply chain. However, with the advent of Industry 4.0 technologies such as Artificial Intelligence, smart sensors, machine vision, IoT, and additive manufacturing, the current era would belong in the digital and computing technologies in which robotics is poised to take a giant leap into the industrial system. Especially autonomous robots are expected a play a critical role in supply chain and logistics management. In addition, the development of next-gen collaborative robots, also called COBOTS, are capable of collaborating with humans that can sense their surroundings, adapt, and learn rapidly. As the cobots are small, cost-effective, and highly flexible, they can easily adapt to the changing requirements on a shop floor and fit into various departments.

Automation and robotics would become an integral part of the self-steering supply chain of future industries that are highly efficient, flexible, and cost-effective [102]. The key differentiator between the traditional industrial robots and the new-gen cobots is the application of the latest technologies such as machine vision, smart sensors, superior navigation and communication channels, and advanced algorithm-based neural networks, which improves a cobots’ ability to auto-learn, flexibility to adapt to changing requirements, and agility [103]. With the introduction of cobots, the current targeted application for complex and routine tasks would see a transformation into end-to-end deployment throughout the supply chain. Automated and uninterrupted manufacturing, intra-logistics using robots, material handling, unmanned assembly line and fabrication, robotic warehousing and packaging, autonomous trucks [104], automated last-mile delivery, reverse-logistics using drones, and delivery robots [105] are a few of the supply chain areas were automation, and robotics are expected to see significant growth in the current decade.

7. Additive Manufacturing (AM)

The Additive Manufacturing (AM) technology was developed in the early 1980s to replace the traditional manufacturing processes such as machining, casting, injection molding, forging, and so on. The process is used to convert a 3-dimensional CAD model (Computer-Aided Design) directly into a finished part by adding layers of material one over the other to obtain the required shape and size [106]. Hence, it is also called 3D printing or rapid manufacturing. The flexibility in using a wide variety of raw materials such as polymers, metals, ceramics, and so on makes the process a suitable alternative to traditional manufacturing processes. Especially process is attractive for making prototypes, reducing complexity in assemblies with lesser parts, and products that have limited lot sizes. As industries around the globe and across sectors have started realizing the benefits of Industry 4.0 technologies or smart factory technologies, a very high level of automation and product customization are expected as the key benefits, and AM is believed to play a major role

[107]. Kunovjanek et al. [108] have grouped the benefits of AM technology in the supply chain context into different categories in line with the SCOR model, as shown in **Table 3**. Their study shows that reduction in production, transportation, and packaging costs, reduced ecological footprint, lead time reduction in product development, increase in supply chain throughput, and lower maintenance costs are a few important benefits of AM in the supply chain. They have also shown that aerospace and industrial, and consumer goods manufacturing companies have shown significant interest in AM technologies. However, other studies have shown that the automotive, healthcare, bio-medical, and energy sectors are the other key beneficiaries [109].

Table 3. AM in supply chain management.

Field of Research	Subfield and Related Literature
Plan	Process integration and simplification to reduce overall lead time in planning.
Source	Lesser inventory and transportation lead time due to reduced assembly parts.
Make	Reduction in raw material usage, lesser assemblies, and highly customizable parts to meet customer demand.
Deliver	Reduction in the dependency on multiple suppliers can reduce delivery lead time.
Return	Reduction in scrap and recycling of unused AM material.

Especially, AM technology became a crucial part of the supply chain due to the unforeseen disruptions caused in manufacturing companies due to the COVID-19 pandemic. It was used across various sectors to counteract the interruptions significantly by increasing the production of certain critical medical implants, offsetting the challenges caused by the non-availability of unskilled labor, and reducing the time to make complex and highly customized parts [110]. In many critical aerospace and defense applications, the technology has reduced the lead time to a few days from the current lead time of nearly a year due to blockages in forging and casting supply chains [111]. This gives product-based organizations the flexibility to adjust rapidly to fluctuations in demand, freedom of design, shorter development time, reduced component weight, and less inventory cost. As the AM can eliminate or significantly reduce secondary finishing operations such as machining, the overall energy requirement to manufacture parts is reduced, which also helps organizations to achieve their sustainable manufacturing targets.

