"*We cannot wait until there are massive dislocations in our society to prepare for the Fourth Industrial Revolution.*"

Robert J. Shiller

Acknowledgements

This paper brings my master's degree in Business Engineering to an end. Writing it was the most rewarding achievement of my studies at the Louvain School of Management.

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Abstract

This paper addresses the question of how the Industrial Internet of Things (IIoT), defined as the industrial aspect of the fourth industrial revolution, will impact supply chain management (SCM) decisions. With this goal in mind, we first describe the conceptual and historical approaches of both the industry and supply chain management. The question of the legitimacy of a new industrial revolution is answered positively and the supply chain management discipline is organised in a flow-based model of ten managerial categories.

A thorough cross-field literature analysis delivers the main changes, opportunities and challenges that the upcoming IIoT will bring to supply chains. A neutral approach is favoured and the generally optimistic literature regarding the IIoT is questioned. Cyber-physical systems will indeed redefine the way we provide goods and services to customers and therefore, the way entire supply chains are managed, strategically and operationally. More information, connectivity and intelligence will optimise operations to enable mass customisation and faster than ever times-to-market. Those changes will gradually transform supply chains into smart supply ecosystems, where inter-company boundaries will fade, and the nature of cooperation will evolve. Nonetheless, there is still a long way to go. Early implementations are challenged by issues of cybersecurity, interoperability, missing regulations, inter-company cooperation, cost of investment, and fear of change due to potential job restructuring.

Our results are supplemented by qualitative surveys targeting SCM and IIoT professionals. This methodology is meant to discuss additional insights, detect contradictions with the literature and assess the current state of developments.

Contents

List of Abbreviations

3PL	Third-Party Logistics
4PL	Fourth-Party Logistics
AM	Additive Manufacturing
ATO	Assemble To Order
BOM	Bill Of Material
CIM	Computer-Integrated Manufacturing
CMI	Customer Managed Inventory
CPFR	Collaborative Planning, Forecasting and Replenishment
CPS	Cyber-Physical System
CRC	Centralized Return Centre
CRP	Capacity Resource Planning
ECR	Efficient Consumer Response
EDI	Electronic Data Interchange
EPC	Electronic Product Code
ERP	Enterprise Resource Planning
ETO	Engineer To Order
FMS	Flexible Manufacturing System
HMI	Human-Machine Interface
I4.0	Industry 4.0
ICT	Information and Communications Technology
IIC	Industrial Internet Consortium
IIoT	Industrial Internet Of Things
IoS	Internet Of Services

IoT	Internet Of Things
M2H	Machine To Human
M2M	Machine To Machine
MES	Manufacturing Execution System
MPS	Master Production Schedule
MRO	Maintenance, Repair, and Operating
MRP	Material Requirements Planning
MRP II	Manufacturing Resource Planning
MTO	Make To Order
MTS	Make To Stock
OEE	Overall Equipment Effectiveness
OM	Operations Management
PAC	Production Activity Control
PAN	Personal Area Network
PLC	Programmable Logic Controller
PLM	Product Life-cycle Management
QR	Quick Response
RFID	Radio-Frequency IDentification
S&OP	Sales And Operations Planning
SC	Supply Chain
SCM	Supply Chain Management
SOP	Standard Operating Procedure
TMS	Transportation Management System
TOC	Theory Of Constraints
TPM	Total Productive Maintenance
TPS	Toyota Production System
VMI	Vendor Managed Inventory
VSM	Value Stream Mapping
WMS	Warehouse Management System

Introduction

Motivations

After the World Wide Web breakthrough in the 1990s, the massive adoption of social media in the 2000s and the emergence of cloud services a few years ago, the Internet of Things (IoT) is likely to be the next technological "*wave of the Internet*" (Case, 2016) and was brought up for the first time in 1999 by the British entrepreneur Kevin Ashton. He wanted to picture a system in which the physical world could exchange data with computers with the help of ubiquitous sensors (Witkowski, 2017). The IoT is imagined as "*creating a world whereby every object has a digital identity and can connect to a data network*" (Gershenfeld, Krikorian, and Cohen, 2004, p.80). The radio-frequency identification (RFID) technology has been widely adopted by companies among several sectors to grant objects, people and animals their digital identity (Tu, Lim, and Yang, 2018). A formal definition from the Oxford Dictionary states that the IoT is "*the interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data*" (Oxford Dictionary, n.d.). The novelty of the concept allows us to separate IoT applications in two categories. On one hand, the applications that are already well-known to the public and, if not yet invented, realistically imaginable in a near future. Examples are connected cars, that enable software providers to gain access to transport data, as well as connected heart transplants, that send real time data to hospitals to shorten the reaction time for treatment. No later than last year in China, along with the rise of sharing economies, tier-one cities welcomed the introduction of public bikes that do not require parking in specific storage places. The bikes are connected to the Internet, allowing their monitoring by bike sharing companies, their pre-location and booking using a smartphone, and the instant report of default and misconduct. On the other hand, the IoT also brings its lot of futuristic applications, already envisioned by numerous entrepreneurs, researchers and politicians around the globe. They include complete interconnection of buildings, cities, environments, supply chains and energy networks; affecting industries such as retail, financial services, health care, education, energy, transport and manufacturing.

The inclination for more connectivity is only a forerunner to the upcoming growth in technology applications. Using connectivity to drive new insights and optimisations can be applied to manufacturing processes and overall supply chains. According to the American IT professional Alasdair Gilchrist (2016), author of *Industry 4.0: The Industrial Internet of Things*, there are four IoT vertical strategies (see Appendix A.1), where the Industrial Internet of Things (IIoT) is the one that encompasses the largest amount of disciplines, including energy production, manufacturing, agriculture, health care, retail, transport, logistics, aviation, space travel and many more. Claiming that the IIoT is simply the IoT concept applied to the factory floor is thus an understatement. Several terminologies are used when describing the IoT applied to the industry, including the IIoT, the "industrial Internet" (coined by General Electrics), the "Internet of Everything" (termed by Cisco) or the "Industry 4.0" (I4.0). Even if those terms, mostly the three first ones, are often used interchangeably, a clear distinction is to be made with the I4.0 which does not have the same origin and involve different sets of stakeholders, goals and implications (Elrod, 2016). A paper from Bledowski (2015) of the MAPI Foundation lists their differences clearly:

- The I4.0 comes from the German government, whereas the IIoT was coined by GE and other multinational companies to set up the nonprofit organisation Industrial Internet Consortium (IIC), comprising private companies and academic institutions around the world. The I4.0 thus has a national focus while the IIoT is a global phenomenon.
- The I4.0 aims to ensure the German's industrial leadership against threatening data-oriented competitors (e.g. Google) by effectively supporting innovation, while the IIC members started cooperating after realising that they could only gain from sharing best industrial practices.

- The I4.0 focuses on manufacturing (from design to customer service integration) through embedded systems, automation and robotics, while the IIoT targets all disciplines mentioned by Gilchrist where industrial components can be connected to the Internet, provide data as feedback and increase efficiency.
- The I4.0 further emphasises hardware – Germany's comparative advantage being manufacturing-related, while the IIoT is equally attentive to software, owing to the variety of IIC members.
- The I4.0 is particularly relevant to SMEs (by focusing on *Mittelstand* companies working together) (Kohler and Weisz, 2016) while the IIoT attracts many larger companies.
- The I4.0 pictures a "*theoretical description of a vision of future manufacturing*", while the IIoT "*is firmly embedded in things as they exist today while seeking to solve interoperability and security challenges for the future*".

While there are clear differences, those concepts are often used as synonymous and refer to similar movements. They are evolving in parallel without noticeable competition, they share some members and "*occupy the same real estate of technology*" (Bledowski, 2015).

Across this paper, we will aggregate the technological innovations of the fourth industrial revolution under the label IIoT rather than I4.0 for specific reasons. We see no interest in analysing the specific case of the German manufacturing sector and its SMEs, nor to focus on hardware applications. Rather, we aim to understand how an increasing connectivity and integration can benefit today's factories and equipment, and potentially give rise to a fourth industrial revolution implying myriads of economic and societal implications. Moreover, the IIoT targets sectors that are closely related to manufacturing without intrinsically being part of it (such as transport, inter-company logistics and product flows) which are key elements of supply chain management. Finally, most of the IIoT and I4.0 literature on the technology is overlapping. This gives us some leeway to decide between the two labels, with an exception for specific terms coming directly from the *Plattform Industrie 4.0* initiative.

Research questions

This paper addresses the question of how the IIoT, defined as the industrial aspect of the fourth industrial revolution, will impact supply chain management decisions. With this goal in mind, we will first conduct a literature review on the conceptual and historical approaches of the industry and supply chain management. Chapter 1 decomposes the evolution of the industry and discusses the legitimacy of a potential fourth industrial revolution and its implications. Chapter 2 explains the theory behind the supply chain management discipline, incorporates its history with that of the industry and proposes a tangible model to analyse supply chain management categories individually. After that, a thorough cross-field literature analysis in chapter 3 delivers the main changes, opportunities and challenges that the upcoming IIoT will bring to supply chains by assessing its impact on the model. Finally, we discuss our results with qualitative surveys targeting SCM and IIoT professionals in chapter 4. The main objective of this last chapter is to gather additional insights, detect contradictions with the literature and realise the current state of developments. Eventually, our contributions are threefold:

- **Categorisation.** The literature on the fourth industrial revolution is very novel. Regarding supply chains, most articles focus on broad and basic IIoT and management concepts or on the opposite, tackle very technical areas. Consequently, there is a strong need of categorisation to better define how supply chains will be impacted.
- **Centralisation of realistic assessments.** A better categorisation will help us draw clearer and more organised conclusions for each SC categories in a single paper, which the literature fails to provide so far. Moreover, most of the literature is purposely optimistic. This thesis serves no politic or economic agenda and aims at providing a complete landscape of opportunities and challenges for a realistic vision of future supply chains.
- **A call for action.** The objective of our centralised and categorised analysis is to provide academics with a solid ground to pursue further research in this area, while supplying managers and entrepreneurs with a tool to understand how disruptive the fourth industrial revolution might be for their future business, no matter the industry.

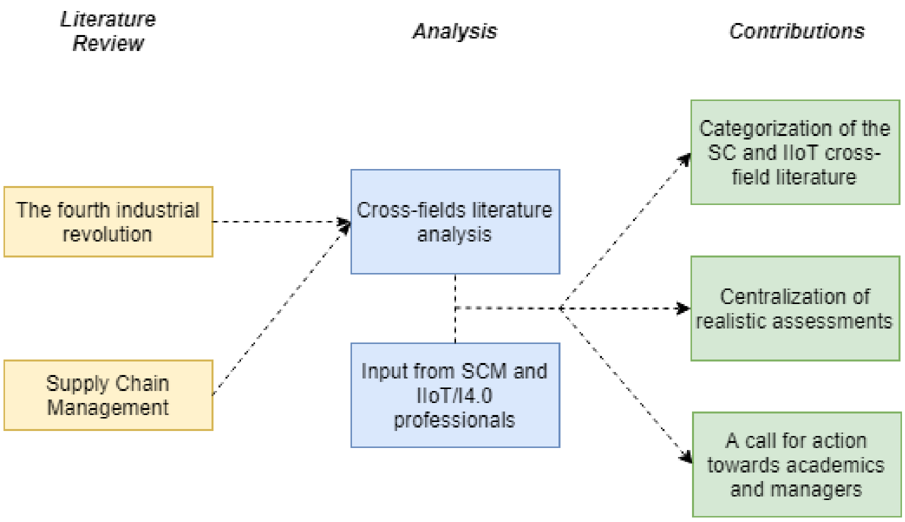

FIGURE 1: Research questions

Limitations

By working towards the completion of this paper, we encountered two types of limitations.

- **Novelty of the subject.** The concepts of I4.0 and IIoT were used the first time, respectively, in the German Hanover Fair in 2011 and by General Electric in late 2012. This has three direct consequences on the scope of this thesis. First, very few companies are aware of an upcoming fourth industrial revolution, let alone the ones that initiated assessments or effective changes in their business models. IIoT data is thus rare in many industries. Second and *a fortiori*, even if a handful of companies in the IIoT implementation phase might observe results, they would never agree to share their springboard to a potential leadership position in future markets. A quantitative approach was thus discarded from the start. Third, new concepts will emerge in the following years that might perturb the accuracy of our results.

- **SCM is very broad.** Managing a supply chain implies dealing with a myriad of sub-disciplines and decisions which are, most of the time, industry-specific. A master's thesis could be written on the influence of the fourth industrial revolution on each SCM categories. We decided, instead, to provide a general support for further research and a call for action towards managers involved with those categories.

Part I

Literature review

Chapter 1

The fourth industrial revolution

The IIoT and the I4.0 both refer to a new industrial revolution. Even if some influent people such as Jeremy Rifkin, the American economic theorist, discuss the upcoming of a third industrial revolution, most of the scientific community seems to agree upon the arrival of a fourth revolution. The terminology is not to be concerned about in this paper, since all parties agree that an industrial revolution is indeed on the way. But what are the scientific criteria that allow such denomination of "revolution"? Schwab (2016, p.11), founder of the World Economic Forum, describes a revolution as being an "*abrupt and radical change*". He proceeds by portraying an industrial revolution as the appearance of "*new technologies and novel ways of perceiving the world [that] trigger a profound change in economic systems and social structures*". In the following subsections, we will first list the revolutions already undergone by the industry and respecting those criteria of technological, economic and social changes. Since the three first legitimised industrial revolutions are not the main focus of this thesis, a general overview will prevail over a detailed explanation of the three criteria. Nonetheless, the fourth industrial revolution will be scrutinised according to them.

1.1 Historical perspective on the industry

1.1.1 The first industrial revolution: mechanisation

The manufacturing sector has evolved through different stages during the last two and a half centuries. Until the middle of the 18^{th} Century, industrial activities mainly took place in people's homes or small workshops held by extended families, working together towards craft models, using simple machines and hand tools. The maker was the physical owner of its creation and his skills were valued. That changed drastically when what we commonly call the "Industrial Revolution" emerged in Great Britain in the end of the 18^{th} Century. The current convention is to date the first industrial revolution from the 1780s, when the British international trade statistics showed a significant upward movement (Deane, 1980). However, it cannot be seen as a fix date as it resulted from changes in many different social and technological factors driven by a need for other sources of energy for machines and high labour and animal costs (Agrell, 2017).

This period witnessed important developments in industrial sectors such as cotton, steel and mechanical construction. The first industrial revolution also introduced the adoption of large-scale production factories, fueled with high productivity equipment owing to technological advances in hydraulic force machines and steam power.

The textile industry was the one that carried the others. It went through five important developments. In 1733, John Kayne patented the flying shuttle, allowing the cloth to be woven faster. In order to improve the spinning wheel which processed one single thread at a time, James Hargreaves, a British weaver and carpenter, invented the spinning Jenny in 1764 ("James Hargreaves, Inventor of the Spinning Jenny," 2010). This new frame allowed multiple threads to be woven at the same time and was the first real mechanised invention of the spinning wheel. In 1769, Richard Arkwright patented the water frame: the first powered, automatic and continuous textile machine which spun strengthened threads faster than ever before. This invention marked the transition from home production to mass manufacturing in factories ("Richard Arkwright," n.d.). In 1779, Samuel Crompton combined the best features of both Hargreaves and

Arkwright's inventions to design the spinning mule and finally, Edmund Cartwright patented the power loom in 1785, further increasing the weaving speed ("The Industrial Revolution: Samuel Crompton and the Spinning Mule," n.d.).

