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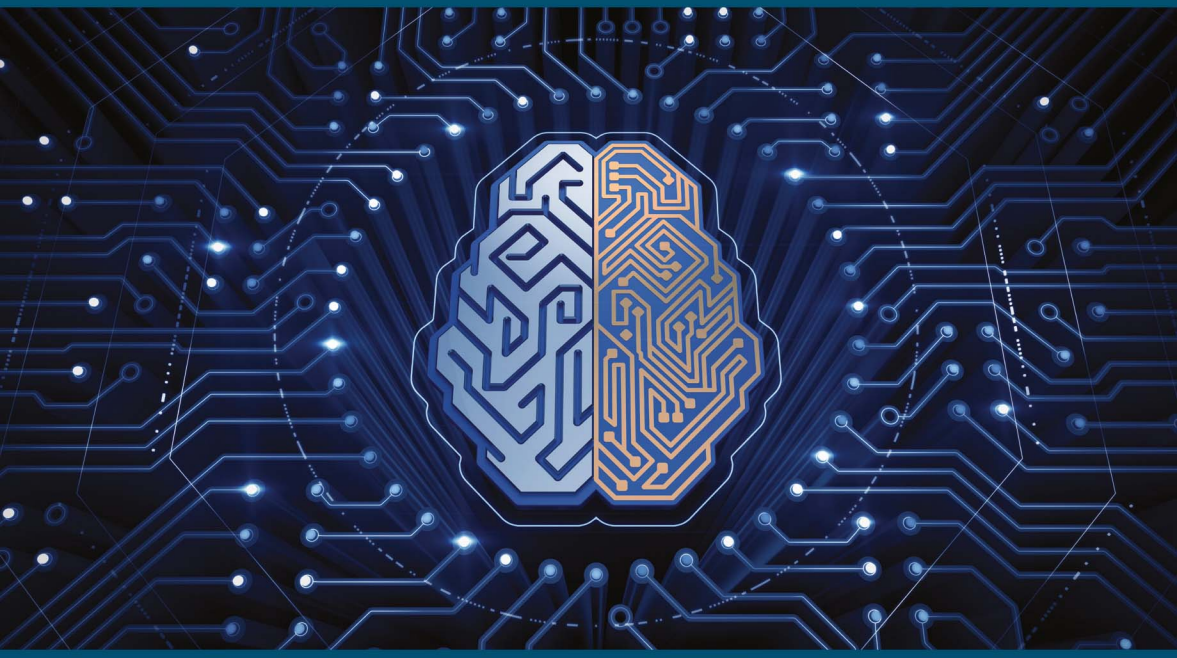

Connected Innovation and Technology X.0 1

Advancing Digital Transformation: Innovational Strategies for Smart Industry and Sustainable Innovation

Edited by Farouk Yalaoui
Nhan-Quy Nguyen, Yassine Ouazene
Maria Zemzami, Leïla Merghem-Boulahia

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Preface

Connected Innovation, the Heart of Industry X.0

In this book, “Connected Innovation and Technology X.0 1”, we explore the transformative impact of digital technologies across various sectors of the economy. The evolution of logistics and industry from historical practices to the current data-driven, automated processes highlights the shift toward a more integrated, efficient and innovative future, denoted as Industry X.0.

The journey of logistics, a foundational element of industry, traces back centuries, evolving from the supply needs of Roman armies to the intricate, data-driven logistics of today. This historical perspective underscores the continuous innovation and adaptation that have defined logistics, setting the stage for its integration into the broader concept of Industry X.0. Industry X.0 represents a shift toward digital reinvention, leveraging advanced digital technologies to transform business models, enhance human-centric experiences and fuel innovation and growth.

At the core of Industry X.0 is the digital transformation of core businesses, a pivot from product focus to experiential platforms, the redefinition of ecosystems, the creation of new business models, the enhancement of human resources skills and the management of an intelligent pivot. These pillars are essential for organizations to handle the complexities of the digital landscape, ensuring a seamless transition to new, innovative paradigms.