8. Conclusions

In the last few decades, the supply chain has seen numerous challenges, which also resulted in the incorporation of many novel technologies and strategies which completely transformed the function. Implementation of advanced Industry 4.0 technologies such as Artificial Intelligence, Internet of Things (IoT), Big data and analytics, blockchain, automation and robotics, and additive manufacturing provides the opportunity for industries to achieve the highest level of operational efficiency, agility, innovation, and customer service, which transforms it into a digital supply chain. In simple words, by automating every process, placing sensors in every asset, and creating a closed network, the technologies collaborate to achieve the highest possible performance. The vertical and horizontal integration of these technologies into the product life cycle can bring a transformation across the supply chain network and build a resilient supply chain. The focus of digitizing the supply chain is to provide advanced forecasting techniques, granular data access to customer preferences, predictive analysis in upstream and downstream activities, reduced lead time, real-time production with high flexibility to adapt to changing customer behavior, flexible logistics and delivery processes, real-time and end-to-end transparency, and visibility to the entire supplier network, a high level of automation throughout the supply chain to improve quality and process efficiency, and data-driven decision-making possibilities at every stage. The study shows that Industry 4.0 technologies can give agility, transparency, and resilience to the supply chain, which would make it customer-centric, demand-driven, and automated. In addition, the review shows that although the benefits of implementing Industry 4.0 technologies into supply chains are well recognized, the application, related research, and real-life use cases are still scarce, but it is clear that businesses that fail to embrace the technologies would eventually cease to exist. If the pandemic has exposed bottlenecks in our supply chain practices, integrating advanced Industry 4.0 technologies is the solution. Therefore, the question that organizations face is not "if" to adopt the technologies" but "when".