Two other notable developments are worth mentioning. The coke-fired blast furnace, invented by Abraham Darby in 1709, facilitated the production of cheaper iron in bigger quantities. It was mostly used to produce rails, bridges and building structures (Le Moigne, 2017). In addition, the first steam machine was invented by Thomas Newcomen in 1712 and improved by James Watt in 1781, introducing steam as a new source of mechanical power. It subverted the whole manufacturing sector by replacing hand power, windmills and water wheels as the main fuel for the production of food, clothing and shelter (Bachman, 2006). It allowed the development of steam-powered train in 1804 that sped the carriage of goods nationally, then internationally, before becoming a mean of transport for people.

1.1.2 The second industrial revolution: electric power

Where the first industrial revolution drove the growth of industries such as coal, iron, textiles and railroads, the second industrial revolution marked the expansion of electricity, petroleum, steel and the first assembly lines. It was driven by layout and space requirements, efficiencies between humans and machines and Taylor's work on the division of labour (Agrell, 2017). Historians agreed to date the peak of this revolution between 1870 and 1914 (Engelman, 2015).

The beginning of the revolution saw the massive adoption of electricity, thanks to Edison's electric incandescent light bulb invention made for households in 1879. It changed the way people worked and lived, since most of the activities were done at daylight. This lead to a number of other inventions: first telephones, radio waves, small electric cars, elevators (leading to taller buildings), phonographs, motion pictures, electric generators (leading to refrigerators and washing machines) and so on (Engelman, 2015). Electricity progressively replaced steam-powered engines in various applications. Another great invention of the time was the internal combustion engine which helped the design of the first automobiles and airplanes. Finally, in the 1870s, the first large-scale assembly lines were created for the meat industry in Cincinnati's slaughterhouses ("Assembly Line - History," n.d.).

Regarding management, Frederic Winslow Taylor published "The Principles of Scientific Management" in 1911, stating a new work division following the principles of repetition and simplicity of tasks. It optimised individual processes conducted by workers who were paid according to their yield. A few years later, Henry Ford put those ideas into practice and initiated assembly lines for his Ford T in big factories. Lead times for car construction dropped drastically and mass production became the norm. The continuous search for performance led to a new breakthrough in the 1950s with Taiichi Ohno, a Toyota Motors engineer. He developed the Toyota Production System (TPS), which later became lean manufacturing.

Economically, two depressions are observed in 1873 and 1897, due to extraordinary but unstable growth in production. The competition among businesses was tough, especially in the steel and oil industry. In a nutshell, "*the second industrial revolution was a period of extremes: great wealth and widespread poverty, great expansion and deep depression, new opportunities and greater standardization*" (Engelman, 2015). Poor work conditions, low wages, danger, long hours and no social protection were considered as the norm.

1.1.3 The third industrial revolution: automation

The third industrial revolution was triggered when the passage from mechanical and analogue electric technology to digital electronics and information technology allowed the first glimpses of automation. The main advancements of this era, starting from the early 1970s on, are the computer, the Internet and ICT. Altogether, they led to a digital revolution where the value of information gained significant momentum with regards to the value of physical goods. Manufacturing processes became gradually more complex, which roused needs for increased speed, consistent qualities, protected labour and more accurate planning (Agrell, 2017).

With those objectives in mind, the first programmable logic controller (PLC), the Modicon 084, was designed in 1969 for the automobile industry and purposed to control the manufacturing process, noticing instant complications and allowing the personnel to react faster to mishaps. A PLC is an "*industrially hardened computer-based unit that performs discrete or continuous control functions in a variety of processing plant and factory environments*" (Romero Segovia and Theorin, 2012). Examples of its applications are controls of equipment, processes, motion and batch. Industrial computers are easy to programme and fit extreme environments, replacing hard wires, timers and sequencers that were costlier to install, maintain and allowed much more human errors.

Other mentionable inventions include the transistor in 1947, that built the way for the creation of PC and PLC. In the late 1980s, businesses started to view computers as a necessity to improve their operations. The first cell phone was designed in the same period. The next decade, the World Wide Web was introduced and by 1996, the Internet became part of households and most business operations. In the 2000s, the digital revolution spread across the developing world and Internet/smartphones penetration grew exponentially (Janssen, n.d.). Within the current decade, cloud services took the digital era further, allowing mobile devices to handle extreme amounts of data from remote servers.

Digital technologies are still being improved today and the boundaries between the automation revolution and the next one might seem blurry at first sight. Let us have a look at what separates them in terms of technology, impact on economic systems and on social structures.

1.2 The fourth industrial revolution

According to Alasdair Gilchrist (2016, p.3), author of *Industry 4.0 – the Industrial Internet of Things*, the IIoT "*provides a way to get better visibility and insight into the company's operations and assets through integration of machine sensors, middleware, software, and backend cloud compute and storage systems*". The digitisation of the enterprise enables users to study large amounts of data via cutting-edge analytic methods, resulting in operational efficiency gains, accelerated productivity and thus, profits. Other benefits than integration, transparency, efficiency and profitability gains are flexible and reconfigurable supply chains (i.e. smart equipment can automatically reconfigure themselves to manufacture various types of items, allowing companies to deal with unstable demand and specific customisations), resource and energy efficiency (i.e. big data analytics enable accurate knowledge of processes and consistent quality through accurate planning, affecting resources as well as energy consumption) as well as friendliness to staff (e.g. no need to perform routine tasks that will be automated, user-friendly HMI, remote repair work through the cloud, etc.) (Wang, Wan, Li, and Zhang, 2016).

As discussed in the introduction of this paper, the main organisations working towards those objectives are the IIC with the Industrial Internet of Things and the German government with the Plattform Industrie 4.0. The first one was founded in 2014 by General Electrics, AT&T, Cisco, IBM and Intel and gathers more than two hundred members in 2018 ("IIC Member Directory," n.d.). The second one came from a sense of emergency by the German government to lose their industrial leadership in favour of developing countries (which have access to lower costs of labour with growing expertise) or data-oriented corporations (which hold users' data and can potentially guide consumers' choices). From the 2000s, Germany decided to apply more aggressive and collaborative policies regarding its industrial sphere: in 2005, the DFKI (German Research Centre for Artificial Intelligence) launched the "Smart Factory" project with a competition of industrial companies. In 2006, the BMBF (Federal Ministry of Education and Research) started to approach the cyber-physical systems (CPS) technology. All these initiatives lead to the official launching of the "*Industrie 4.0*" programme in 2011. First focused on the IoT, it nowadays affirm the equal importance of the Internet of Services (IoS) within the movement (Kohler and Weisz, 2016).

We now have an idea of *what* the IIoT is, *why* it is valuable and *who* are the main actors thriving for its implementation. Before gaining more insights on *how* will the IIoT reach the above-mentioned benefits via the technology in section 1.2.1 and *what impacts* it will have on economic systems and social structures in sections 1.2.2 and 1.2.3, let us mention the importance of the *when*: why is a fourth industrial revolution at sight now even though its technologies have been around for quite some time? There are three main reasons. First, the complex industrial systems caused by an increasingly customised demand resulted in the humans' inability to address further efficiencies. This caused machines to run well below their capabilities. Second, the decrease in costs of equipment such as sensors, actuators as well as and services such as bandwidth, storage and analytics allows data interrogation at a larger and more meaningful scale. Third, even though they existed beforehand, technologies such as cloud computing, analytics and wireless networking matured and are now more affordable, available and reliable from an industrial perspective, creating novel opportunities (Gilchrist, 2016).

According to Charles Schwab, an industrial revolution involves new technologies and a novel way to perceive the world in terms of economic systems and social structures. Let us analyse the fourth industrial revolution according to each of those three criteria.

1.2.1 Criteria I: technology and elements

The fourth industrial revolution marks a split with the third by means of ubiquitous interconnections between machines, made possible by a cyber-physical system (CPS). According to Acatech, the German National Academy of Science and Engineering, CPS are "*systems with embedded software (as part of devices, buildings, means of transport, transport routes, production systems, medical processes, logistic processes, coordination processes and management processes), which directly record physical data using sensors and affect physical processes using actuators; evaluate and save recorded data, and actively or reactively interact both with the physical and digital world; are connected with one another and in global networks via digital communication facilities (wireless and/or wired, local and/or global); use globally available data and services; have a series of dedicated, multimodal human-machine interfaces*" (Acatech, 2011, p.15).

The CPS thus marry automation with the Internet, as the logical evolution of Computer Integrated Manufacturing (CIM), under which a factory's processes are all automated and under computer control. Thanks to CPS, the IIoT does not only represent a new technological layer on top of the others but interconnects all physical and non-physical elements together. In that sense, this industrial revolution can be called "*interactional*" (Kohler and Weisz, 2016, p.27).

It is generally admitted that one of the Industry 4.0's main objective is the arising of digital manufacturing, also known as the smart factory, that comprises "*smart networking, mobility and flexibility of industrial operations and their interoperability, integration with customers and suppliers and in the adoption of innovative business models*" (Barreto, Amaral, and Pereira, 2017, p.1247). But what is "smart"? According to the German engineer and professor Detlef Zuehlke (2010), expert in the transition between the IoT and its integration in factories, the smart objective applies to everything, down to the tiniest piece of device, that has a certain level of built-in intelligence. The popular radio-frequency identification (RFID) technology is a pioneer in the field, pasting each raw material to be processed by the smart factory with readable and writable RFID tags. They contain information on how to organise machines and configure the production route around them, while saving the history in real time on the tag's memory and contributing to the overall supply chain's transparency. According to another study on the smart factories by Wang et al. (2016), the products and machines become smart when they are not only granted with communication, computing and controlling capabilities (which establish the bases for automation), but are also provided with autonomy and sociality. Being autonomous, the smart device makes decisions by itself and is not controlled by other entities. Being social, the smart device understands and follows a common set of language rules, that allows it to communicate with equipment from various vendors. This phenomenon is also called "interoperability".

To realise the benefits of the smart factory, we should bring our attention to the three types of integration allowed by an IIoT organisational structure. The companies BITKOM, VDMA, and ZVEI (2015, p.16) published, through Acatech, a position paper stating the definitions in brackets below.

- The **horizontal integration** across the entire value creation network describes "*the cross-company and company-internal intelligent cross-linking and digitalisation of value creation modules throughout the value chain of a product life cycle and between value chains* *of adjoining product life cycles*". The value creation network involves many agents, such as suppliers, partners and clients; and is built on business models and cooperation contracts to facilitate internal cooperation (Barreto et al., 2017).

- The **vertical integration** of subsystems within a factory describes "*the intelligent cross-linking and digitalisation within the different aggregation and hierarchical levels of a value creation module from manufacturing stations via manufacturing cells, lines and factories, also integrating the associated value chain activities such as marketing and sales or technology development*". This vertical networking pictures smart production systems, i.e. the integration from smart products (lowest level) to smart factories (higher level), to create a flexible and adaptable manufacturing system (Barreto et al., 2017).

- The **end-to-end engineering (or through-engineering) integration** across the entire product life cycle describes "*the intelligent cross-linking and digitalisation throughout all phases of a product life cycle: from the raw material acquisition to manufacturing system, product use, and the product end of life*". It enables the product's customisation at each step.

In order to understand how those integrations work, let us have a look at the technology in greater detail. Vlad Krotov (2017), associate professor at the computer science and information systems department of Murray State University, summarises the technological nodes of the IIoT and pictures it as a complex socio-technical system, divided into three different environments: technological, physical and broad socioeconomic (summarised in Appendix A.2).

The technological environment consists in the enterprise/factory's tools: hardware/software, networking technologies, data, an integrated platform and technical standards that enable interactions of the objects in the physical environment.

1. **Hardware.** The information retrieved from IoT elements will be readable thanks to hardware components: computers, tablets, phones and wearable products (smart glasses or watches). A special mention is to be made for RFID technology. Its electronic tags will be stuck to IoT devices and wirelessly receive and transmit information about them,

containing a cheap and low-battery integrated processor. They are also gratified with a memory and interface for wireless communications (Wang et al., 2016). They provide the items with unique identifiers (electronic product codes or EPC) containing information that RFID readers and wireless sensors will then be able to capture in a centralised database. The connection from devices directly to the Internet can be achieved by embedded communication hardware, e.g. networking cards.

2. **Software.** There are two types of IoT software: application software (apps in the front-end and server-side supporting them in the back-end) as well as middleware. These latter play the role of "inter-operator" between software coming from different vendors, with different technology and communication protocols. For example, a middleware could ensure the connection between an ERP and a third-party e-commerce application such as Lazada.

3. **Networking.** Different types of networks can sustain machine-to-machine (M2M) and indirectly machine-to-human (M2H) communications. Within IoT technologies, wireless networks are privileged over Ethernet cables and allow objects to communicate data with each other via Bluetooth Personal Area Network (PAN), and with the Internet via Wi-Fi connection. Those two types of networks require close distance to the transmitter except for larger areas where an object may necessitate a connection to a mobile network (e.g. 4G) or a satellite. A good example would be the connection between a client's mobile phone and a biker delivering food remotely via mobile application.

4. **Data.** In the world of IoT, big data are characterised by three "V's": volume, variety and velocity. The IIoT challenge is to introduce machines that integrate real time updates (via sensors), broadcast (via networks), and mining (via cloud services) of data. Actuators will then allow machines to react to new data inputs automatically. Data is the primary raw material of this fourth industrial revolution (Frank, Roehrig, and Pring, 2017).

5. **Integrated platforms.** Present in the back-end of the solution, an Internet-based platform (or "cloud") supports all IoT applications, integrates the hardware components and stores their relative data. The three building blocks or delivery ways of cloud services are

SaaS, PaaS and IaaS, each of them offering a different level of flexibility and control. A company may also choose to keep all information within its walls. The integrated platform will then be built "on premises". A differentiation between all those solutions can be found on Appendix A.3 within the specific example of Microsoft Azure.

6. **Standards.** The IoT technology is still fresh and there is a strong need for international interoperability standards for software and hardware integrations. In the field of SCM, an attempt is the GS1 EPC Global Architecture Framework for unique identifiers of physical goods. Those EPC will have different formats to be readable by RFID technology (binary form) and suitable for interenterprise information exchange (text form) ("EPC/RFID - Standards," n.d.). On a broader perspective, standards are being built in a collaborative way within industry associations. Early 2018, the IIC and the *Plattform Industrie 4.0* announced the publication of a joint paper on architecture alignment and interoperability between the two leading IIoT reference architecture models: IIRA and RAMI 4.0 (Quatromoni, 2018). These models take into account all elements mentioned in this section.

The physical environment consists interconnected humans and objects working in an omnipresent wireless network that allows their automatic communication and interaction.

1. **Humans and non-human objects.** Humans, machines, products and even animals may become interconnected thanks to all the elements of the technological environment. For instance, receiving real time data from cattle with RFID tags and EPC would allow meat control and traceability across the entire supply chain (Case, 2016). On the shop floor, guided by a mobile interface, humans can act as knowledgeable "augmented operator" with the responsibilities of monitoring and verifying production processes and strategies and manually interfering with the system when necessary. They act as flexible problem solvers in the growing technical complexity (Mrugalska and Wyrwicka, 2017).

2. **Physical surrounding.** Two types of physical environments surround humans and non-human objects and may as well be connected with the IoT. The first type consists in substances such as air, water or soil, whose properties can be monitored thanks to wireless sensors and sent to the network. Those substances are considered similar to the other

IoT devices, as they provide data in a similar way. The second environment is purely physical and differs in the way that it interacts with IoT-connected objects only in specific locations: a picking dock, a whole building or a factory. For instance, a sports company warehouse might set up a picking dock's door equipped with RFID readers that will scan every product's EPC. It will then send footwear in stock location A, sport uniforms in location B and products to returned to a reject location via different conveyor belts.