The integration of logistics into Industry X.0, or Logistics X.0, marks the digitalization and automation of the supply chain, emphasizing the use of

sophisticated technologies and artificial intelligence for enhanced decision-making and operational efficiency. This evolution toward Logistics X.0 is marked by a shift from Big Data to Smart Data, the autonomy of logistical operations and the application of Internet of Things (IoT) technologies for real-time decision-making and total product traceability.

This book explores the multifaceted challenges and opportunities presented by connected innovation and technology X.0, across various sectors, including manufacturing, healthcare and energy efficiency. It addresses the digitization of decision processes, product service traceability, the automation and robotization of operations, the development of decision-making tools, data security and staff training. These discussions are critical for understanding the implications of Industry X.0 on future jobs, skills and operational frameworks.

The book is structured into three parts, each focusing on different aspects of innovation and technology in the context of Industry X.0:

– Part 1, "Innovations in Production and Smart Supply Chain Management", presents insights into how Industry 4.0 technologies are reshaping supply chains and production. It includes discussions on the integration of Lean methodologies with Industry 4.0 for sustainable supply chain management, strategies for maintenance and quality control in manufacturing, and energy efficiency optimization in supply chains.

– Part 2, "Performance Evaluation and Optimization for Industry X.0", considers the performance assessment of networking protocols within the industrial Internet of Things (IIoT), security enhancements in 5G and 6G networks, innovative techniques for algorithm optimization, flexible job-shop scheduling challenges and using simulation for balancing workload and reducing wait times in healthcare settings.

– Part 3, "Sustainable and Efficient Solutions Design", focuses on technological innovations for sustainability and efficiency. This includes advancements in automatic weed detection, energy management in smart buildings, frugal innovation for water scarcity solutions and the use of additive manufacturing for designing materials with optimized thermal properties.

This book examines the challenges ahead in digitizing decision processes, ensuring product service traceability, automating and robotizing operations, developing decision-making tools, securing data and training staff. These elements are crucial for all parties involved in adapting to and maturing in the Industry X.0 environment, which requires a broad range of skills and competencies in data management, robotics, automation and software development.

We hope that this book provides a clear view of the latest research and practices in technology, innovation and management. Our goal is to share insights about the future of smart manufacturing and green solutions, helping readers see how technology can greatly improve efficiency, productivity and sustainability in various industries.

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May 2024

PART 1

Innovations in Production and Smart Supply Chain Management

1

Supply Chain Views from an Industry 4.0 Perspective

Today, building and running a smart supply chain (SSC) is difficult. To handle these issues, supply networks must become more intelligent. More intelligent supply chains have shown a lot of promise. Before any modifications can be made, the commercial and technical obstacles must be resolved, as well as any issues with the policy. A total of 294 studies have been examined in depth as part of a systematic literature review. The examination of the papers centered on scrutinizing the analytical unit and identifying the most cutting-edge technological approaches for establishing an intelligent supply chain. The outcomes of the study revealed a predominant emphasis among researchers on exploring the concepts and methodologies associated with intelligent supply chains.

1.1. Introduction

There has been an increase in interest in Industry 4.0 in the supply chain in recent years, which represents an interconnected system in the various processes and activities that produce value in the form of goods and services in the customer's hands (Christopher 2005). The majority of supply chains are known for having numerous supply–demand issues, such as overstocking, stock-outs and delivery delays, which have been hot topics in the literature (Wong et al. 2012). This is because of complexity, uncertainty and other factors.

The supply chains have become more complicated, expensive and fragile. For instance, when supply chains interlace more and more, a company's sensitivity to unanticipated consequences and interruptions grows significantly (Abdel-Basset et al. 2018). The adage "cheaper, faster and better" is still common in management,

Chapter written by Ghita BOUCHTAOUI, Lamia HAMMADI, Ridha DERROUICHE, Roberta COSTA-AFFONSO and Abdessamad EL BALLOUTI.

but traditional supply chain tactics and procedures have shown some inconsistency in dealing with the increased complexity, unpredictability and vulnerability of supply chains. According to Sam Palmisano, who served as Chairman of the IBM Corporation from 2003 to 2012, the incorporation of "smart" into decision-making procedures and management systems represents an enhancement compared to the previous narrow focus on speed and capacity. In fact, it is anticipated that conventional supply chain management improvements will continue to progress further (Zhao et al. 2020).