References

1. Aslan, E. How Supply Chain Management Will Change in the Industry 4.0 Era? In Research Anthology on Cross-Industry Challenges of Industry 4.0; Information Resources Management Association, IGI Global: Hershey, PA, USA, 2021; pp. 1015–1035.
2. Geodis. A White Paper on Supply Chain Worldwide Survey. 2017. Available online: https://geodis.com/sg//sites/default/files/2019-03/170509_GEODIS_WHITE-PAPER.PDF (accessed on 15 September 2022).
3. Top 5 Supply Chain Management Challenges and How to Overcome Them (With Real-Life Examples). 8 April 2021. Available online: https://www.easyecom.io/blog/top-5-supply-chain-management-challenges-and-how-to-overcome-them-with-real-life-examples/ (accessed on 15 September 2022).
4. Muthuswamy, P.; Shunmugesh, K. Artificial intelligence based tool condition monitoring for digital twins and industry 4.0 applications. Int. J. Interact. Des. Manuf. 2022.
5. McCulloch, W.S.; Pitts, W. A logical calculus of the ideas immanent in nervous activity. Bull. Math. Biophys. 1943, 5, 115–133.
6. Toorajipour, R.; Sohrabpour, V.; Nazarpour, A.; Oghazi, P.; Fischl, M. Artificial intelligence in supply chain management: A systematic literature review. J. Bus. Res. 2021, 122, 502–517.
7. Mobarakeh, N.A.; Shahzad, M.K.; Baboli, A.; Tonadre, R. Improved Forecasts for uncertain and unpredictable Spare Parts Demand in Business Aircraft's with Bootstrap Method. IFAC-PapersOnLine 2017, 50, 15241–15246.
8. Tsang, Y.P.; Choy, K.L.; Wu, C.H.; Ho, G.T.S.; Lam, C.H.Y.; Koo, P.S. An Internet of Things (IoT)-based risk monitoring system for managing cold supply chain risks. Ind. Manag. Data Syst. 2018, 118, 1432–1462.
9. Ignaciuk, P.; Wieczorek, Ł. Continuous Genetic Algorithms in the Optimization of Logistic Networks: Applicability Assessment and Tuning. Appl. Sci. 2020, 10, 7851.
10. Ferreira, L.; Borenstein, D. Normative agent-based simulation for supply chain planning. J. Oper. Res. Soc. 2011, 62, 501–514.
11. Naz, F.; Kumar, A.; Majumdar, A.; Agrawal, R. Is artificial intelligence an enabler of supply chain resiliency post COVID-19? An exploratory state-of-the-art review for future research. Oper. Manag. Res. 2022, 15, 378–398.
12. Sohrabpour, V.; Oghazi, P.; Toorajipour, R.; Nazarpour, A. Export sales forecasting using artificial intelligence. Technol. Forecast. Soc. Change 2021, 163, 120480.
13. Ketter, W.; Collins, J.; Gini, M.; Gupta, A.; Schrater, P. Real-Time Tactical and Strategic Sales Management for Intelligent Agents Guided by Economic Regimes. Inf. Syst. Res. 2012, 23, 1263–1283.
14. O'Donnell, T.; Humphreys, P.; McIvor, R.; Maguire, L. Reducing the negative effects of sales promotions in supply chains using genetic algorithms. Expert Syst. Appl. 2009, 36, 7827–7837.
15. Shakya, S.; Chin, C.M.; Owusu, G. An AI-based system for pricing diverse products and services. Knowl.-Based Syst. 2010, 23, 357–362.
16. Casabayó, M.; Agell, N.; Sánchez-Hernández, G. Improved market segmentation by fuzzifying crisp clusters: A case study of the energy market in Spain. Expert Syst. Appl. 2015, 42, 1637–1643.
17. Sarvari, P.A.; Ustundag, A.; Takci, H. Performance evaluation of different customer segmentation approaches based on RFM and demographics analysis. Kybernetes 2016, 45, 1129–1157.
18. Stalidis, G.; Karapistolis, D.; Vafeiadis, A. Marketing Decision Support Using Artificial Intelligence and Knowledge Modeling: Application to Tourist Destination Management. Procedia-Soc. Behav. Sci. 2015, 175, 106–113.
19. Rekha, A.G.; Abdulla, M.S.; Asharaf, S. Artificial Intelligence Marketing: An application of a novel Lightly Trained Support Vector Data Description. J. Inf. Optim. Sci. 2016, 37, 681–691.
20. Martínez-López, F.J.; Casillas, J. Artificial intelligence-based systems applied in industrial marketing: An historical overview, current and future insights. Ind. Mark. Manag. 2013, 42, 489–495.
21. Kwong, C.K.; Jiang, H.; Luo, X.G. AI-based methodology of integrating affective design, engineering, and marketing for defining design specifications of new products. Eng. Appl. Artif. Intell. 2016, 47, 49–60.