The broad socioeconomic environment embeds multiple actors and their respective impacts. Entrepreneurs and business leaders working in and for the IoT landscape tackle technical and legal challenges and set the course of the technology in the direction of smart factories. Legislative bodies strive for standards, industry associations for interoperability and consumer advocacy groups for consumers rights protection. At the end, customers take on a more important role in the value chain of the new IoT business models.

1. **Customers.** The implementation of IIoT technologies should focus on delivering value for the customer (Gierej, 2017). He will be placed in the centre of new business models built around the IoT with his needs translated in the customer value proposition. He will have more decision leverage than ever as his order triggers the whole supply chain. His specifications dictates the product's RFID tag that will in turn interact with the connected enterprise and its equipment. Integrating the client's feedback at every stage of the PLM to ensure the product's viability is an alteration of his place in the value chain (Kohler and Weisz, 2016). Using this logic, new business models will see each customer as a trigger for new product and service variations, and a catalyst for open innovation. A good illustration of the changing role of the customer lies in additive manufacturing that emerged from increasingly demanding requirements for speed and customisation. It helps customers moving from a passive role at end of the value chain to an active central position, triggering a portfolio of products and services aiming at individualising offerings (also called "batch size 1" or "mass customisation") and accelerating time to market (Kiel, Arnold, and Voigt, 2017). Producing batch size 1 products at costs equivalent to those in mass production is one of the goal of the *Plattform Industrie 4.0* initiative.

2. **Legislative bodies.** The legal risk for new IoT business models is high because of the changing nature of regulations. Compliance with current legislature and thorough analyses are required to anticipate national and international laws and decrees that could potentially dictate the company's success or failure. Nevertheless, the collection of data will, in the future, ease legislative bodies' efforts to track business compliance. In the food and health care industries, data monitoring will have a significant impact, especially in countries where corruption levels score high and SOP are ill-defined.

3. **Industry associations.** The cooperation of companies within similar industries enables synergies in terms of resources, leverage and time. It pushes the speed for the adoption of new technology standards, since companies act as a unified front to fight against or strive for new regulations. Some existing IIoT associations are the GSI for retailers, the IIC for the introduction of new systems and devices and the AGMA for American companies and consultants.

4. **Consumer privacy groups.** When discussing data gathering, privacy and security are major concerns for crowds of end-users. Many popular media, such as the television series *Black Mirror*, pictures the extreme consequences that proliferation and mishandling of data can bring: remote hack and control of devices, scan of private environment and collection of information about specific individuals against their will. Privacy groups have merged to prevent misuse of data, but can as well become a major hindrance to the development of IoT technologies.

5. **Technology entrepreneurs and their strategies.** The IIoT entrepreneurs of tomorrow will have to deal with all the aforementioned elements. The innovations they will strive to achieve might be incremental or disruptive. Since we are addressing new technologies and talking about a fourth industrial revolution, the new ways of managing a company that the IoT offers will be likely to foster disruptive innovations in a near future, which themselves might change our society's landscape and encourage new business entrants to do the same.

In order to be considered a legitimate revolution, the IIoT and I4.0 phenomena must express drastic technological, economic and societal changes. The content of the two following sections will mainly be based on the book *The Fourth Industrial Revolution* by Klaus Schwab, as a general overview on the future of economic and societal changes.

1.2.2 Criteria II: impact on economic systems

Macroeconomic perspective

The impact on global economy might be assessed through the two main criteria of GDP growth and employment, even though every main macro variable (e.g. GDP, investment, consumption, inflation, etc.) will be affected correlatively.

The period following WW II has been called the secular stagnation, due to a mild annual average GDP growth rate around 3-3.5%. Population ageing and productivity are two factors that will be influenced by the fourth industrial revolution before impacting future growth rates. Retired workforce is increasing and a new revolution enabling people to live longer and healthier will negatively affect consumption aspects and the proportion of entrepreneurial initiatives. Governments will thus need to tackle working age, retirement and individual life-planning questions, for an aging world is destined to grow slower unless a revolution in productivity allows smarter instead of harder work. Speaking of productivity, the past decade has shown that its growth remained slow despite technological progress (The Conference Board, 2015). To embrace a potential rise in productivity, there is a strong need to update its indicators that still do not capture the right value of smart services (e.g. Uber) whose efficiency addition remains uncounted. The fourth industrial revolution will increase our capabilities to deal with negative externalities (thanks to advances in the energy sector) and enable the inclusion of markets that still need to be integrated in the global economy (thanks to future omnipresence of ICT). All of this will spur growth. But in order to reach the most-awaited productivity explosion promised by the IIoT and I4.0, entirely new economic and organisational structures will be required. The fourth industrial revolution will first affect advanced economies. There is thus a risk of a "winner-takes-all" dynamic between countries, where the gaps between them increasingly widen in terms of income, skills and infrastructure. For example, the I4.0 initiative objects to re-shore industrial manufacturing to Germany if low-cost labour does not ensure competitiveness anymore (Kohler and Weisz, 2016). This would further divide economies while creating social tensions and conflicts.

Regarding employment, fears of an irreversible technological impact on jobs have burdened all industrial revolutions. This time, the speed, breadth and depth of the transformation might create more shaking. Technological progress has two competing effects on jobs: a destruction effect that forces employees to unemployment, and a capitalisation effect of new occupations and businesses creation coming from the demand for new goods and services. A study from Frey and Osborne (2013) analyses the potential effect of technology on employment across 702 different professions and their probability to be automated. Their summarising table can be found in Appendix A.4, and they conclude that the job destruction factor is likely to take place much faster than during the previous revolutions and towards greater polarisation. High-income cognitive and creative jobs and low-income manual professions will rise but middle-income routine jobs will decline.

Not only the job market, but also the nature of jobs will change drastically. In his book *Free Agent Nation*, Daniel Pink (2001) depicts the upcoming of a world where the leading work model is a series of transactions between a worker and a company rather than a lasting relationship. Within the "on-demand" economy, professional activities are separated into precise tasks and individual projects before being tossed in a virtual cloud of potential workers, called "free agents", which are located anywhere in the world. The advantages for companies are the demise of legal obligations such as minimum wages, taxes and benefits; whereas those for independent workers reside in freedom, mobility, reduced stress and greater job satisfaction. This might either lead to a flexible work revolution that will empower any individual with an Internet connection and optimise the search for skills; or lead a world where a new working class suffers from a loss of labour rights and job security (Gratton, 2011).

Microeconomic perspective

Those macroeconomic factors will undoubtedly impact all individual businesses and the way they are led and organised. The overflow of information allows a portion of firms to reach lightspeed success (e.g. Snapchat) and disruptive innovations (e.g. Uber). For a business to prosper, its leader must constantly learn and adapt, when the race for innovation makes talent, more than capital, the key factor of success. After the challenge of digitisation brought up by the third industrial revolution, the fourth one implies the achievement of a much more complex innovation form based on the integration of multiple technologies. It is thus vital for companies to diagnose their capabilities for adaptation before losing their competitive edge.

Business across industries will be impacted in four major ways. First, customer expectations are shifting towards greater product and service experiences. More than ever, end users have a willingness to share data and interact. Data and metrics will provide, in real time, valuable insights on customer needs and behaviours. Transparency in supply chains also gives increasing power to clients, providing them with additional ways to compare products and services. Second, products and services are enhanced with data. This increases their value and gives space to improve supply chain productivity and efficiency. Third, new types of inter-company collaboration are formed to strive for innovation and prevent being casted out by disruptions. However, a complete cooperation is often difficult to implement and require businesses to develop their strategies and align their processes towards the common project, sometimes as far as by creating innovative business models. Fourth, operating models are being not only digitised, but turned into virtual platforms connected to the physical world. For example, a shared transport economy such as Mobike in China allows end users to locate and rent a bike for the consumed time only. Thus, we no longer need to purchase the object, but rather pay for the service it underlies via the digital platform (Lan, Ma, Zhu, Mangalagiu, and Thornton, 2017). This also forces companies to invest in cybersecurity systems to avoid breakdowns or hacking.

Corporate decisions regarding supply chain management fall in this category, and this paper's objective is to gain a comprehensive view on how the fourth industrial revolution might affect them. Before tackling the SCM paradigm and the concrete analysis, we will have a look at the last required criteria to legitimise the fourth industrial revolution: its impact on social structures.

1.2.3 Criteria III: impact on social structures

The impact on social structures might be assessed through changes across three structural layers: governments and countries, societies and individuals.

Governments, countries and international security

Generally speaking, public institutions will change the way they operate via digitised structures that will improve their overall performance. But the disruption digs deeper. Power is increasingly shifting from state to non-state actors as social media and their groups allow basically anyone to exercise influence by giving a voice and coordinating efforts. Public authority is thus increasingly constrained, while governments become unable to rule efficiently. Looking at the other side of the coin, the uprising of mass surveillance through big data might create very powerful public authorities. The Chinese "Social Credit system" initially planned for 2020 might be the first step in the creation of such public surveillance structure (Viswanath, 2018). In either scenario, governments will be mostly considered as public service centers assessed on their capability to provide efficient individualised services. Today, legislative bodies are outrun by technological changes and unable to cope with them (e.g. the question on how to deal with blockchain-based finance). Their survival will require them to adapt to a world of disruption menaced by new and competing power structures. Maintaining governmental functions such as competitiveness, fairness, intellectual property and safety will be crucial in a society where, either everything that is not explicitly forbidden is allowed, either the opposite prevails.

Technology does not know any border. Geography has several implications for technology. Countries and regions that thrive in creating tomorrow's international standards regarding new technologies will gain substantial economic advantages. In opposition, countries that establish conservatism might find themselves being the laggards of the digital economy. Countries and regions are draining their prosperity from cities, which represent their main innovation ecosystems and technological hubs. Cities will tend to become "smart" by setting up ICT in many public applications. They comprise innovative businesses and universities and will become a country's laboratory for the fourth industrial revolution.

International relations and security will be seriously impacted by the fourth industrial revolution, especially by the aforementioned shifts of power to non-state players. Social segregations created by the on-demand economy might cause deeper social unrest. The definitions of war, peace, and of who is a combatant are getting fuzzy in a revolution that enables individuals to impair others in an easier way and on a larger scale. Wars, whether physical or not, are being fought in a virtual world which lowers the threshold of starting them, with more uncertainty of who triggered them. AI may provide robots and weapons with the ability to decide shooting without human intervention. Inevitably, each technological innovation will have its lot of positive and negative applications.

Societies

The impacts on countries, regions and cities make it obvious that the fourth industrial revolution will influence societies in many ways. The question will be how to adopt a new modernity while conserving cherished traditional values. We will discuss society from the lens of social classes and communities as the most important drivers of transformation.

The fourth industrial revolution might further increase inequality at the expense of left-aside low-skilled labour, as companies are looking for more limited and innovative skillsets. Unequal societies tend to be more violent (Wilkinson and Pickett K, 2009), with the biggest part of populations feeling powerless in reaching any level of prosperity or meaning. A potential winner-takes-all dynamic, increasingly out of reach for middle-class workers, might provoke insecurity and serious social challenges.

Digitisation already spurred the uprising of new forms of belonging and communities. Digital media are in the center of the fourth industrial revolution and connect people in enhanced ways by maintaining friendships across time and distance. They also provide waves of information and opportunities for individuals to have a voice. Nonetheless, serious dangers hover above digital media, such as governments using technology to suppress or oppress groups of individuals seeking for governmental transparency; or the risk of non-state actors scattering propaganda and gathering people around extremist causes.

Individuals

The new revolution might force us to rethink the question of human nature. So far, technology has been used as a tool for personal development (e.g. the smartphone as an extended limb), but we might find ourselves confronted with many ethically-sensitive situations in the near future. Until what point should we develop human augmentation and life extension? Will we always be able to keep AI under control? Will designer babies alienate the way we think about procreation? In a nutshell, the birth of a human transformation possibility is a change unlike anything humans have ever faced before.

Moreover, some concerns emerge on how harmful the impact on relationships, social skills and ability to empathise might turn out to be. There are fears that entire generations of young people, immersed from birth in social media, would struggle to listen, make eye contact or read body language.

Finally, our individual privacy is at stake. It is one of the biggest issues that side-kicked the emergence of the Internet. Popular debates argue on the degree until which we can trade privacy for additional convenience, and the threat posed by some mass corporate or governmental surveillance.

Chapter 2

Supply chain management

We now have better insights on how the industry evolved and how the fourth industrial revolution might unfold technologically, economically and socially. The scope of this paper is limited to its impact on supply chain management decisions. This is why a second theoretical paradigm, supply chain management, needs to be tackled to get a better cross-fields understanding. This chapter first introduces the discipline's concepts and definitions (conceptual perspective), before reviewing its evolution and comparing it to that of the industry (historical perspective). Finally, we state our chosen SCM model which paves the road for the next chapter, the analysis.

2.1 Overview and concepts

Supply chain management (SCM) is one of the fundamental activities of any company delivering goods and services to a set of B2B or B2C customers. Managing operations may seem obvious when picturing a company that gathers raw materials, transforms, stocks and delivers goods to its customers. It may be less so when discussing dental services or property businesses. Those industries nonetheless involve many SCM elements and their mishandling can lead those businesses to failure.

A supply chain is a network of organisations (suppliers, factories, distributors, clients, third-party logistics...) taking part in the manufacturing, delivery and sale of products or services to clients (Le Moigne, 2017). Supply chains do not only tackle supply, but also demand considerations. In addition, they are more often represented in networks than in chains, due to their complexity and the number of actors in the industry.

Organisations exchange three types of flows: product, financial and information flows. One could argue that an additional one, the risk, is shared across a supply chain since the emergence of inter-company cooperation. Whether it should be called a flow is a matter of purpose, but it nonetheless has a considerable influence on supply chain decisions.

The purpose of any SC is to optimise those flows. A consistent share of information between companies will provide traceability on transactions. An optimised logistic system will move the products most efficiently and at the lowest possible cost (w.r.t. the business' constraints). Inter-company cooperation will reduce the financial risks and let the members agree upon the best contract. A management discipline is fully dedicated to optimising the SC performance.

The word "supply chain management" was used for the first time in 1982 in an article from Oliver and Webber (Svensson, 2007), *Supply-chain Management: Logistics Catches Up With Strategy*, even if it has accompanied military, trade and industry developments for centuries (Le Moigne, 2017). Since 1982, managers and engineers gave the term dozens of definitions. The Council of Supply Chain Management Professionals (n.d.) (CSCPM) gives the following one, retrieved on February 24, 2018:

> "*Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.*"

The term "operations management" is often intertwined with the discipline defined above. But what are the differences between them? According to Krajewski, Ritzman, and Malhotra (2013, p.22), operations management (OM) is "*the systematic design, direction, and control of processes that transform inputs into services and products for internal, as well as external, customers*". Internal customers refer to the downstream processes waiting for the arrival of goods within the same company or department. A closer look at those definitions highlights the fact that OM focuses on intra-organisational processes and SCM on inter-organisational processes. A fully vertically-integrated firm would mostly focus on materials and operations management, where the coordination is implicit. Contracting with partners and clients is thus mainly applicable in SCM. In the following lines, to avoid cumbersome debates about the legitimacy of those terms, we will assume that SCM encompasses OM elements.

2.2 Historical perspective on supply chain management

In the previous chapter, we briefly stated the revolutionary changes undergone by the industry during the last two centuries. In this section, we want to set the focus on the evolution of the SCM discipline itself for two reasons. First, to place SCM in its historical context and marry it with that of the industry. Second, to understand key concepts used in our model and analysis.