The notion of the "smart supply chain" is being used to implement intelligent transformation using advanced technologies, such as the Internet of Things (IoT), Big Data, blockchain, artificial intelligence (AI), cloud computing, cyber physical systems, paperless warehousing and digital twins. These phrases were developed based on the connectivity of intelligent devices and systems that make use of the technologies listed above, allowing them to self-correct and self-adapt to changing environmental conditions (Wu et al. 2016).

The remainder of this chapter is organized as follows. The definition of an SSC and its characteristics are presented in section 1.2. The crucial technologies for the creation of SSC are then covered in section 1.3. The methods used to conduct a systematic literature review are presented in section 1.4. Section 1.5 analyzes the literature and presents its findings. The debate and potential research directions are presented in section 1.6. Section 1.7 concludes the chapter.

1.2. Smart supply chain

1.2.1. *Definition*

Today, creating and managing an SSC is difficult. This entails a supply chain that is outfitted with cutting-edge technology that enable process automation, real-time inventory tracking and ongoing supervision (Tripathi and Gupta 2020). It also makes it possible for customers, supply chain participants and the technology itself to interact. Applications for SSCs undoubtedly offer several benefits that would otherwise be unattainable. For instance, they allow us to track the position of a product along the value chain. Additionally, understanding customer needs helps to optimize production and reduce costs. Using emerging technologies for in-depth analysis can steer decision-making upstream in the production process, allowing for the evaluation or exclusion of specific stakeholders (Xie et al. 2020). This wealth of information can be leveraged to enhance overall business decision-making. Enhanced corporate procedures are being developed to enhance efficiency and enable quicker responses.

SSCs have the potential to eliminate numerous recurring inefficiencies, as the human capacity to identify and resolve many system issues has been surpassed by the dynamic complexity. Consequently, it has become more challenging to enhance performance using traditional methods, leading companies to recognize the urgent need for innovative solutions driven by technological advancements and changes in business models. Furthermore, smart devices are being used everywhere, and instrumentation prices have dropped significantly in recent years (Zhu et al. 2012). Nowadays, instrumentation, monitoring and analytics can be supported widely by computing and information technology (Xie et al. 2020).

1.2.2. *Characteristics of smart supply chain*

Using these criteria as a foundation, Abdel-Basset et al. (2018) offered the six most important SSC traits, which are in line with the suggestions in IBM's study on its Future of Supply Chain survey from 2017 (IBM 2017). The following is our informational summary:

– Instrumented: it includes use of sensors, actuators, intelligent devices to automate transaction, along with RFID technology, which stands for radio frequency identification and is a low-cost, low power wireless communication system that is fully passive or battery-assisted passive (BAP) (Witkowski 2017 and Lee 2015). For example, smart devices collect and integrate data in real time and with transparency from point of sale to manufacturing to row material. It also includes the use of sensors to predict and act.

– Interconnected: every element within the supply chain must be interconnected, encompassing components, products and various smart devices used for supply chain monitoring, along with customers, suppliers and information systems. The extensive connectivity within global supply chain networks enables collaborative planning and decision-making.

– Intelligence: it is anticipated that making big decisions will make it easier for the SSC to achieve its ideal overall performance. It is important to note that the supply chain makes decisions on its own, independent of any outside factors. For instance, the supply chain network reconfigures itself after a disruption. Comprehensive modeling, simulation and the ability to make wise decisions all contribute to the perfect prediction-response paradigm, which is used to predict future events.

– Automated: it will develop the ability to assign responsibility for decisions by placing orders for the raw materials needed in accordance with the production schedule created, or by rearranging the networks in response to disruptions. Machines and robots will replace low efficiency and unskilled labor in the (manual) processes.

– Integrated: the wide interconnectedness will make global collaboration and supply chain stage coordination easier. By becoming socially responsible, innovative and smart, collaboration is quickly becoming recognized as being fundamental to successful companies.