22. Taratukhin, V.; Yadgarova, Y. Towards a socio-inspired multiagent approach for new generation of product life cycle management. Procedia Comput. Sci. 2018, 123, 479–487.
23. Cardoso, R.N.; Pereira, B.L.; Fonseca, J.P.S.; Ferreira, M.V.M.; Tavares, J.J.P.Z.S. Automated Planning Integrated with Linear Programming Applied in the Container Loading Problem. IFAC Proc. Vol. 2013, 46, 153–158.
24. Wang, T.; Ramik, D.M.; Sabourin, C.; Madani, K. Intelligent systems for industrial robotics: Application in logistic field. Ind. Robot. 2012, 39, 251–259.
25. Knoll, D.; Prüglmeier, M.; Reinhart, G. Predicting Future Inbound Logistics Processes Using Machine Learning. Procedia CIRP 2016, 52, 145–150.
26. Klumpp, M. Automation and artificial intelligence in business logistics systems: Human reactions and collaboration requirements. Int. J. Logist. Res. Appl. 2018, 21, 224–242.
27. Eslikizi, S.; Ziebuhr, M.; Kopfer, H.; Buer, T. Shapley-based side payments and simulated annealing for distributed lot-sizingÕ. IFAC-PapersOnLine 2015, 48, 1592–1597.
28. Lee, C.K.M.; Ho, W.; Ho, G.T.S.; Lau, H.C.W. Design and development of logistics workflow systems for demand management with RFID. Expert Syst. Appl. 2011, 38, 5428–5437.
29. Kucukkoc, I.; Zhang, D.Z. A mathematical model and genetic algorithm-based approach for parallel two-sided assembly line balancing problem. Prod. Plan. Control 2015, 26, 874–894.
30. Sanders, D.; Gegov, A. AI tools for use in assembly automation and some examples of recent applications. Assem. Autom. 2013, 33, 184–194.
31. Olsson, E.; Funk, P. Agent-based monitoring using case-based reasoning for experience reuse and improved quality. J. Qual. Maint. Eng. 2009, 15, 179–192.
32. Gligor, A.; Dumitru, C.-D.; Grif, H.-S. Artificial intelligence solution for managing a photovoltaic energy production unit. Procedia Manuf. 2018, 22, 626–633.
33. Ennen, P.; Reuter, S.; Vossen, R.; Jeschke, S. Automated Production Ramp-up Through Self-Learning Systems. Procedia CIRP 2016, 51, 57–62.
34. Sousa, A.R.; Tavares, J.J.P.Z.S. Toward Automated Planning Algorithms Applied to Production and Logistics. IFAC Proc. Vol. 2013, 46, 165–170.
35. Quiñónez-Gámez, O.P.; Camacho-Velázquez, R.G. Validation of production data by using an AI-based classification methodology; a case in the Gulf of Mexico. J. Nat. Gas Sci. Eng. 2011, 3, 729–734.
36. Bravo, C.; Castro, J.A.; Saputelli, L.; Ríos, A.; Aguilar-Martin, J.; Rivas, F. An implementation of a distributed artificial intelligence architecture to the integrated production management. J. Nat. Gas Sci. Eng. 2011, 3, 735–747.
37. Mayr, A.; Weigelt, M.; Masuch, M.; Meiners, M.; Hüttel, F.; Franke, J. Application Scenarios of Artificial Intelligence in Electric Drives Production. Procedia Manuf. 2018, 24, 40–47.
38. Martinez-Barbera, H.; Herrero-Perez, D. Development of a flexible AGV for flexible manufacturing systems. Ind. Robot. 2010, 37, 459–468.
39. Kasie, F.M.; Bright, G.; Walker, A. Decision support systems in manufacturing: A survey and future trends. J. Model. Manag. 2017, 12, 432–454.
40. Camarillo, A.; Ríos, J.; Althoff, K. Knowledge-based multi-agent system for manufacturing problem solving process in production plants. J. Manuf. Syst. 2018, 47, 115–127.
41. Taylan, O.; Darrab, I.A. Fuzzy control charts for process quality improvement and product assessment in tip shear carpet industry. J. Manuf. Technol. Manag. 2012, 23, 402–420.
42. Brandenburger, J.; Colla, V.; Nastasi, G.; Ferro, F.; Schirm, C.; Melcher, J. Big Data Solution for Quality Monitoring and Improvement on Flat Steel Production. IFAC-PapersOnLine 2016, 49, 55–60.
43. Tsafarakis, S.; Saridakis, C.; Baltas, G.; Matsatsinis, N. Hybrid particle swarm optimization with mutation for optimizing industrial product lines: An application to a mixed solution space considering both discrete and continuous design variables. Ind. Mark. Manag. 2013, 42, 496–506.
44. Ma, Z.; Leung, J.Y.; Zanon, S. Integration of artificial intelligence and production data analysis for shale heterogeneity characterization in steam-assisted gravity-drainage reservoirs. J. Pet. Sci. Eng. 2018, 163, 139–155.
45. Trentesaux, D.; Thomas, A. Product-Driven Control: A State of the Art and Future Trends. IFAC Proc. Vol. 2012, 45, 716–721.
46. Munguia, J.; Bernard, A.; Erdal, M. Proposal and evaluation of a KBE-RM selection system. Rapid Prototyp. J. 2011, 17, 236–246.