In 1905, the Independent newspaper uses the word "supply chain" for the first time in the context of war (Benjabutr, 2013). Similarly, the word "logistics" was only used for military strategies. Relative to what we would call supply chain management today, two distinct practices were often mentioned in the early 20^{th} Century (Robinson, 2015). First, on the manufacturing side, the discipline of "industrial engineering" was pioneered by Frederic Taylor in 1911 and executed by Henry Ford for his "Model A Car" in 1927. The automobile industry used the mass production concept to achieve economies of scale. Second, on the transport side, the discipline of "operations research" was required by the complex military problems in the field of logistics during the 1940s. Good examples lie during WWII, when the combination of "Operation Neptune" (by sea) and "Operation Overlord" (by land) involved nearly 3 million personnel, 11,000 aircraft, 7,000 ships, 185,000 troops and 20,000 vehicles in the first wave of the Normandy landings.

They were planned jointly by British and American strategists for nearly three years (Bellamy, 1994).

With time, those two practices were addressed jointly and referred as "supply chain engineering". The most notable contribution in this domain was Frederic Taylor's "scientific management" which stated the following principles. They were meant to improve the quality of the materials and their handling speed (Taylor, 1997, p.19).

- **Theory replacing experience:** for each task of a man's work, replace the rule-of-thumb work method with a scientific study.
- **Training:** scientifically train and develop each workman rather than passively leaving them to train themselves as best as possible.
- **Documentation and control:** provide detailed instruction on the principles and a performance supervision for each worker's individual task.
- **Work division:** divide work and responsibilities nearly equally between management and workmen, so that managers apply scientific principles to planning the work and workmen perform tasks without planning responsibilities.

After the contributions of the first and second industrial revolutions, processes mechanisation and warehousing concerns (unit loads, pallet lifts, stock locations design and plant layout) became the focus of logisticians. Spectacular growth of mass production practices was a driver for change, due to increasingly labour-intensive material handling. Improvements in transport management quickly followed by the invention of containers by Malcolm McLean in 1956 (PLS Logistics, 2015). Other notable advances from this decade were postponement (or delayed differentiation), which became a first solution to react on time to a precise demand; and the barcode, whose first patent emerged in 1952 to improve the products' traceability (DBK Concepts, 2017).

By the 1960s, cooperation among industry members strengthened to gain competitive advantage on raising competition: joint considerations of warehousing, material handling and freight transport were popular topics of the customer / supplier relationship. The concept of "bill of material processor" by IBM's engineer Gene Thomas was invented as an early version of the materials requirements planning (MRP) to improve manufacturing planning systems (Mallory, 2016). Year 1963 saw the birth of the National Council of Physical Distribution Management, which undertook the first scientific studies behind supply chain engineering (gradually popularised under the label "physical distribution"). By the 1970s, with reverse logistics, researchers started to think of a secondary direction of product flows (Benjabutr, 2012).

By the 1980s, the third industrial revolution and data computerisation changed the game for the above-mentioned practices. With data, randomness disappeared: storage was optimised and trucks borrowed the fastest route. Material handling and transport encountered disruptive innovations. The 1980s saw the emergence of personal computers, which gave access to planners and graphics to ease decision-making. Many organisations started to solve complex optimisation problems in order to commercialise them (e.g. the traveling salesman problem). The first novel on supply chain management, *The Goal*, was written in 1984 by Eliyahu Goldratt (2014). It defined the theory of constraints (TOC) as a model that describes the effect on profitability of decision-making by a SC in terms of time. TOC is also a method of managing bottlenecks (Zenjiro, 2012). Logistics had gained a reputation of being important, complex and very expensive, meaning that there were significant improvements to be done by trained professionals (Benjabutr, 2012). In 1985, the National Council of Physical Distribution Management became the Council of Logistics Management to picture "*the evolving discipline that included the integration of inbound, outbound and reverse flows of products, services, and related information*" (Robinson, 2015). The same year, the first full-scale supply chain analysis was complete for the textile industry and the concept of third party logistics (3PL) was developed. After studying the TPS, John Krafcik introduced the term "lean manufacturing" for the first time in 1988 (Benjabutr, 2012).

The 1970s saw the first MRP software to improve the efficiency of basic processes (e.g. production scheduling and inventory management). The manufacturers from the 1980s realised they needed to integrate more functions, such as accounting and forecasting requirements, leading them to MRP II. It is only by the 1990s that ERP systems emerged to build the path to integrating databases coming from all a company's departments (Tamang, 2017). They opened new collaboration possibilities by integrating customers and suppliers through sales and purchasing apps. Technology raised debates, such as the arbitrage between investing in greater technology or in chopping forms of work that do not add value (i.e. lean manufacturing). In 1993, the concept of efficient consumer response (ECR) emerged as a strategy to increase service level to consumers through close cooperation among retailers, wholesalers and manufacturers. Those businesses may gain larger profits in acting as a unique supply chain actor than each of them pursuing their own business goals (Zenjiro, 2012). In the mid-1990s, the label "supply chain" gained global recognition, in parallel with the continuous scientific improvements that made the globalisation of manufacturing and its teaching in universities possible. The objective of "going global" to grab more and more demand put forth the need for logistics strategies to deal with broad and complex networks. Supply chain management increasingly referred to strategic issues, where logistics referred to tactical and operational issues (Robinson, 2015). In 1997, a study from Padmanabhan and Whang showed the world how to reduce the bullwhip effect; and Cachon and Fisher brought the concept of continuous replenishment on the table to support ECR in the food industry (Benjabutr, 2012).

During the 2000s, the discipline extended to green and sustainable supply chains in order to abide COP environmental directives. In 2002, an international container security initiative was put in place to address threats to border security and global trade (Benjabutr, 2012). In 2005, the Council of Logistics Management changed his name to the Council of Supply Chain Management Professionals (Robinson, 2015), which gave us our definition of SCM. With the upcoming fourth industrial revolution, future supply chains will strive for even more traceability and integration through CPS, IoT systems and customer-centred business models based on mass customisation and faster time-to-market requirements.

2.3 SCM model: categories and decisions

After gaining more knowledge about the conceptual and historical perspectives of SCM, we finally have all cards in hand to build the model that will serve as support to analyse the impact of the fourth industrial revolution on the management discipline. The aforementioned definition from the CSCMP distinguishes between different subcategories: sourcing, procurement, conversion, logistics and coordination. We will use those concepts, but in a reformed, more detailed and flow-based fashion that will help us organise our work.

After digging in the literature, we found that the book *Supply Chain Management: achat, production, logistique, transport, vente* from Rémy Le Moigne (2017) depicts such comprehensive and flow-based approach by dividing supply chain decisions in ten categories. First, we will take those components one by one in order to go through the concepts and best practices they embed. Then, in the next chapter, we will analyse how the IIoT will impact each category and their managerial decisions according to the literature published so far. Finally, we will discuss those findings with different SCM and IIoT specialists.

2.3.1 Logistic network and operations strategy

The first category covers only strategic decisions that will engage the company in the long term. We will discuss factories design, logistic networks and operations strategies.

Factories will be located depending on their objectives: low-cost countries, market proximity (being close to client or to suppliers) or access to technology. The poor logistics of a region need to be considered. The number of factories will optimise the arbitrage between delivery times and factory costs. Being in different countries adds non-negligible complexities (e.g. exchange rate evolution, global and local demand differences, costs and legislations). Those factories will specialise by product to foster productivity, by market to address better local demand, or by manufacturing process to take advantage of technology.

The firm also needs to decide how goods will arrive to its factories (procurement network) and how they will be shipped to customers (distribution network). It can decide to deliver directly or go through distribution centers or other types of platforms.

Finally, the company will choose the procurement rule and answer the question: "what will make my products move: a forecast or a client?"

Those decisions may be revised when lurking for new markets, restructure costs or shorten delivery times.

2.3.2 Sourcing

To buy goods from the supplier, the company needs to follow a sourcing strategy, itself in line with the corporate strategy. The sourcing department of a company takes decisions on what to buy, from whom and following which purchasing strategy. It also defines the relationship with suppliers.

The sourcing department will first define strategic orientations and objectives regarding the company's needs and budget. It will choose sourcing levers, such as volume concentration, best prices or improvement of the supplier relationship. The sourcing strategy will be defined according to the chosen levers: which products will be made, and which will be bought? Is there a possibility to integrate vertically or bypass suppliers?

Afterwards comes the supplier selection, which involves supplier market analysis (e.g. what is the negotiation power in the industry?) and criteria selection based on the sourcing strategy (e.g. price, quality or respect of the environment). The supplier portfolio is then created and contracts will follow.

The company might want to decide the long-term relationship it wants to establish with its suppliers. It can be a classic sales/purchases relationship, a collaboration or real partnership with all departments working together. It can go as far as co-developing products and co-improving individual processes to further strengthen its supply chain.

Sourcing department performance can be traced by indicators (e.g. average order value or cost) and improved by adjusting levers (e.g. concentrating volumes, sourcing internationally or combining processes with suppliers).

2.3.3 Procurement

Procurement is different from sourcing. The purchasing department, often responsible for procurement, will ensure effective ordering and replenishment of goods for the operational planning of the company. It consists of three steps: managing purchase inquiries and orders, receiving goods and controlling vendor bills.

Purchasing inquiries are internal documents sent to the purchasing department to initiate the acquisition of a specific quantity of goods. Purchase orders will follow and are generally automated using reordering methods. When demand is constant and predictable, procurement will most likely be carried out by fixed order quantity, in which the time between orders may vary. For unpredictable demands, the company may use periodic review systems, in which the time between orders does not vary, but quantities do. The choice of the reordering method might depend on other factors such as perishability of the product, inventory cost, delivery time and product value.

The process of receiving goods will be explained in detail in subsection 2.3.8. Controlling vendor bills is nowadays done very conveniently by software.

2.3.4 Production

Not all businesses produce. Manufacturing involves many concepts, methods and processes that need to be understood, planned, controlled and executed. This subsection tackles them briefly and closes on how production performance can be improved.

Before being able to produce, the plant layout needs to be established for production, inventory and equipment areas. The R&D department is responsible for creating bills of material (BOM), plan routings and set up work centers. According to the type of product, different manufacturing types can be found in factories: continuous (e.g. in textile, chemical and metallurgic sectors), repetitive (e.g. in the automotive industry via assembly line), discrete (e.g. for more customised products via job-shop disposition) or by project (i.e. for complex unitary products). Factories often combine those manufacturing types according to their needs.

Production planning is nowadays mostly automated by enterprise resource planning (ERP) systems. They are "*information systems that integrate processes in an organisation using a common database and shared reporting tools*" (Dredden and Bergdolt, 2007, p.47). However, let us look at the intrinsic planning logic. The sales and operations planning (S&OP) is first established to balance supply and demand in line with commercial plans. It will be used for families of products and takes the whole supply network into account. This plan will be updated every month and generally be valid for a period of between six months and three years. Once the S&OP completed, the master production schedule (MPS) will define the quantities to produce and the stock level to reach each week, per product and per period. Thanks to the more detailed MPS, the company can ensure delivery dates to clients. On an even shorter horizon, the material requirements planning (MRP) determines the quantity of required components to manufacture the MPS's planned products, while indicating the date at which those components must be available. Those schedules made the assumption that the company has enough capacity to fulfil any demand. The capacity resource planning (CRP) details the necessary capacity to execute all production tasks.

Once all capacity and resources needs are planned, production activity control (PAC) comes into play and is performed in four steps: prepare production documents, follow the aforementioned detailed scheduling (taking into consideration the TOC), launch production while respecting priorities, and monitor results for each factory.

Production department performance is traced down by effectiveness and efficiency indicators. They may be improved by acting on classical levers (e.g. outsourcing to low labour cost countries or externalise parts of the production) or by applying lean strategies (visual control, 5S method, Kanban method and value stream mapping are just popular techniques among others) and flexible manufacturing. Besides, manufacturing processes impact the environment: measures as energetic efficacity improvement, water consumption reduction, waste and pollution prevention can reduce this impact.

2.3.5 Maintenance

Maintenance refers to "*the set of all technical, administrative and management actions, during an equipment's life cycle, that aims to maintain or restore it in a state where he can fulfil the required function*" (AFNOR, 2002, p.6). After understanding maintenance typology, it is crucial to analyse maintenance policies, prepare maintenance plans and monitor interventions.

We can distinguish between two types of maintenance: preventive and corrective. The levels of maintenance are usually hierarchised by levels of urgency and complexity. A dependability study is usually written by the R&D department when conceiving a new system, describing the equipment's reliability, maintainability and availability.

Choosing a maintenance policy consists in fixing its orientation (method, programme and budget) to match goals set by the company's direction. Objectives might be, among others, be the availability and the lifetime of the equipment, the security, the products' quality or the respect of the environment.

Maintenance plans will follow the policy and only concern preventive maintenance. They state what activities should be realised for each equipment, the interventions frequency and the preparation of work orders and documents. When a problem occurs, a corrective maintenance will diagnose the failure, perform a corrective action and a functional test. The results of this test will be recorded for future exploitation.

An equipment is never performing continuously. Production workers have to consider workshop's opening and closing hours, the planned stops for cleaning, preventive maintenance, modifications and breakdowns. A way to monitor an equipment performance is the overall equipment effectiveness (OEE) criterion. To improve that performance, many companies set up the total productive maintenance (TPM) technique, which involves multiple departments and all hierarchical levels. The TPM is based on the production system effectiveness and an adapted work environment.

2.3.6 Sales

Sales order management is usually delegated to the customer service department of a company and follows a specific process: forecast the demand; manage, realise, ship and invoice sales orders; manage complaints and after-sales service. The customer service depends on many other departments, such as marketing, sales, logistics, finance and production.

The demand for a product or service might be stable, seasonal, cyclic, following a trend or random. Forecasting is executed in three steps. First, forecasting the demand per department, each of them following a set of assumptions and criteria. Forecasting techniques might be quantitative (time series, linear regression, etc.) or qualitative (market studies or expert advice). Then, consolidating the previsions from all departments. This step is onerous as those latter might have different incentives. Finally, measuring previsions reliability and improving the process.

Before processing the sales order, a quotation is usually sent to customers. Once the agreement reached, contracts can be created. Specific sales orders need to be considered when dealing with international clients (e.g. export orders will comprise incoterms, tariffs, taxes and exchange rates), with other branches of the same company (intercompany orders) and when receiving urgent orders (e.g. use of fast-paced means of transport or disrupting the manufacturing priorities). The validation of sales order first needs confirmation from the inventory manager: is the quantity available and capable to promise? Is the transport available? Does the sales price enable the company to reach the margin requirements? An ERP system allows to fast-track all those considerations. Furthermore, the operations strategy has an impact on the sales order realisation. In the case of MTS, the sales order consumes the available stock. In ATO and MTO configurations, it respectively generates an assembly work order and a manufacturing order. In the case of ETO, the engineering department analyses the requirements before sending a manufacturing order. Shipment of sold merchandises is explained in more detail in subsection 2.3.8. Finally, sales order invoicing can be applied at the ordering time, at the delivery time or on a regular basis (e.g. for consulting services).

The final logical step of the customer service department is to handle customer complaints in case of quantity shortages, quality issues and incorrect invoices. After-sales service also ensures the company's reputation by fulfilling after-sales requests.

The performance of the sales department can be traced by indicators (e.g. forecast accuracy, on-time delivery or return rate) and improved by installing integrated systems to automatise the activities that do not add value to the process.

2.3.7 Product flows monitoring

After analysing the six first categories, a manager would know how to purchase, produce and sell his products according to the corporate strategy. However, he does not know how his goods will move along the supply chain. This is the role of product flows monitoring: define the stock management policy and the replenishment method, and plan then track product flows.