– Innovated: along with self-learning and the exploration of novel techniques to incorporate ongoing developments for better meeting needs, continuous improvement is a crucial element of the rapidly evolving SSC.

1.3. The essential technologies for the development of the smart supply chain

1.3.1. *Internet of Things*

Traditional supply chain management methods pose a number of problems, such as overstocking, lengthy deliveries and stock-outs. These problems are due to the various complexities and uncertainties that exist in real-life supply chains (Azizi et al. 2021). We need to make supply chain management systems smarter in order to solve these problems, so we have used IoT in supply chain systems (Sharma et al. 2020). IoT is described in a variety of ways; some academics define it as a network of cooperative and connected software, hardware, databases, virtual and physical items, and sensors (Kumar and Sharma 2021). The IoT provides greater visibility into various enterprise processes and data. By having a better control of these different aspects and statistics, organizations will be able to offer superior services, improve product quality and customer satisfaction, and decrease labor costs. The monitoring and analysis of collected data will also facilitate production and automation (Azizi et al. 2021).

RFIDs can be added to objects to identify materials and things, including equipment and furniture. The correct information provided by RFID use will aid in efficient management. It is also possible to track an object's complete lifecycle (Abdel-Basset et al. 2018). In the case of storage in warehouses, intelligent shelving and pallets will support modern inventory management. Commodity tracking and tracing becomes speedier, more precise, predictable and secure (Witkowski 2017). Analysis relating to the development of a "connected fleet" can be used to automatically plan supply chain improvement operations and forecast failure. The effects of IOT on SC include the following (Abdel-Basset et al. 2018):

– Improving inventory control: using the IoT, real-time inventory visibility has been made possible. Without real-time visibility, the inventory management process will rely on estimation. Additionally, manual data collection contributes to inventory disorder issues. Inventory is accurately 100 with the addition of sensors (Lee and Lee 2015).

– Real-time supply chain management: in a conventional supply chain, information about demand is shared across all partners. However, the newest RFID tag technologies allow for the collection of many kinds of data, including manufacturing and expiration dates and warranty duration, which will result in effective supply chain management.

– Logistics transparency is maximized by leveraging smart objects to make the entire supply chain aware of all transport information. The likelihood of monitoring and preserving products will rise as a result. It also reduces the cost of returns and significantly affects consumer satisfaction (Hu et al. 2023).

1.3.2. *Big Data*

These days, due to the Internet's quick expansion, such a vast volume of information is produced and gathered every day that its processing and analysis are beyond the scope of conventional instruments (Babiceanu and Seker 2016). Big Data is a technology, nevertheless, that allows us to perform analysis. It enables us to effectively manage and utilize this constantly expanding database (due to the collection of data from several sources) (Witkowski 2017). The described technology enables analysis and the differentiation of what is significant from what is not, assisting in drawing conclusions and facilitating the efficient transmission of knowledge to achieve corporate objectives. Big Data has four dimensions, according to Forrester's definition.

– Volume (amount of data): it is related to technological capacities to manage these data by the McKinsey Global Institute: "the concept of Big Data refers to datasets whose size exceeds the capacity of ordinary tools for collection, storage, management and analysis".

– Variety (variety of data): Big Data originates from a variety of sources, such as social networking sites, transactional systems and the Internet. These data, which include elements like photographs, videos and information from social networking sites, are dynamic and extremely unstructured, rendering them unsuitable for conventional modes of analysis (Narwane et al. 2023).

– Velocity (the speed of generation of new data and analysis): analysis of Big Data occurs in near real-time to ensure that the accurate findings can be promptly applied to the ever evolving and dynamic data stream.

– Value (value of data): the overall goal is to narrow down the vast amount of information to what matters to us most, which is why it is crucial that the outcomes accurately reflect the actual situation and generate the most profitable business operations.