47. Amirkolaii, K.N.; Baboli, A.; Shahzad, M.K.; Tonadre, R. Demand Forecasting for Irregular Demands in Business Aircraft Spare Parts Supply Chains by using Artificial Intelligence (AI). IFAC-PapersOnLine 2017, 50, 15221–15226.

48. Florez, J.V.; Lauras, M.; Okongwu, U.; Dupont, L. A decision support system for robust humanitarian facility location. Eng. Appl. Artif. Intell. 2015, 46, 326–335.

49. Vahdani, B.; Iranmanesh, S.H.; Mousavi, S.M.; Abdollahzade, M. A locally linear neuro-fuzzy model for supplier selection in cosmetics industry. Appl. Math. Model. 2012, 36, 4714–4727.

50. Zhang, X.; Chan, F.T.S.; Adamatzky, A.; Mahadevan, S.; Yang, H.; Zhang, Z.; Deng, Y. An intelligent physarum solver for supply chain network design under profit maximization and oligopolistic competition. Int. J. Prod. Res. 2016, 55, 244–263.

51. Sinha, A.K.; Zhang, W.Z.; Tiwari, M. Co-evolutionary immuno-particle swarm optimization with penetrated hyper-mutation for distributed inventory replenishment. Eng. Appl. Artif. Intell. 2012, 25, 1628–1643.

52. Zgaya, H.; Zoghlami, N.; Hammadi, S.; Bretaudeau, F. Negotiation Model in a Multi-Agent Supply Chain System for The Crisis Management. IFAC Proc. Vol. 2009, 42, 1026–1031.

53. Dias, J.C.Q.; Calado, J.M.F.; Osório, A.L.; Morgado, L.F. RFID together with multi-agent systems to control global value chains. Annu. Rev. Control 2009, 33, 185–195.

54. Pino, R.; Fernández, I.; De la Fuente, D.; Parreño, J.; Priore, P. Supply chain modelling using a multi-agent system. J. Adv. Manag. Res. 2010, 7, 149–162.

55. Min, H. Artificial intelligence in supply chain management: Theory and applications. Int. J. Logist. Res. Appl. 2009, 13, 13–39.

56. Chong, A.Y.-L.; Bai, R. Predicting open IOS adoption in SMEs: An integrated SEM-neural network approach. Expert Syst. Appl. 2013, 41, 221–229.

57. Yanqing, D.; Edwards, J.S.; Yogesh, K.D. Artificial intelligence for decision making in the era of Big Data – evolution, challenges and research agenda. Int. J. Inf. Manage. 2019, 48, 63–71.

58. Regal, T.; Pereira, C.E. Ontology for Conceptual Modelling of Intelligent Maintenance Systems and Spare Parts Supply Chain Integration. IFAC-PapersOnLine 2018, 51, 1511–1516.

59. Merlino, M.; Sproġe, I. The Augmented Supply Chain. Procedia Eng. 2017, 178, 308–318.

60. Ben-Daya, M.; Hassini, E.; Bahroun, Z. Internet of things and supply chain management: A literature review. Int. J. Prod. Res. 2019, 57, 4719–4742.

61. Ross, D.F.; Weston, F.S.; Stephen, W. Introduction to Supply Chain Management Technologies; CRC Press: Boca Raton, FL, USA, 2010; ISBN 1439837538, 9781439837535.