Five types of stock can be found in a factory: raw materials, work in progress, semi-finished goods, finished goods and MRO supplies. The main role of the inventory is to decouple the products pushed by supply and those drawn by demand by constituting a buffer. An inventory can assure many functions, including cycle stock (necessary to cover demand in between two replenishments), security stock (that aims to cover unplanned decreases), lot size inventory (stock supplied in excess for economic reasons) and pipeline inventory (stock in transit). The total cost of an inventory can be computed as the sum of the acquisition cost (or manufacturing cost), the carrying cost, the ordering cost and the stock-out cost.

Different stock management policies can be defined according to the type of stock or by segmenting products according to their performance (e.g. using ABC analysis). Indeed, segmentation of products is necessary to avoid the costs of treating performing products the same way as floundering ones. For example, the most popular products will be stocked in all warehouses and shops, whereas less performing ones would only be available in some shops. Then, a replenishment method can be retained for each product. This replenishment differs according to the number of echelons in the logistic network. In subsection 2.3.3, reordering techniques for mono-echelon networks were discussed. For multi-echelon inventories, reordering needs to consider not only the quantity, but also the site to replenish. There are three approaches: let each site order independently; create a distribution resource planning (DRP) that estimates from down- to upstream what products need to be replenished for each site; or optimise goods allocation on each site by algorithm.

When the stock management policy and replenishment methods are defined, each logistic node and each product can be replenished, taking warehousing and transport constraints into account (see subsections 2.3.8 and 2.3.9).

Product flows performance can be traced by indicators (e.g. out-of-stock rate, inventory turnover or inventory obsolescence) and improved by joint management of the flows with other supply chain members. This last solution is often the most appropriate to reduce the bullwhip effect. Many methods have been tried through time, like QR, VMI or CMI. Nowadays, companies tend to collaborate by using ECR (efficient consumer response) and CPFR (collaborative planning, forecasting and replenishment). These methods focus on the supply chain's performance rather than individual performance. The CPFR is based on a joint demand forecasting and S&OP.

2.3.8 Warehousing and products handling

Now that the flow of products is defined, the warehousing management system will establish how merchandises will be stocked and handled at the different nodes of the supply chain. After describing some of the warehousing's typology, we will analyse its processes: reception of products, inventory management and shipping of goods.

The two types of inventory platforms are warehouses to stock merchandises, and logistic hubs to assemble and disassemble them. When the goods are not to be stocked, the logistic hub will be called cross-docking platform. A warehouse is made of several areas: reception zone (with control and deconditioning), the stocking area (made of racks for reserve and picking), the order preparation area (for consolidation and labeling) and the shipping area (with packing, control and waiting zones). The infrastructure will play an important role in the efficiency of the flow. The company will thus have to choose wisely among different stocking methods, handling equipment and conditioning means. The first decision of the inventory manager will be to decide whether to in- or outsource logistics and material handling activities. To focus on its core business, many companies may decide to outsource them to logistics service providers, 3PL or 4PL.

Receiving merchandises from the transport mean to the reception zone will require to assign thereto personnel and equipment. Workers will apply a conformity control and then transfer the goods to the stocking area in fixed or random locations. Stock levels and locations will be traced by theoretical stock for accounting inventory valuation. This latter can be conducted periodically or by cycle. According to the chosen method, the goods will be valued at their production cost or their acquisition cost, respectively for manufactured and bought products. Shipping merchandises will require the preparation of personnel and equipment as well. A picking list will inventory the goods to ship to fulfil one or several orders. The products will either move to the picker automatically (by conveyor) or be selected manually by order, group of orders or stocking zone. Pick to light and voice picking technologies will help reducing human errors. After picking, the goods are sorted by order and late differentiation operations may still be conducted. The conditioning can be carried out during the picking (pick and pack) or in the shipping area (pick then pack).

Warehousing management performance can be traced by indicators (e.g. on-hand inventory, shipping accuracy or space utilisation) and improved by reducing warehouse costs. Hence, a warehouse management system (WMS) is often set up. It consists in an ERP or a best-of-breed solution that automates product flows within a warehouse and manages equipment, infrastructure, reception, product handling and shipment of goods.

2.3.9 Transport

Many departments participate in the transport management of an enterprise. After describing the most common transport management typology and international specifications, we will analyse its processes: order planning, preparation and execution of transport orders.

Transport can be carried out by land (truck or rail), by sea (maritime or riverine), by air, by fixed installations or by multimodal systems. Transport nodes gathers seaports, river ports, airports, dry ports and logistic hubs. The routing mode is also included in the company's strategy: transport by lots (from loading to unloading point), express transport (where the delivery deadline is guaranteed), urgent transport (for immediate requests) and specialised transport (needing specific equipment or specialised know-how). International transport also brings its lot of concerns, with many more economic actors entering the supply chain. Transport organisers act on behalf of the expediter, from factory to shop. They are responsible for the final delivery. They are commissioners who freely choose the other agents of the international transport. Among them, the maritime agent / air freight agent will select the right shipowner / plane owner to perform the transit. The port forwarder will select or subcontract warehousemen to deploy the stowage, loading and unloading operations. Before executing the transport, incoterms (or international commercial terms) are agreed upon and allow the members of the supply chain to know their responsibilities in case of mishaps.

When the transport strategy is set up, the orders are to be planned. The pricing is established in function of various parameters (e.g. weight, volume or distance traveled). The bigger the tonnage and distance traveled, the cheaper the price per ton. Maritime transport has its own complex pricing parameters. After receiving transport orders, the logistic provider will define a transport plan that minimises empty rides by using continuous move routings (using the same truck to load merchandises for the return) or by grouping suppliers (multi-pick) and delivering to different clients (multi-drop) along the same run. When the routing is clear, the company ordering the charter will prepare the legal documents to comply with legislation. The loading plan will be created to define the stacking of transport units. During the transport itself, the fleet can be traced by GPS to be notified in advance for risks of schedule perturbation or, for perishable goods, quality degradation.

Transport management performance can be traced by indicators (e.g. empty miles, full truck rate or CO_2 emissions rate) and improved by reducing transport costs. On one hand, variable costs will depend on the distance traveled (e.g. fuel, maintenance and toll fees) and always be minimised when transporting full loads. On the other hand, fixed costs will not depend on the distance traveled (e.g. vehicle cost, driver wage and insurance) and may be substantial. Solutions to reduce those costs can be found in outsourcing transport, optimising the routing and the distribution network, setting up continuous drives and maximising the loading. A joint management of the replenishment between supplier and client enables the achievement of those optimisations. As seen in subsection 2.3.7, the CPFR can be used as a basis for cooperation among supply chain members. At the company level, a transport management system (TMS) might be used as an integrated software that allows planning, management and tracing of fleet operations. TMS might also serve as support for communication technologies (e.g. EDI). Transport also has a considerable impact on the environment. When possible, the company should try to use massified and ecological transport modes by rail, river or sea.

2.3.10 Reverse logistics

Reverse logistics is the process of routing merchandises from their consumption point to a consolidation hub in order to recover their value and minimise their environmental impact. It is a priority for companies willing to engage in the circular economy. We will describe its processes of collecting, transporting and sorting sold goods.

The products must first be controlled to be sure that they will not enter the return flow vainly (e.g. check if the warranty still applies). They are two collection methods: pick-up, where the company delivers to a client and take advantage of being on site to collect goods to return; and drop-off, where clients drop their merchandises at a pickup point. This last method allows to reduce the costs of the “first kilometer”. Merchandises are rarely designed for reverse logistics, which makes return transport harder to plan and execute. The goods will first be conditioned to reduce their weight or volume, and sometimes carefully packed to protect them for damages. At their arrival to sorting centres, the products will first be inspected, if possible automatically. According to the type of operations that will be conducted on returned products (repair, recycling of plastics or metals, preparation for reuse), they will be send to specific locations.

Reverse logistics performance might be improved by reducing transport costs. However, those of returned goods is often higher than those of goods being supplied. Indeed, the return is harder to forecast, will rarely allow full truckload and concerns products with a lower value. Companies may need to set up a specific return logistics network and create centralised return centre (CRC) to consolidate reverse flows. One may also consider using massified means of transport like train or boat, which are particularly suitable for carrying heavy merchandises of low value.

Part II

Analysis

Chapter 3

The impact of the IIoT on SCM based on the literature

3.1 Logistic network and operations strategy

Factories will increasingly be guided by demand reactivity and batch size 1 products requirements. The IIoT will thus affect their conception and design, the logistic network connecting upstream to downstream supply nodes and the operations strategy that makes products move.

The number of factories will depend upon many factors, including the company's size, the market's size and the factory capacities. Those criteria have little to do with connectivity. However, the IIoT may have an impact on their location for two reasons. First, reducing lead times by producing at proximity from the market and consumption areas may encourage a relocation of factories. It would make poor sense to invest in modularity within the flexible factory to lose time benefits in transport (especially in B2C industries where distribution often has a greater negotiation power). Second, international offshoring, motivated by labour costs minimisation, will be less appropriate for IoT business models which favour the attributes of quality, service, reactivity and innovation (Kohler and Weisz, 2016). Producing in its home country also helps avoiding international risks and regulations.

Speaking of the factories' *raison d'être*, the IIoT will promote a specialisation by market to address local demand better and faster. Specialisations by product and technology are not adequate (or see their definition changing), since we strive for standardised processes (thus duplicable factories) allowing mass customisation of products in each of them.

Decisions concerning the routing of products across the entire value chain (procurement and distribution networks, if taken from a company's perspective) involve many actors. We can thus bring about the importance of cooperation across companies and the future of contracting. The horizontal integration implied in IIoT organisational structures will reshape the way we think of supply chains. Optimising the performance of the whole chain and building the most efficient cooperation will ensure a company's success against competition. We might then think less and less about individual companies and more and more about cross-company intelligent networks and value chains, as the boundaries between firms and industries shatter (Kohler and Weisz, 2016). We discussed the importance of the time-to-market for B2C companies, but in a B2B frame, firms will integrate suppliers, subcontractors and clients into a shared coordination system where distance will matter in some cases. For instance, outsourcing parts of a factory's complex manufacturing processes to a 3PL (knowledgeable in logistics) and integrating the partner into the company's CPS will allow the two companies to share resources as if they were a single company. An inter-company CPS integration is supposedly the evolution of CPFR systems. We then tend towards a co-opetition state with a planning, knowledge and skills pool available across the supply chain, which represents an opportunity for organisations to "set up modern supply chain ecosystems" (Ketchen, Crook, and Craighead, 2014) and achieve the IIoT benefits of transparency, innovation and intelligence (Bienhaus and Haddud, 2018).

Finally, product flows across the supply chain nodes might have different inflection points explaining different operations strategies (MTS, ATO, MTO, ETO). IoT business models aim at massively customisable products, which place the customer at the beginning of the value chain. He will decide the product first, then its many specifications: existing (ATO, MTO) or not (ETO). The end-to-end engineering integration suggests that the customer requirements will first and foremost trigger product design for its integration into the CPS. This tends to favour ETO as a default operation strategy (Wang et al., 2016).

3.2 Sourcing

The introduction of the IIoT within the whole supply chain will require increased collaboration between suppliers, manufacturers and customers to enable transparency at each step (Tjahjono, Esplugues, Ares, and Pelaez, 2017). We will discuss the supplier / buyer cooperation, sourcing strategies, portfolio management and the main sourcing challenges/success factors of the IIoT.

The cooperation matters discussed in section 3.1 have specific implications for supplier relationship management. With the IoT, it is foreseeable that the life cycles of individual products will shrink. This will require organisations to think of supply chain strategies on a new innovative level to achieve competitive advantages (Schrauf and Berttram, 2016). Cooperation through digitisation thus needs to be rooted within an organisation's business model and strategy. This will align actors' incentives towards visibility and real-time access to information across the entire SC and *a fortiori*, increase the level of trust within the buyer-supplier relationship (Hoejmose, Brammer, and Millington, 2013). Based on this real-time supply chain transparency, "response velocity" will not only be a new attribute to manage the supplier performance, but also a capability to achieve competitive advantage thanks to the technological progress (Handfield, 2016). Digitisation will also play a role of alignment within the company itself, tracking and comparing existing sourcing strategies with the competitive goals of the overall corporate strategy (Bienhaus and Haddud, 2018).

E-Sourcing will increasingly be among the sourcing strategies of IIoT businesses. Not only does it automate the traditional sourcing processes of information sharing and activities of one-to-one communication (Philippart, Verstraete, and Wynen, 2005), but it also provides a shared and transparent platform that, in real time, allows many-to-many communications (Schmock, Rudzki, and Rogers, 2007). The easy access and the proliferation of offers will reduce the initial capital commitment between partners, increase competition between suppliers, lower the prices, and spur the need for strengthened SC relationships and alliances. Geissbauer, Weissbarth, and Wetzstein (2016) summarise the e-Sourcing terminologies under the term "purchasing 4.0" which, however, does not specifically differentiate between sourcing and procurement concepts.

The distribution of negotiation power within the supplier portfolio will change as well due to the presence of companies collaborating through digital sourcing. Those latter firms will reduce the supply risk thanks to transparent flows of information and warning systems at an early stage in cases of mishaps (Gelderman and van Weele, 2005). Furthermore, the supplier portfolio of a company will be incremented with vendors providing all required IIoT technology nodes (Tucker, 2017) (see subsection 1.2.1).

The increasing cooperation and data-driven transactions underline two challenges / success factors for Purchasing 4.0 (Bienhaus and Haddud, 2018).

- **Security.** Digitisation of sourcing (and procurement) imply automated and virtual transactions that are subjected to security threats and malicious attacks. Johnson (2013) highlights the importance of having a common approach on data security by integrating all supply chain members and using shared solutions to safeguard the data ecosystem. This ecosystem contains information on the company, but also on suppliers, customers, commercial strategies, and know-hows (Wang et al., 2016).
- **Trust.** If it was already a key success factor of past supply chain coordination, trust will remain vital in the new integrated and cyber supply chain ecosystems. Trust is fostered by big data, which plays the role of referee over uncertainty issues.

Bienhaus and Haddud (2018) conducted a survey among 414 business participants that highlighted three interesting conclusions regarding the future of sourcing, labeled "sourcing 4.0": the IoT will positively support the creation of full transparency within the supply chain ecosystem; transparency and traceability will strengthen supplier / buyer relationships and level of trust; "face-to-face" meetings will remain important to build up trust for long-term relationships.

3.3 Procurement

If the sourcing function is more strategic, procurement represents a support activity of the value chain (Porter, 2014) that deals with operational replenishment processes through purchase orders. Many procurement functions such as documents handling (sending purchase orders and controlling vendor bills), automatic reordering under specific conditions and inter-department communications are already automated through ERP and other best-of-breed software.

Hughes and Ertel (2016) mention the benefits of automating or outsourcing most procurement functions to gain a further innovative and strategic edge in the sourcing area. This reminds us of the close link between the two departments. Regarding this statement, we can emphasise two interesting remarks. First, the choice of automation over outsourcing allows greater control over the information and ease processes in case of policy changes. Second and most importantly, the use of big data and AI from the IIoT enables the maximisation of procurement efficiency in real time with regards to the company's internal and external needs (respectively capacity and demand). This automatised and optimised procurement will create space and time for the company to concentrate on strategic and cooperation initiatives driven by humans.

The survey from Bienhaus and Haddud (2018) also analysed procurement functions of the IIoT under the label "procurement 4.0" and highlighted three interesting trends (Bienhaus and Haddud, 2018): big data will be collected, analysed and processed within the procurement function; AI will support daily decision making in procurement and decrease operational activities; and the procurement process optimisation will provide more time and resources to support strategic efficiency, effectiveness, and profitability of sourcing.