1.3.3. *Blockchain*

Blockchain is an innovative technology, which is used to store and transmit information. It should be seen as a kind of register. It can contain different data such as information and transactions. All of these elements are organized in the form of blocks, hence the term blockchain (Turjo et al. 2021). This technology is interesting because it uses a decentralized network. It does not have a control center. The data are therefore not stored on a server, but on a large number of computers. This is called a distributed database. In this type of database, the actors of the distributed systems exchange information with each other without having to refer to a central actor. It strengthens the communication between suppliers, companies and consumers (Lohmer et al. 2022). In this way, in conjunction with all the elements of IIoT (mobile robots, sensors, robotics, smart labels or other devices controlled by the WMS), the blockchain facilitates the following (Turjo et al. 2021):

– Increased productivity, saving time and money: a more powerful and secure information transfer network allows warehouse automation to work better, with more cycles and fewer errors.

– Trust and transparency in the supply chain: information is exchanged between agents through a set of nodes that verify each new piece of data recorded.

– Real-time traceability: because of the interconnection between all the participants in the network, the company controls the traceability of products in real time, which results in a faster and more efficient service for the end customer.

Data are encrypted using an asymmetric encryption mechanism in blockchain. The encryption and decryption keys in this system can be kept and used individually without the usage of secure channels. By encrypting IoT data, blockchain ensures data privacy, resulting in more secure user privacy. The use of blockchain technology in the process of product tracking can produce a chain with clear tracking and sharing capabilities, since blockchain data have visible, uncorrected and unanalyzable qualities. The blockchain network is scalable because it is maintained by a network of participants. The network's computational capacity increases as more affiliates join (Bahga and Madisetti 2016). With the capability to verify everything on the blockchain, greater trust can be placed in the system (Yang et al. 2018).

1.4. Methodology

This section concerns the methodology used for this study; we used a PRISMA statement to answer our research question. The systematic literature review contributes to the development of existing knowledge bases (Tranfield et al. 2003).

1.4.1. *Systematic literature review*

The following steps were used to conduct a systematic literature review:

– identification of publication by keywords;

– selection by exclusion criteria;

– eligibility by inclusion criteria;

– synthesis of data.

A description of the procedures in a systematic literature review is shown in Figure 1.1.

Figure 1.1. *Systematic literature review process*

The initial step in conducting a systematic literature review involves identifying relevant publications. To identify the publications, we determined keywords that are related to the SSC, new technologies and Industry 4.0. If we summarize our search string, then it can be the conjunction of several keywords. We applied the search string to Science Direct, Springer Link and Emerald Insight publications. A total of 583 publications appeared in the first phase of the search, including journal articles, book sections and conference papers. We analyzed the search results and deleted the duplicates. A list of keywords used by us is given in Table 1.1.

Letter	Keywords	Synonym 1	Synonym 2	Expression	Combination
A	Smart supply chain	Intelligent supply chain	Supply Chain 4.0	A-A1-A2	A + B + C
B	IOT	Internet of Things	IIOT	B-B1-B2	B + A + C
C	Blockchain	Blockchain security	Smart contracts	C-C1-C2	C + D + E
D	Smart warehouse	Warehousing 4.0	Connected warehousing	D-D1-D2	D + B + C
E	Transport 4.0	Connected vehicles		E-E1-E2	
F	Industry 4.0	Smart industry	Connected industry	F-F1	A + F

Table 1.1. *Keywords*

The second step involves the initial criterion, which focuses on the timeframe of the literature, spanning from 2015 to 2022. This period was chosen because the majority of relevant papers and a substantial number of new trends and applications related to this topic have emerged within this timeframe. To assess whether the selected papers are relevant to the research topic, an examination of publications was conducted as part of the second criterion, which emphasizes both relevance and quality. We conducted a thorough examination of the abstracts, keywords and titles of the selected papers. If the title, keywords and abstract did not clearly indicate the study's main topic, we proceeded to review the full text. Papers with titles and abstracts that did not meet our inclusion criteria were eliminated. The criteria used for selecting articles for inclusion were twofold: first, they had to primarily focus on SSC, and second, they needed to involve the implementation of innovative technologies to create an intelligent supply chain within the context of Industry 4.0.