62. Salehi-Amiri, A.; Jabbarzadeh, A.; Hajiaghaei-Keshteli, M.; Chaabane, A. Utilizing the Internet of Things (IoT) to address uncertain home health care supply chain network. Expert Syst. Appl. 2022, 208, 118239.

63. Shokouhifar, M.; Sabbaghi, M.M.; Pilevari, N. Inventory management in blood supply chain considering fuzzy supply/demand uncertainties and lateral transshipment. Transfus. Apher. Sci. 2021, 60, 103103.

64. Sohrabi, M.; Zandieh, M.; Afshar-Nadjafi, B. A simple empirical inventory model for managing the processed corneal tissue equitably in hospitals with demand differentiation. Comput. Appl. Math. 2021, 40, 281.

65. APICS. Supply Chain Operations Reference Model, Version 12.0. 2017. Available online: http://www.apics.org/docs/default-source/scor-p-toolkits/apics-scc-scor-quick-reference-guide.pdf?sfvrsn=2 (accessed on 15 September 2022).

66. Verdouw, C.N.; Beulens, A.J.M.; Van der Vorst, J.G.A.J. Virtualisation of floricultural supply chains: A review from an Internet of Things perspective. Comput. Electron. Agric. 2013, 99, 160–175.

67. Ng, I.; Scharf, K.; Pogrebna, G.; Maull, R. Contextual variety, Internet-of-Things and the choice of tailoring over platform: Mass customisation strategy in supply chain management. Int. J. Prod. Econ. 2015, 159, 76–87.

68. Yu, J.; Subramanian, N.; Ning, K.; Edwards, D. Product delivery service provider selection and customer satisfaction in the era of internet of things: A Chinese e-retailers' perspective. Int. J. Prod. Econ. 2015, 159, 104–116.

69. Wang, T.; Zhang, Y.F.; Zang, D.X. Real-Time Visibility and Traceability Framework for Discrete Manufacturing Shopfloor. In Proceedings of the 22nd International Conference on Industrial Engineering and Engineering Management 2015; Springer: Singapore, 2015; pp. 763–772.

70. Rymaszewska, A.; Helo, P.; Gunasekaran, A. IoT powered servitization of manufacturing—An exploratory case study. Int. J. Prod. Econ. 2017, 192, 92–105.

71. Putnik, G.D.; Varela, M.L.R.; Carvalho, C.; Alves, C.; Shah, V.; Castro, H.; Ávila, P. Smart Objects Embedded Production and Quality Management Functions. Int. J. Qual. Res. 2015, 9, 151–166.

72. Ondemir, O.; Gupta, S.M. Quality management in product recovery using the Internet of Things: An optimization approach. Comput. Ind. 2014, 65, 491–504.

73. Chukwuekwe, D.O.; Schjoelberg, P.; Roedseth, H.; Stuber, A. Reliable, Robust and Resilient Systems: Towards Development of a Predictive Maintenance Concept within the Industry 4.0 Environment. In Proceedings of the EFNMS Euro Maintenance Conference, Athens, Greece, 30 May 2016.

74. Reaidy, P.J.; Gunasekaran, A.; Spalanzani, A. Bottom-up approach based on Internet of Things for order fulfillment in a collaborative warehousing environment. Int. J. Prod. Econ. 2015, 159, 29–40.

75. Qiu, X.; Luo, H.; Xu, G.; Zhong, R.; Huang, G.Q. Physical assets and service sharing for IoT-enabled Supply Hub in Industrial Park (SHIP). Int. J. Prod. Econ. 2015, 159, 4–15.

76. Choy, K.L.; Ho, G.T.S.; Lee, C.K.H. A RFID-based storage assignment system for enhancing the efficiency of order picking. J. Intell. Manuf. 2017, 28, 111–129.

77. Kong, X.T.R.; Chen, J.; Luo, H.; Huang, G.Q. Scheduling at an auction logistics centre with physical internet. Int. J. Prod. Res. 2015, 54, 2670–2690.