3.4 Production

In this section, we will first analyse the impact of the IIoT on production systems, manufacturing types and routings. Then, we will discuss planning issues linked with the growing technical complexity of the industry. Furthermore, we will take a look, in the IIoT frame, at the relevance of production paradigms and strategies such as lean manufacturing and flexible manufacturing. The section will end with potential benefits for sustainable production.

In subsection 1.2.1, we stated the different benefits pertaining to the smart factory, principal objective of the I4.0 initiative that is mainly concentrated on shop floor and production progress. The smart factory will work with a manufacturing type that is difficult to classify into the traditional production line and job-shop labels. An article from Wang et al. (2016) illustrates the difference between the traditional production line and the smart factory production system. We summarised the key elements in Table 3.1 below. A graphical representation of the differences can be found in Appendix A.5.

TABLE 3.1: Differences between the traditional production line and the smart factory production system. Source: Wang, Wan, Li, and Zhang (2016)

Criterion	**Traditional production line**	**Smart factory system**
Types of products	Single or limited	Multiple
Resources	Limited and predetermined	Diverse, to produce multiple types of small-lot products
Machines	Several specialised, non-redundant machines deployed along the line	Redundant, adaptative and reconfigurable machines
Routing	Fixed, through a tailored, opened conveyor belt with inputs and outputs	Dynamic, through a closed conveyor system supporting various routes
Organisation	Machines are preprogrammed to perform the assigned functions. Malfunction of one can break the full line	Functions are distributed to multiple entities which will negotiate with each other to adapt to the system dynamics
Networking	M2M communication is not necessary. Control network between a machine and its substations can exist	Machines, products, information systems and people are connected via high speed networking
Data	Information may be recorded by individual machines but seldom used by others	Big data is transferred via high bandwidth to the cloud, in order to be processed

Machines and equipment operate according to the “plug’n’work” (or “plug’n’produce”) principle, enabled by wireless communication working together with modular physical constructions. Because no physical connections exist between the components other than the power supply, IoT elements can be replaced or added to the production process relatively easily in case of a modification or extension (Zuehlke, 2010). The IIoT nodes will recognise their function and enter the system through automatic integration. Smart devices interacting with new elements will not stop the process, but rather constantly adapt to their surroundings. Nonetheless, to thwart threats to production performance, managers need to be sure that the smart products are not taking decisions based on local information. This can only be solved if the servers receive information not only from the smart machines involved in the product routing, but also from all other distributed sensors of the factory. Only this way will the system achieve a global efficiency state by coordinating the behaviours of smart artefacts (Wang et al., 2016).

Since products never have to go through the whole system in a IIoT setting, we can expect an average shortening of production cycles and manufacturing routes (Barreto et al., 2017). The integration of location sensing systems (e.g. RFID technology) into the production processes is a major condition to meet the flexibility of such a closed system (Zuehlke, 2010).

The increasing technical complexity of the industry prevents ordinary planning and control practices (Barreto et al., 2017), where systems are often incompatible with one another. We will discuss factory planning from the lens of the automation pyramid (illustration in Appendix A.6), which depicts well the complexities linked to the various control systems' integration. From the ERP at the top-level planning to the M2M communication at the bottom, the pyramid explains the vertical logic of industrial processes management. Digitisation has a flattening effect due to the growing ERP and MES technologies that involve gradually more interoperability with the other layers. Some experts even speak of a complete vertical inversion, claiming that within an IIoT frame, the smart product pilots its own production processes, from planning to control (Kohler and Weisz, 2016). This will only be possible if the products and equipment can communicate with each other through semantic interoperability of data. That would allow the product to plan and execute its own routing. There already exists some planning solutions coming from equipment and IT companies. They integrate planning, simulation, MES and ERP functions, support the complete product life cycle and prove the flattening trend of the pyramid (Zuehlke, 2010). In the long run, they aim for complete semantic interoperability and shared international standards.

Lean strategies for production are still relevant in the context of the IIoT. This paradigm of waste reduction is still thoroughly applied by manufacturing companies through the Six Sigma, VSM, Kanban cards and so on. Kohler and Weisz (2016) seem to think that there is no linear continuity between the lean thinking in the IIoT, that the latter suggests an alternative way to think of the production time and space, focusing more on adaptability and flexibility rather than on the systematic aim to reduce waste. Other authors such as Mrugalska and Wyrwicka (2017) analysed the improvements that can be brought by the IIoT for lean strategies. We summarised some of their ideas in Table 3.2.

TABLE 3.2: Examples of possibilities offered by IIoT technologies for lean practices. Source: Mrugalska and Wyrwicka (2017)

Lean practice	**Improvements brought by the IIoT**
Kaizen	Continuous improvement is spurred by the collection and analysis of data retrieved from repeated actions dug by actuators, sensors and wireless technologies of smart products and machines.
VSM	Data allows a clearer visualisation of manufacturing processes and flows of information. These in turn enable ever-precise current state maps and highlight waste in a VSM schema.
Kanban	Smart products contain Kanban information to control production processes. Smart machines, thanks to RFID technology, detect product Kanban cards in real-time.
Poke Yoke	Data is collected in the remote cloud mainly to avoid operational mistakes, which is the main idea of Poka Yoke.
SMED	The plug'n'work principle makes it possible to introduce the SMED method into entire production lines.
Jidoka Q.C.	The augmented operator's aim is to reduce the time between two failure occurrences, e.g. through the Andon method, showing signal lights on one's smart interface (e.g. tablet) in real time. Alerts will be recorded in a database to be further studied for continuous improvements.

Differently from lean manufacturing, the flexible manufacturing system (FMS) is characterised by the ability to produce a various but similar goods and is closely related to economies of scope (Matsumura and Shimizu, 2015). We can thus consider that the IIoT shares FMS's final aim of mass customisation and the progress in both paradigms is complementary. An enabler of such flexibility is the additive manufacturing (AM), often mentioned along the IIoT in the context of production. This technology enables local, on-demand manufacturing of mass-customised products, which allows factories to relocate within the client's facilities (in B2B) or closer to the market (in B2C). This contrasts with traditional manufacturing processes where most parts come from centralised production units (Dallasega, Rauch, and Linder, 2018). AM thus increases the efficiency of multi-product development processes for factories specialising in flexibility (Rauch, Dallasega, and Matt, 2016).

Pertaining to the IIoT technology impact on sustainable production, Beier, Niehoff, and Xue (2018) discuss three areas of improvement: transparency, resource efficiency and sustainable energy. First, if industrial production benefits from increased transparency, environmental managers will detect pollution and waste pain points without difficulty. Reporting on environmental management data may also be beneficial to the company's reputation. Second, resource efficiency can be improved in different ways. The availability of digital customer information reduces the risk of overproduction, while additive manufacturing produces light and geometrically-efficient elements with less CO_2 emissions. Third, sustainable energy prospects in production are twofold. Energy saving is improved by software solutions offering energy optimisation methods and data analytics. Thanks to optimised savings, the IIoT might also raise the share of consumed renewable energy in production thanks to a better control on data, e.g. by storing what is needed and releasing surplus, enabling more profitable energy usage.

3.5 Maintenance

The smart adjective does not only apply to consumer goods, but also to industrial equipment whose design and engineering will be of crucial importance for a company's competitiveness (Rauch et al., 2016). Maintenance operations will be planned and applied on smart equipment. Just as for smart products, the smart equipment must be designed with predictive maintenance concerns as to reduce the future risk and amount of needed corrective operations. The vertical and through-engineering integrations of the smart factory must be taken as requirements, for the machine must be able to communicate with the connected infrastructure, and that for its entire life cycle. Liu and Xu (2017) place those machines under the label “Machine Tool 4.0” or “Cyber-Physical Machine Tool”, with regards to the I4.0 and its CPS. To support smart manufacturing systems, they affirm that those smart tools must enable real-time computations and networking. This will grant them with additional intelligence and autonomy in their final aim to be more profitable and resource-efficient.

Interesting applications for preventive maintenance are the ability to set up parameters for triggering alerts and automating the responses beforehand. With this purpose in mind, a more specific concept is often mentioned alongside maintenance improvements: the “digital twin” (or “cyber twin”). Resulting from heavy machine learning and analytics, it is a “*“digital model of the physical machine tool with embedded computational capabilities*” (Liu and Xu, 2017, p.73) that functions as the brain of the equipment. The digital twin comprises four main elements: an information model, a database, intelligent algorithms and analytics, and M2M interfaces. In a virtual reality, they run time-based scenarios that forecast future states and failures. With this outcome, technicians will develop and fine-tune equipment to prevent those predicted mishaps. The incorporated AI also enables the existing equipment to become smarter and automatically react to foreseen scenarios, mitigating failures and safety issues (McCarthy, 2018).

This way, AI provides advantages to reduce the manual need for corrective maintenance. An always-accurate equipment status would provide production detours without disruption in case of mishaps (Chadha, 2017). For example, the real-time data collection of a smart oven would send alerts when the temperatures reach levels outside the specified norms. This quick exchange of information also allows on-site technicians to work more effectively with the equipment while instantly assessing its OEE history via M2H interface (Tucker, 2017). In case of an unpredicted scenario, computer-aided maintenance manufacturing working with robotics deliver a second layer of maintenance efficiency, with autonomous robots solving and repairing the most common issues automatically and without human intervention (Barreto et al., 2017).

3.6 Sales

Clients are members of the supply chain and the conclusions of section 3.2 on the supplier / buyer relationship can be applied to the sales department as well: achieving competitive advantage and transparency through shared supply chain strategies and integrating those latter ones in business models to generate alignment and trust. Moreover, the company's relationship with clients is subjected to the same challenges of trust and data security.

Regarding cooperation, the difference with the sourcing department is that the company will most likely handle contracts with downstream logisticians and transporters itself, whereas upstream flows are often managed by the supplier. Where cooperation with clients is a key factor of the horizontal integration of the IIoT, the end-to-end engineering integration specifically starts from the sales department, as it is triggered by customer requirements to build the chain's structure. The sales order will set off product design and development, production planning and engineering, production, services, maintenance and recycling (Wang et al., 2016). Thus, we can say that the fourth industrial revolution is characterised by a reorganisation of the value chain around the final customer: the order directly triggers replenishments across the entire supply chain (Kohler and Weisz, 2016). It is more than ever in the company's interest to value customers as collaborative partners and to integrate them early, creating the opportunity to reach higher communication and satisfaction levels. This is true not only in B2B relationships but also in "a new form of B2B2C characterised by a direct reaching of end customers" (Kiel et al., 2017), which can be achieved by bypassing the corporate client or by approaching the end user together with the intermediary actor.

The proximity with the clients might be a coordination factor as well. As seen in section 3.1, the distance between the manufacturing plant and the final customer tends to be reduced for lead time control. Furthermore, the AM technology will support the sales department in contracting on tighter delivery schedules, allowing local, on-demand production of mass customised components (Dallasega et al., 2018).

From the company to downstream actors, dynamic and flexible sales channels are needed to fulfil complex customer requirements. The literature mentions the upcoming of a new type of marketing distribution channels: “omnichannels” (Brynjolfsson, Hu, and Rahman, 2013). Pertaining to the horizontal integration of a supply chain ecosystem once more, omnichannels use communication and physical crossing across multiple vertical distribution channels (from the supplier to the end customer) to produce one coherent distribution system adjusted to the purchaser’s need (Cummins, Peltier, and Dixon, 2016). This way, clients are not attached to a particular retail outlet but choose the one that maximises facility and comfort of shopping (Szozda, 2017). Collaborative distribution channels further highlight the solution of cooperative warehousing, that dampen damages linked to unexpected order cancellations, new customer requests and changes of delivery order or destination. They thus improve customer service (Reaidy, Gunasekaran, and Spalanzani, 2015).

On a less strategic note, transparency will increase the accuracy of demand forecasting and optimise, via ERP systems, other operational activities such as sales order management and invoicing (Barreto et al., 2017).

3.7 Product flows monitoring

So far, we analysed the impact of IIoT solutions on strategic and operational SCM decisions for each node of the chain independently. The three next categories focus on the links between those nodes, i.e. how products are moved across the supply chain.

In order to trace products in real time across the entire value chain, data is collected according to pre-defined parameters using radio frequency identification. RFID primarily comprises three elements (Fan, Tao, Deng, and Li, 2015): a tag shaped by a chip containing an antenna; a reader broadcasting radio signals and receiving answers from tags in return; and a middleware that links RFID hardware and enterprise applications such as ERP or MES systems. This technology uses radio waves to communicate in real time (from any distance and without any contact) with a multitude of items and subsystems equipped with the same technology. The data is then transmitted through the wireless network to the specified IP address of the server. The latter then opens a monitor to create a connection with the hardware before listening to the sent data. Interoperability through common semantic language must be achieved to recognise and resolve the hardware first, then the information. The data is then stored in a database following the construction of a data table, so that it can be integrated with software and run through analytics (Zhao, Yu, Wang, Sui, and Zhang, 2015). A technical flow chart of the data communication between a client and the server can be found in Appendix A.7.

Let us look at the benefits of installing such a visibility system. A model of message warning enables instant responsiveness of the control system, as each retrieved parameter will be compared with a critical threshold defined beforehand in the database. Messages will be transmitted from the system to the users responsible for the SC's specific hardware. Thanks to AI, the system itself may decide whether to take autonomous action or to send customised messages to users according to the circumstances (Fan et al., 2015). RFID technology combined with AI thus avoid data flood and reduce complex artificial operations. It also solves the problem of information reliability in products' traceability systems. Other traceability technologies include Bluetooth and smart sensors (Lin, Wang, Bi, Qiu, and Hassan, 2016), which allow traceability down to the smallest subsystem: screws, individual gears and even gaskets (Schütze, Helwig, and Schneider, 2018).

We now know how RFID works and what are its benefits in monitoring product flows. However, three challenges must be considered: RFID investment costs, data security and property issues. Those challenges will be discussed in the final section of this analysis (3.11), as they concern all categories.

3.8 Warehousing and products handling

During the last two decades, the inclusion of ICT in logistics has become increasingly vital for the organisational efficiency, evidenced by the integration of ERP systems with WMS. This section distinguishes strategic logistic questions, the warehouse and its elements, logistic processes and inventory performance.

Our first concern is strategic and resolves the question of insourcing or outsourcing warehousing and logistics. As seen in section 3.1, the inter-company borders will tend to fade towards a cross-company intelligent network. This highlights the need for process specialisation to optimise cost, quality and customisation attributes. This holds true for logistics services as well, spurring outsourcing to become the norm. Some experts discuss the possibility of a virtual logistics market (or "logistics mall") (Hofmann and Rüsch, 2017), where it is possible to call for tenders at a larger scale for one-time logistic services. They also doubt its efficiency as logistics are often company- (or product-) specific and require a trustful coordination and communication of data between supply chain members, as explained in the strategic decisions, sourcing and sales categories.

Warehousing layout and equipment will be impacted as well. Logistic hubs might use the smart conveyor system (mentioned in section 3.4) which handles goods according to the exchange of information between the load and the warehouse. According to Witkowski (2017, p.767), intelligent shelving and pallets will become a "*driving force of modern inventory management*", improving tracking & tracing activities to be more precise, faster, safer and able to predict issues. Handling means such as pallets, forklifts and even trucks are connected to the CPS as well to be monitored in real time for status, location, repair scenarios and analytics (Reaidy et al., 2015). In application, Wal-Mart required its top 100 suppliers to deliver their merchandises with RFID tags on pallets to give more transparency to its pallet-level system (Fan et al., 2015). Finally, warehouse workers themselves, as augmented operators, will need continuous access to data through devices (e.g. tablets) working with a company-specific application (Vavra, 2015).