After a comprehensive examination of the full texts, a total of 294 articles were chosen for the systematic literature review. In section 1.5, we present the results and findings of both the frequency and qualitative analyses.

1.5. Analysis and synthesis

Once the appropriate collection of pertinent papers has been assembled, the data analysis and synthesis procedure begin. Finding correlations between diverse study materials is the aim of synthesis, as opposed to analysis, which aims to break down each study into its component parts and describe the general relationships and connections (Tranfield et al. 2003). The analysis and synthesis of this study are shown in the subsections that follow.

1.5.1. *Frequency analysis*

1.5.1.1. *Type of publication*

We used a frequency analysis to look at the various sorts of publications that were present in our sources in our sample of 294 articles. Figure 1.2 summarizes the analyses' findings and gives an overview of the different publication types we found. As a matter of fact, 84% of all publications in our sample were journal articles, making up the vast bulk of our sample. This equates to 246 articles overall from the 294 publications analyzed. The preponderance of journal articles in our sample reflects the importance of this format in the topic being studied. Journal articles are frequently regarded as a key source of academic research. In addition, we discovered that out of the 294 publications, 41 book portions, also known as book chapters, make up 14% of our sample. The fact that book parts were included in our sample illustrates the variety of sources we examined for our research. Book

portions are frequently used to explore more particular issues or contribute to collective works. Finally, conference papers make up a tiny percentage of our sample, accounting for only 2% of all publications, or seven papers out of the 294 publications we looked at. The rapid distribution of new research is frequently facilitated by conferences, and despite the fact that they contribute less frequently, they can nonetheless provide vital insights into the topic being investigated. In conclusion, our examination of the frequency of different publishing forms in our sample reveals that journal articles predominate, followed by book portions and conference papers. This distribution of sources highlights the variety of sources used in our study and aids in providing more thorough knowledge of the subject matter.

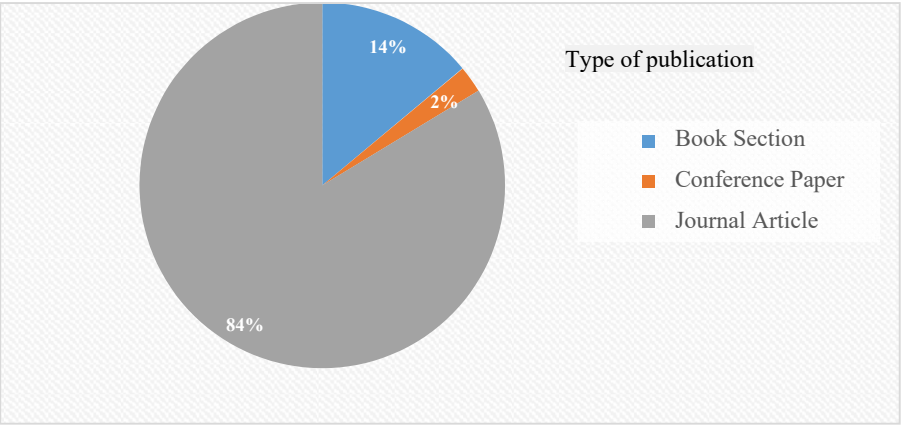

Figure 1.2. *Type of publication. For a color version of this figure, see www.iste.co.uk/yalaoui/connected1.zip*

1.5.1.2. *Year wise publication*

Figure 1.3 illustrates a steady increase in the number of articles published over the years. In 2015 and 2016, only two articles were published. This number increased in 2017 and 2018, reaching 10 articles. Since 2019 and through 2020, there has been a sharp rise in the number of articles, with 31 articles published in 2019 and 60 in 2020. By 2021, this number had surpassed 105 publications, and up to May 2022, there were 78 articles published. This distribution demonstrates a significant upward trend in literature over time. If the number of publications in the scientific community doubles within 10–20 years, it indicates growing interest in a research area (Beske-Janssen et al. 2015). The literature in this field has already far exceeded this threshold, highlighting the burgeoning scholarly interest. This finding further underscores how well established the subject is within the supply chain management (SCM) community. In summary, the data in the figure show a notable increase in the number of articles published over the