78. Yao, J. Optimisation of one-stop delivery scheduling in online shopping based on the physical Internet. Int. J. Prod. Res. 2017, 55, 358–376.

79. Mathaba, S.; Adigun, M.; Oladosu, J.; Oki, O. On the Use of the Internet of Things and Web 2.0 in Inventory management. J. Intell. Fuzzy Syst. 2017, 32, 3091–3101.

80. Gu, Y.; Liu, Q. Research on the Application of the Internet of Things in Reverse Logistics Information Management. J. Ind. Eng. Manag. 2013, 6, 963–973.

81. Parry, G.C.; Brax, S.A.; Maull, R.S.; Ng, I.C.L. Operationalising IoT for reverse supply: The development of use-visibility measures. Supply Chain Manag. Int. J. 2016, 21, 228–244.

82. Thürer, M.; Pan, Y.H.; Qu, T.; Luo, H.; Li, C.D.; Huang, G.Q. Internet of Things (IoT) driven kanban system for reverse logistics: Solid waste collection. J. Intell. Manuf. 2019, 30, 2621–2630.

83. Balaji, M.S.; Roy, S.K. Value co-creation with Internet of things technology in the retail industry. J. Mark. Manag. 2017, 33, 7–31.

84. Büyüközkan, G.; Göçer, F. Digital Supply Chain: Literature review and a proposed framework for future research. Comput. Ind. 2018, 97, 157–177.

85. Darvazeh, S.S.; Vanani, I.R.; Musolu, F.M. Big Data Analytics and Its Applications in Supply Chain Management. In New Trends in the Use of Artificial Intelligence for the Industry 4.0; Martínez, L.R., Rios, R.A.O., Prieto, M.D., Eds.; IntechOpen: London, UK, 2020.

86. Geunes, J.; Chang, B. Operations Research Models for Supply Chain Management and Design. In Encyclopedia of Optimization; Floudas, C., Pardalos, P., Eds.; Springer: Boston, MA, USA, 2008.

87. Wang, G.; Gunasekaran, A.; Ngai, E.W.T.; Papadopoulos, T. Big data analytics in logistics and supply chain management: Certain investigations for research and applications. Int. J. Prod. Econ. 2016, 176, 98–110.

88. Murugesan, S.; Sudharsanan, T.; Murugesan, V.; Muthuswamy, P. Overall Equipment Effectiveness (OEE) analysis and improvement in a spinning unit. Int. J. Appl. Eng. Res. 2015, 10, 3791–3796.

89. Richey, R.G.; Morgan, T.R.; Lindsey-Hall, K.; Adams, F.G. A global exploration of Big Data in the supply chain. Int. J. Phys. Distrib. Logist. Manag. 2016, 46, 710–739.

90. Javaid, M.; Haleem, A.; Singh, R.P.; Suman, R. Significant Applications of Big Data in Industry 4.0. J. Ind. Integr. Manag. 2021, 6, 429–447.

91. Arunachalam, D.; Kumar, N.; Kawalek, J.P. Understanding big data analytics capabilities in supply chain management: Unravelling the issues, challenges and implications for practice. Transp. Res. Part E Logist. Transp. Rev. 2018, 114, 416–436.

92. Yaga, D.; Mell, P.; Roby, N.; Scarfone, K. Blockchain technology overview. arXiv 2019, arXiv:1906.11078.

93. Raja Santhi, A.; Muthuswamy, P. Influence of Blockchain Technology in Manufacturing Supply Chain and Logistics. Logistics 2022, 6, 15.

94. Klapita, V. Implementation of Electronic Data Interchange as a Method of Communication Between Customers and Transport Company. Transp. Res. Procedia 2021, 53, 174–179.