The evolution of WMS within the CPS enables the integration of all logistic processes and activities. For example, means of transport will share their position and predicted arrival time to the intelligent WMS, which will trigger the necessary preparations (docking slot, arrival and delivery sequences and just-in-time optimisations) (Barreto et al., 2017). In the previous section, we explained how RFID technology improves the traceability of products at every location. Each arriving load is recorded in the system with its information (e.g. what and how much) stored on the server (Szozda, 2017). The WMS will then automatically allocate a storage space, according to the inventory area and delivery specifics, and assign it the right type of equipment for autonomous handling within the hub (Barreto et al., 2017). Considering product picking, one might wonder what the distribution of work between human workers and autonomous machines might look like in the IIoT. Boos, Guenter, Grote, and Kinder (2013) explain that when the warehouse operations are not completely automated, a M2H interface supports workers with an intelligent assistance system (e.g. smart glasses) as an extension of pick-to-light and voice-picking solutions to minimise search times by constant data transmission. The "intelligent bin" concept is also promising for improving the order picking process. The bin being integrated with the CPS, the worker must only confirm the picking by pressing a button. In latest developments, the bin will count the merchandises by image recognition (Dregger, Niehaus, Ittermann, Hirsch-Kreinsen, and ten Hompel, 2018). After picking, downstream loading is also expected to require less human involvement, let aside control activities (Hofmann and Rüsch, 2017). Pertaining to manpower control, more precise sales forecasts (see section 3.6) will also counteract short-term manpower planning in volatile demand situations, by notifying every worker through the company application in case of an emergency (Dregger et al., 2018).

The integration of RFID tags with WMS will provide real-time information on inventory levels, facilitating decision making in case of adjustments and preventing out-of-stock situations (Barreto et al., 2017). Since the CPS knows the time and amount of goods to be delivered, it always anticipates and ensures the availability of finished goods, and *a fortiori* of raw materials through their BOM. Fan et al. (2015) discuss the positive impact of RFID technology on inventory inaccuracies and conclude by stating that retailers will, gradually, decrease their buffer levels (existing to prevent damage, theft and errors) as uncertainty diminishes and forecast accuracy rises. Finally, the real-time information on stock levels also allows the accounting department to avoid the traditional and complex single-period valuation process.

3.9 Transport

The IIoT is likely to influence the partnerships between a company and its logistic providers. After discussing strategic decisions, we will see how the latter can achieve competitive advantages by focusing on new connected transport management software, infrastructure and equipment. Finally, environmental benefits are mentioned.

The choice of a delivery service provider is a strategic decision that breaks down to cooperation between partners. Incoterms are not likely to be affected by the IIoT, as they allow a legal distribution of responsibilities among supply chain actors. However, as seen in section 3.1, cooperation issues of trust and security are affecting logisticians just as suppliers and clients. Yu, Subramanian, Ning, and Edwards (2015, p.108) confirm by stating that "*technology facilitates both the horizontal flow of information among business partners and the vertical flow of information along shippers and consignees*". Transporters play an active role in deliveries, which is highly valued by end users as they might affect the overall customer satisfaction. Traditional criteria in choosing a transporter are service performance (quality, cost, flexibility, delivery time, value added service) and management quality (competency, reliability and sustainability); whereas more recent criteria include IT performance (IT compatibility, competency and capacity) (Buyukozkan, Orhan, and Ersoy, 2009). What are the new criteria highlighted by IoT technologies?

In their article on "logistics 4.0", Barreto et al. (2017) mention the importance of transport management systems (TMS) and intelligent transport systems (ITS) in the future of logistics.

- **TMS.** Integrated with other company software (such as ERP, WMS or ITS), its objective is to use real-time data to reach more efficiency and effectiveness in logistic processes through end-to-end visibility. To do this, it contains applications such as freight costs control, communication and negotiation processes simplification (with partners and clients), fleet location, and movements tracking (via GPS). It also has integrated optimisation algorithms (such as shipments consolidation for maximum tonnage, best routing and continuous drives planning). Like the other software, it is platform-independent and usable by any person with related access.

- **ITS.** Seen as a complement of TMS, ITS is a new field of transport management that embeds new technologies such as computing hardware, sensors, data analytics, virtual operations and planning techniques. Its objective is to increase safety, reliability, speed and traffic flow while reducing risks, accident rate, carbon emissions and air pollution. ITS applications are purposed to be implemented in land, air, water and rail systems and accessible via multimodal devices (smartphone, vehicle, infrastructure and information network). Examples of applications are intelligent truck parking, multimodal cargo, CO_2 footprint estimation, priority and speed advice to reduce fuel consumption and eco-drive support for energy efficiency.

Thanks to those technologies, demand-driven transport processes might increasingly secure on-time deliveries and improve customer satisfaction across the supply chain (Hofmann and Rüsch, 2017). Additional IIoT applications for deliveries might provide notifications for hazardous routes, a monitoring of precious and dangerous materials and the control of transport and storage conditions (Witkowski, 2017). Regarding perishable goods supply chains, sensor technology can control the truck's temperature, humidity and other food quality parameters during transport (Zhang, Zhao, and Qian, 2017).

Those software are obviously linked to transport infrastructure and equipment. The IoT technology encourages vehicles to use more and more powerful sensing, networking, communication and data analytics capabilities (Barreto et al., 2017). Location tracking technologies for trucks are enabled either by GPS (via satellite) or by GIS (via software), while location tracking for products is possible through RFID (Dallasega et al., 2018). Nichols (2018) discusses the use of different shipping fashions in the frame of the I4.0. The use of self-driving cars in an industrial context is said to reduce car accidents and delivery time, by increasing the amount of time spent on the road (e.g. autonomous driving when the driver needs to sleep), which is specifically beneficial for fresh food. By sea deliveries represent a promising area, since a majority of the world's transport is conducted that way. Drones as an emerging transport method in the IIoT have been under pilot test by several key international delivery service providers (Yu et al., 2015), which aim to take the workload off their drivers in remote rural areas and busy urban streets. However, they concern small orders only. Last but not least, trains are still a viable option for quick and secure transport across countries, as an intermediate between air (fast but expensive) and sea (cheap but much slower) shipping. An article from Fraga-Lamas, Fernández-Caramés, and Castedo (2017, p.1457) discusses smart railways as "*a combination of interconnected technological solutions and components, as well as modern transportation infrastructure*", connecting tracks to trains in an energy-efficient way. Their vision exceeds the scope of this paper as they take the concept of "smart trains" from connections with smart cities, ports and airports to a wider national approach. A good insight to draw out of their paper, however, is the need for logistic companies to invest in two types of infrastructure: hard (warehouses, fleet and hardware) and soft (laws, regulations, knowledge and software). Sun and Ryoo (2018) forecast the same needs for preparation but with a lens on smart city logistics that comprise robots, self-driving trucks, transport drones and more, connected by means of smart sensors, sharing data through wireless networks and connected to the Internet.

Exactly like the IoT environmental benefits in production (section 3.4), transport might benefit from sustainable energy (e.g. information and advices on energy consumption), transparency (e.g. real-time access to emissions) and resource efficiency (e.g. reduction of long hauls thanks to AM) improvements (Beier et al., 2018).

3.10 Reverse logistics

The field of reverse logistics implies a particular degree of uncertainty that induces the need for various processes. Dealing with all returned products in a standardised way will create waste for many recyclable, valuable products and thus, reduce potential profits (Gu and Liu, 2013). We will first discuss the specificities of z reverse logistics management system in comparison with TMS and WMS, then analyse the IoT impact on its processes.

Dealing with each product independently requires accurate information. Just like WMS and TMS, an ERP application or a best-of-breed software is also required to keep track of the products to be returned, and a reverse logistics management system is different in five ways (Xu, 2005). First, there is a need for high information reliability, as the uncertainty associated with products to return is greater than for forward logistics. The management can thus take a decision according to the situation. Then, data in the software is not deleted after some time, which increases the complexity of data maintenance. Third, the information about products lasts for their whole life cycle. This way, the software supports a circular economy. Fourth, a product item is unique in the database, but its returning scenarios are numerous, which results in a more complex data system with extremely diverse information properties. Finally, at the start of reverse processes, information about the products is located and scattered among customers. This decentralisation makes it harder to plan reverse than forward logistics.

Thanks to the integration of product flows across the entire supply ecosystem and the RFID technology, more accurate forecasts about backflow data can be made, hence refining risk management processes. Moreover, a shared database among manufacturers, vendors, transporters and even a front-end interface for end users might reduce the lack of maneuverability of reverse logistics (Govindan, Palaniappan, Zhu, and Kannan, 2012). For example, when a product returns to the CRC, both the equipment manufacturer and the independent 3PL will access all relevant information from production to recycling thanks to the CPS. Finally, each new case of product return might serve as example for new scenarios to be integrated with the system later on. Gu and Liu (2013) call this the “backflow product processing decision-making support system”. Following the concept of the circular economy, supply chains are seen as a close loop where decisions from the reverse logistics department might influence a new product’s design and engineering, which would reduce the overall resources and energy consumed through a product’s life cycle. Gu and Liu (2013) call this the “resource re-utilisation management”.

3.11 Challenges

For the most part, the impacts of the IIoT on supply chain categories were positive and optimistic, and that for three reasons. First, the main challenges to be mentioned will encompass all categories and the links between them. It is thus better to gather them in a separate section. Second, a certain number of articles seek to encourage companies to participate in the initiative by addressing mainly IIoT opportunities (Hofmann and Rüsch, 2017). Third, the fourth industrial revolution is at an early stage. Its big picture is still uncertain and applications are rare, which means that future challenges might unfold. The five following subsections go through challenges that have already been identified as critical for an IIoT implementation.

3.11.1 Data and process security

The IIoT involves a growing dependence on technology to achieve competitive advantage. The security of data and information is thus one of the most critical challenge to build the supply ecosystem (Barreto et al., 2017). The CPS needs to be under control under nearly every normal condition to avoid two types of scenarios. First, breaches and viruses might affect the industry at a much larger scale than before, having mentioned the fading boundaries between companies. Cybersecurity aims to protect the CPS' integrated network and its linked devices against malevolent intrusions attempting to alter their planned behaviours (Riel, Kreiner, Macher, and Messnarz, 2017). This makes cybersecurity the biggest risk factor in the future of manufacturing as well ("2016 Manufacturing RiskFactor Report," 2016). The design of software, processes and products are thus much more complex than before. Second, there is an increasing number of smart products, data and users overseeing them. The server capacity limits and the frequency bands within networks should thus be expanded considerably to avoid slowdowns or worse, breakdowns (Zuehlke, 2010). Similarly, RFID tags and smart sensor devices have a limited energy capacity, which might freeze processes and the entire integrated system in case of depletion. The energy capacity of smart devices need to be increased, as real-time communication consumes plenty (Sun and Ryoo, 2018). Energy efficiency is thus a relevant challenge in processes security.

3.11.2 Cooperation and data property

Outside cybersecurity, cooperation between the supply chain actors adds additional challenges: willingness to cooperate and data property.

Across most of SC categories, we mentioned the relevance of trust within the supply ecosystem. The ideal state would imply full trust and cooperation to reach an optimised value chain efficiency and transparency. However, even if digitisation has been proven to facilitate cooperation, several experts express their concern whether a full end-to-end integration is achievable (Hofmann and Rüsch, 2017). For example, the integration between suppliers, clients and logistic providers is already high in the automotive industry, which makes it less likely for them to invest considerably more into IIoT solutions that might only generate marginal benefits. Schütze et al. (2018) consider the hypothetical case where raw data is issued from the factory but only the component manufacturer has the relevant knowledge to interpret it. The producer must be willing to transmit the complete raw data, containing confidential information (e.g. production volume) to its component manufacturer. The case becomes increasingly complex with the number of suppliers, co-opetitors and clients.

Traditionally, a product changes property as soon as it moves down to the next supply node. But what about its data? A smart product's life cycle is subject to complex ownership issues that need to be agreed upon contractually in advance. Its data will never completely belong to a single entity for two reasons: fading boundaries between companies imply a shared database; and the close loop value chain induced by reverse logistics predicts the possibility of a product to return to its logistician and manufacturer. The ideal state would be that a smart products' data is owned by its entire supply ecosystem. The question in that case is how to separate the access between legitimate and unauthorised users, which is key to ensure clients' privacy and the service reliability (Gu and Liu, 2013). In subsection 4.2.2, we will discuss blockchain as potential solution for this issue. In a factory itself, user permissions should be set carefully to ensure system decentralisation and control, which reduces the impact of an individual mishap (Zuehlke, 2010). Thus, a cooperation mechanism is needed on how to deal with other supply chain nodes to guarantee the IIoT benefits of real-time (and better, forecasted) data management. This brings us back to trust and the necessity to be credible through adapted IIoT business models and contracts, including joint management systems such as CPFR.

3.11.3 Interoperability and standards

To reach a complete integration of the technical and physical IIoT environments, data needs to be able to transmit and recognise the same semantic language, i.e. to reach interoperability of data. As discussed in section 3.4, the automation pyramid illustrates the complexities linked to integrating various control systems and the subsequent impact on operations planning. The biggest difficulty is to retrieve all data and processes over a standard interface defined semantically (within a company first, then within the supply ecosystem), integrating all layers from the unit level to the ERP. Even though models are often incompatible with one another, we saw that many integrated solutions already exist in the industry. Their aim is to be vendor-independent to reduce cost and development efforts while ensuring high availability and reliability across their lifetime (Zuehlke, 2010). While additional time and research might be needed to flatten the automation pyramid completely into one fully integrated system called CPS, the challenge is mostly seen as bridgeable. The support of industry associations and governments to define international technology standards will be decisive in that matter.

3.11.4 Cost and investment

In order to be realist and implementable, the IIoT benefits must be compared with the cost and ROI of adopting these solutions. The cost of traceability technologies is by no means negligible and might hinder their widespread adoption on the unit level. Required investments comprise the hard infrastructure (e.g. adapted factory, warehouse and fleet but also RFID tags, sensors and actuators), the technology (software and networking) and the knowledge. In short, separate investments in all IIoT environments (Yu et al., 2015). The purpose of this paper is not to perform a thorough financial analysis, especially because of sector specificities and the rapid evolution in prices of technology factors. We will however expose some general investment insights.

Regarding RFID and traceability of product flows, Fan et al. (2015) conducted a mathematical study assessing the profitability of centralised and decentralised supply chains under pre-defined assumptions. First, for centralised SC, they concluded that if a firm wants to be profitable with RFID, it needs to consider both the cost of investment and the inventory shrinkage recovery rate that depends on the product properties (e.g. low for perishable goods). In the case of a circular economy and close loop supply chains (and thus, for non-perishable products), RFID would have more chance to be profitable. Then, in the case of decentralised SC, the results also depend on the balance of power between partners. Retailers might be more sensitive to the shared cost (fixed and variable) of investing in RFID than the suppliers. In the end, the retailer's power will define sharing ratios to compel the manufacturer to accept (or not) reduced margins.

In an estimation attempt, Gu and Liu (2013) take the case, five years ago, of a retail company gathering more than 750 stores who made a budget estimation for an IoT implementation throughout the company. RFID technology was estimated to 25 million dollars, with an additional 200 million in item products and equipment. Because the IIoT involves additional changes in organisation and processes, the real cost might be much higher. Additional concerns lie in customised products and their short life cycles that imply a constant need for expensive new design (Zuehlke, 2010). However, if the objective of the IIoT and I4.0 initiatives of mass customisation is to be achieved, lot-size 1 product will be designed and produced at the cost of mass production units.