95. Azzi, R.; Chamoun, R.K.; Sokhn, M. The power of a blockchain-based supply chain. Comput. Ind. Eng. 2019, 135, 582–592.
96. Javaid, M.; Haleem, A.; Singh, R.P.; Khan, S.; Suman, R. Blockchain technology applications for Industry 4.0: A literature-based review. Blockchain Res. Appl. 2021, 2, 100027.
97. Hellani, H.; Sliman, L.; Samhat, A.E.; Exposito, E. On Blockchain Integration with Supply Chain: Overview on Data Transparency. Logistics 2021, 5, 46.
98. Tucker, M. Sourcing Minerals Responsibly with Blockchain Technology. Available online: https://www.ibm.com/case-studies/rcs-global-blockchain/ (accessed on 30 November 2021).
99. Almutairi, K.; Dehshiri, S.J.H.; Hoa, A.X.; Dhanraj, J.A.; Mostafaeipour, A.; Issakhov, A.; Techato, K. Blockchain Technology Application Challenges in Renewable Energy Supply Chain Management. Environ. Sci. Pollut. Res. 2022, 1–18.
100. Dehshiri, S.J.H.; Emamat, M.S.M.M.; Amiri, M. A novel group BWM approach to evaluate the implementation criteria of blockchain technology in the automotive industry supply chain. Expert Syst. Appl. 2022, 198, 116826.
101. Kagermann, H. Change through digitization: Value creation in the age of Industry 4.0. In Management of Permanent Change; Pinkwart, A., Reichwald, R., Albach, H., Meffert, H., Eds.; Gabler: Wiesbaden, Germany, 2015; pp. 23–45.
102. Hofmann, E.; Sternberg, H.; Chen, H.; Pflaum, A.; Prockl, G. Supply chain management and Industry 4.0: Conducting research in the digital age. Int. J. Phys. Distrib. Logist. Manag. 2019, 49, 945–955.
103. Tantawi, K.H.; Sokolov, A.; Tantawi, O. Advances in Industrial Robotics: From Industry 3.0 Automation to Industry 4.0 Collaboration. In Proceedings of the 2019 4th Technology Innovation Management and Engineering Science International Conference (TIMES-iCON), Bangkok, Thailand, 11–13 December 2019; pp. 1–4.
104. Flämig, H. Autonomous vehicles and autonomous driving in freight transport. In Autonomous Driving; Maurer, M., Gerdes, J.C., Lenz, B., Winner, H., Eds.; Springer: Berlin/Heidelberg, Germany, 2016; pp. 365–385.
105. Jennings, D.; Figliozzi, M. Study of sidewalk autonomous delivery robots and their potential impacts on freight efficiency and travel. Transp. Res. Rec. J. Transp. Res. Board 2019, 2673, 317–326.
106. Padmakumar, M. Additive Manufacturing of Tungsten Carbide Hardmetal Parts by Selective Laser Melting (SLM), Selective Laser Sintering (SLS) and Binder Jet 3D Printing (BJ3DP) Techniques. Lasers Manuf. Mater. Process. 2020, 7, 338–371.
107. Muthuswamy, P. Influence of powder characteristics on properties of parts manufactured by metal additive manufacturing. Lasers Manuf. Mater. Process. 2022, 9, 312–337.
108. Kunovjanek, M.; Knofius, N.; Reiner, G. Additive manufacturing and supply chains—A systematic review. Prod. Plan. Control 2020, 33, 1231–1251.
109. Ashima, R.; Haleem, A.; Bahl, S.; Javaid, M.; Mahla, S.K.; Singh, S. Automation and manufacturing of smart materials in additive manufacturing technologies using Internet of Things towards the adoption of industry 4.0. Mater. Today Proc. 2021, 45, 5081–5088.
110. Wagoner, D. How Additive Manufacturing is Transforming the Supply Chain. Available online: https://www.pinionglobal.com/additive-manufacturing-supply-chain/ (accessed on 15 September 2022).
111. US Air Force and GE Reach Next Milestone in Pacer Edge Program. Available online: https://www.3dprintingmedia.network/us-air-force-ge-next-milestone-pacer-edge-program/ (accessed on 15 September 2022).