3.11.5 Impact on labour

Concerning the impact of the IIoT on the job market, many insights were given in subsection 1.2.2. Two extremes are found in the literature. On the one hand, employees fear major restructuring, de-qualification, new kinds of stress, increased surveillance and social insecurity. On the other hand, they hope for new types of job creation and growing demand of qualitative labour with a revaluation of know-hows and knowledge (Dregger et al., 2018). Within a SC, the I4.0 initiative in Germany shares this optimistic vision and label this approach “socio-technical system”. Such vision does not choose between humans and machines but integrates them in a single system that exploits the most out of human capabilities (Kohler and Weisz, 2016). Some authors intensely argue that the human should always be put in the centre of any process, whatever the designed technical system. They put forward the need for humans to operate at all processes, from planning to maintenance (Zuehlke, 2010). Technological progress will enhance their mobility and decouple the place of work from their physical location. The downside of it brings up issues of job security and a disturbance of the work-life balance.

Nonetheless, most studies published on the IoT recognise the fact that some categories of jobs across the SC are in the line of automation. For example, activities such as picking, loading and material handling will mostly be performed by intelligent CPS and autonomous robots (as seen for the intelligent bin concept in section 3.8). Human interactions on those levels will be restricted to control activities (Hofmann and Rüsch, 2017). This does not only concern logistics but also low-value creation processes such as in procurement and sales or higher value production and maintenance processes.

For the remaining jobs however, time for IIoT trainings will be required, not only for workers and managers, but also for directors and owners. This will ensure their adaptability vis-à-vis the system (Vavra, 2015) and most likely create new types of jobs with more technical knowledge for all hierarchical levels.

Chapter 4

Qualitative surveys

4.1 Methodology

After the literature analysis, we know better how the fourth industrial revolution will affect supply chains categories and their decisions. The last chapter of this paper aims to provide additional knowledge drawn from interviews of IIoT and SCM professionals. The chosen methodology of separating SCM decisions into ten categories prevents us to prepare and discuss a single efficient questionnaire. As a result, five types of surveys were created to cover specific SCM areas, as well as an additional one to discover the future role of blockchain technology in this cross-field analysis.

The interviewees relate to three types of profiles: IIoT/I4.0 researchers, SCM researchers and professionals and a blockchain analyst. Table 4.1 summarises the profile repartition among experts and the attributable questionnaires. A list and a detailed description of the questionnaires can be found in Appendix B.1 and the questionnaires themselves are attached to Appendix B.2. Finally, interview transcripts and additional information on the contributors are available in Appendix C.

TABLE 4.1: Summary of the contributors and methodology

Professional profile	**Knowledgeable experts**	**Relevant questionnaires**
IIoT/I4.0	I, II	5
SCM	III, IV, V, VI	1, 2, 3, 4
Blockchain	VII	6

4.2 Discussions

The fourth industrial revolution is a very fresh concept. Except for experts I and II who are IIoT and I4.0 professionals, the other interviewees' knowledge was rather scattered and profession-specific, even though all of them were familiar with the technologies involved. Most parts of the discussions highlighted content that we can already find in our literature review or literature analysis: repetitive content is meant to be avoided. This way, we separated this chapter in four areas where experts came up with precious knowledge: additional insights and contradictory arguments regarding SC categories and challenges; the role of blockchain technology within an IIoT framework; the current development of IIoT applications; and the question whether companies should already start implementing IIoT solutions today.

4.2.1 Additional insights on SC categories and IIoT challenges

The interviews brought additional information on three areas related to the logistic network and operations strategy (section 3.1). First, regarding business models, expert V follows the positive opinions of the literature and sets the emphasis on the disruption that would bring a profitable mass customisation strategy. Experts I and III are more reserved. Ordering a motorcycle from Harley Davidson in the US already allows a change in configurations down to six hours before they start producing. However, expert I explains that when sales processes are completely integrated with manufacturing processes (e.g. in a smart factory), configurable blocks might enable changes of configurations until the moment production starts. The second strategic area concerns the question of integrating supply networks. Expert IV wonders why a company would invest in vertical integration tomorrow, when data sharing along with blockchain technologies will enable the transparency and security required to keep control over information. An increasing number of firms will rather specialise on their core business, and this phenomenon can be linked to the on-demand economy mentioned in subsection 1.2.2. Finally, expert V brings up a second advantage of adopting an AM strategy, in addition of the possibility to produce closer to the market. The progress in this area focuses on capacity, flexibility and cost optimisations for production equipment. In the future, it will thus be increasingly easy for smaller entrepreneurs to start a manufacturing business. Linking the two advantages would lead to a scattering of production moving closer to the demand, especially in advanced economies where the ICT is more developed.

Regarding sourcing (section 3.2), most experts agree on the decline of individual relationships in favour of network relationships. Expert I explains that when companies' CPS are interconnected within a common supply ecosystem, firms will order raw materials not even knowing who is producing them, just by specifying options and quality levels. We can thus question the importance of cooperation mentioned in the analysis, or at least its nature. It will require trust to join a supply ecosystem, but the partnerships within might turn weak and opportunistic, and one might wonder about the stability of the ecosystem itself. However, going out of specific dependencies constitutes a real advantage in a sourcing market. Expert V explains that data, cheaper and easier to access, will give companies the ability to conduct business with more and different partners, reducing the need for strong one-to-one cooperation.

About production (section 3.4), expert VI recalls her experience in a project-type manufacturing. She doubts of the utility of IoT technologies in that frame since there is no need for mass customisation. Long and complex projects require specific software with tailoring by consultants, as well as processes designed only for the scope of the project. A project manager could hardly optimise the three pillars of manufacturing (i.e. productivity, quality and cost) by integrating the IIoT into such a specific frame. Still on the shop floor, expert I greatly emphasises the importance of the digital twin for corrective maintenance (section 3.5), which might even be conducted by someone in augmented reality on a remote island that follows an incorporated tutorial. However, the issue with AI is that the individual equipment increasingly gains a value that is lost in case of replacement.

In our sales analysis (section 3.6), we mentioned the perks for a company to sell a smart product to the client and gather his usage data, but expert V also stated some benefits from the client's perspective. The product may communicate functional guidance to customers, transfer feedbacks and even give utilisation advices based on the user's behaviour. The product becomes a complete solution aiming at satisfying customers' personal requirements. Expert I summarises those points in the possibility to have one-to-one "product to consumer" relationships.

Expert IV believes that the enhanced transparency of product flows (section 3.7) has direct benefits for risk management. By tracking the products, uncertainty diminishes and allows managers to take decisions faster and more accurately. With the instant data, the problem is almost solved once the question is risen. Consequently, the easier it is for a manager to take decisions, the easier it would be for an AI to do the same in the future. This raises the topic of managerial jobs automation. Finally, transparent flows reduce the part of the bullwhip effect related to information uncertainty. Regarding warehousing (section 3.8), expert IV explains how smart systems will reduce the cost of conducting inventory valuation by automatic detection of products in warehouses. Furthermore, they will help reducing the cost of maintaining a CPFR between partners, which he thinks will be the basis for the creation of smart supply ecosystems.

Expert III is concerned about two transport issues (section 3.9). First, the safety of self-driving cars and their data collection. AGVs already drive on a small scale in certain companies, but they are mainly used in warehouses and factories. His second concern is about the common language necessary to deal with international shipments. Countries must agree on interoperability standards to scale up the technologies (see subsection 3.11.3). This is however a very competitive topic. About reverse logistics (section 3.10), expert III suggests designing products to be prepared to undergo reverse processes from the beginning, so that companies may plan and optimise recovering, repair and recycling scenarios. Mass customisation is aimed to be manageable in forward flows. Following the same logic, a process of after-sales late differentiation by CRC might be the solution to get the most out of reverse logistic flows.

When speaking of the cost of investing in IIoT solutions (subsection 3.11.4), expert II is optimistic. According to her, a positive ROI will come from five different sources: more turnover per customer from rising satisfaction (B2C); more turnover from new contracts/projects/alliances related to customer satisfaction (B2B); savings from labour costs due to automation; selling knowledge in addition of products and services; and selling not only products, but also its life cycle service. Expert III is more cautious, and thinks that even a company with money to invest should be considerate of not only the cost, but also the time it will take to implement such a project. Even facing a promising technology, overseeing the workload required to implement it may lead the roll-out to failure. Expert IV emphasises the fact that the price of batteries and solar panels is decreasing fast. Factories have a growing incentive to produce their own energy, especially in warm countries, rather than to be dependent on the grid. Expert II admits that small companies might not be able to invest in connected technology. Nonetheless, they can build business models that focus on all the new data arising from other IoT companies: through software and data (e.g. analytics, prediction, algorithms), through knowledge (e.g. face-to-face or online trainings, books, academics) and even through change management services. Expert III imagines small companies adapting thanks to standardisation. Once the technologies are used on a large scale, they will become more affordable.

Regarding labour (subsection 3.11.5), expert II believes that future disruptions will know two periods. During the first one, even if certain jobs will disappear, new jobs will develop, relating strongly to the development and implementation of the IoT. New university majors will emerge along with corporate education programmes to compensate slow government policies on education. Elder workers will be sent to early retirement programmes at the benefit of younger employees that grew up accustomed to the ICT. When the IoT is implemented and runs smoothly and reliably, a second period of labour change will arise by companies reducing their personnel further. Indeed, the ultimate goal of the IIoT is autonomy. Only the employees who understand IoT very well for monitoring purposes will remain. Expert VI confirms by stating that if labour costs will decrease by dismissing staff, the remaining employees will cost and be valued much more.

4.2.2 Blockchain technology for data security, data property and trust

According to the different interviewees, an interesting solution that might tackle the challenge of cybersecurity (subsection 3.11.1) is the blockchain. Expert VII describes it as a database technology that mandatorily imposes a set of rules on the participants that interact with it. A first advantage is that we can compartmentalise the access to information within the database.

Let us take the example of a company hosting a blockchain and integrating its clients. Those latter will agree upon strict confidentiality policies where the company only hosts the clients' data without being granted access to visualise it. Thus, a hacker's attempt to attack the network would only allow him have access to encrypted data with no possibility to see it without the client's ID key. Furthermore, possessing a client's ID would only harm him individually. A company could also set up a multiple-ID key where the approval from the top three managers are needed to access the complete database. The second advantage of blockchain databases are their incorruptibility, meaning that once an entry is written, no one can modify it without leaving a trace, i.e. the modification will be clearly visible by each participant of the blockchain. Expert I adds a third advantage to the benefit of financial transactions, where a blockchain would allow, once the regulations clearly defined, to cut intermediaries (e.g. banks). The drawbacks of a blockchain technology are three-fold. First, the speed of the network can be three to four times slower than classical networks. This is due to the newness of the technology, the small number of actors working towards its improvement and the decentralised characteristics of the database. The second difficulty resides in its complexity and corollaries. The number of knowledgeable blockchain technicians is very limited, so that the cost of implementation (not for hardware, but for maintenance) remains high. Finally, existing applications of blockchain technology are scarce and heavily cocooned, which leaves technicians very few examples to code on.

The implications for data security are huge, especially in the creation of private blockchains. If supply chain members do not have a relationship based on trust, they might achieve it based on a shared blockchain with access rules on their inventory, clients and other types of information (subsection 3.11.2). Expert I goes further in the reasoning by explaining that a company would always know who the user of a product, service or process would be (e.g. who is driving the truck, where the meat comes from and if the bill has effectively been paid). The automotive industry is already using blockchain for rental agreements to prove that the cars are safe to use and what the renter does with them.

Expert VII elaborates on the first advantage in the way that it solves the problem of data property as well (subsection 3.11.2). If a company compartmentalises the access to some information for specific users, it creates "private properties" of encrypted data within the blockchain.

4.2.3 Current state of development of IIoT applications

Experts I and II explain that most of the companies working with the IIC and the Fraunhofer IML remain in an awareness/assessment phase. For companies assessing their readiness for adopting IIoT technologies, the IIC has test beds that aim to simulate transformations of business models and to create proofs of concept. The Fraunhofer IML is also working with Deutsche Telekom in the "Telekom Open IoT Labs", where they jointly test and develop IoT solutions until they are ready for the market, especially in logistics and aviation industries. The rare companies already implementing the technology mainly focus on the shop floor areas (specifically manufacturing and maintenance applications).

Outside of the IIC and the Fraunhofer IML, good examples lie in harbor experiments in Hamburg or Rotterdam, which attempt to increase product flows in their limited areas. They do so by providing trucks and containers approaching the port with RFID tags. Expert IV speaks about his experience in the pharmaceutical sector, where quality requirements render traceability critical. The focus of n-Side is to improve data analytics so that decision-making towards overwhelming amounts of data is simplified. Expert V lists the most famous cases of smart factory developments: the SmartFactoryKL soap plant aims at efficient and profitable mass customisation; the Bosch Rexroth plant focuses on product identification by RFID, configurable work stations, software integration and M2H interfaces; and the Rolls Royce's "Power-by-the-Hour" approach improves maintenance performance with IoT technologies.

4.2.4 Should companies engage in the IIoT today?

With all the information gathered across the previous chapters, we might be getting closer to a managerial contribution by answering the question: "Should companies invest in and implement IIoT solutions today?". Expert I is convinced that if big companies are still hesitating today, they might encounter competitive disruptions in the future and lose a potential title of "hidden champion". Many actors think of the IIoT as an incremental innovation of cloud analytics and RFID technologies. Expert II believes that the biggest driver for implementation is the need to win over the competition. Soon, it might turn out to be a pressure to survive. The future IIoT champions will benefit from autonomous and stable processes, managers focusing only on strategic issues and an increased customer satisfaction through product customisation. They will also take advantage of strong predictive analytics, smart networks and interfaces, reduced operational cost and achievements in transparency, trust and security. Those disrupters might emerge sooner than expected, and the question on how to compete against them might come up too late for unprepared businesses. Expert I agrees by discussing the unreadiness of German companies, despite the I4.0 initiative, in comparison with giant companies such as Google, Apple and Amazon. Those corporations are, thanks to their massive collection of user data, placed on the front line of the fourth industrial revolution.

Conclusion

A fourth legitimate industrial revolution is on the way. It is neither a marketing concept nor an incremental innovation. Technological disruptions will not only affect macro- and microeconomic systems, but also governments, countries, societies and individuals. Cyber-physical systems will redefine the way we provide goods and services to customers and therefore, the way entire supply chains are managed.

Companies will still need to take decisions regarding logistic networks, operations strategies, sourcing, production and sales. Maintenance and reverse logistics will still need to be planned and monitored. Logistics, product flows monitoring and transport will still constitute critical success factors. But the IIoT will jolt the way those categories are managed, strategically and operationally. More information, connectivity and intelligence will optimise all operations to enable mass customisation and faster than ever times-to-market. Procurement is likely to be completely automated, along with mechanical and repetitive functions across all other SC categories. Departments' responsibilities will increasingly shift towards a prevalence of strategic concerns. Future industry champions will mainly look for innovative, highly adaptive and cross-functional job profiles. Those changes will gradually transform supply chains into smart supply ecosystems, where inter-company boundaries will fade, and the nature of cooperation will evolve.

But the literature is overly optimistic, and there is still a long way to go. Company associations such as the IIC and the Fraunhofer IML are building momentum and the topic's literature is growing exponentially. However, only few companies are aware of the IIoT benefits and among them, rare are the ones busy with assessment or implementation projects. In order to be attractive, IIoT solutions must be backed by a flawless interoperability of data and international standards. Only then will prices fall fast enough for companies to consider investing in the whole technological package. Since the IIoT requires the entire supply chain to be on board with data sharing and traceability, the phenomenon is likely to spread fast via business models emphasising the need for cooperation. It is one thing for a company to convince partners to cooperate, but it is another to rally its own employees under the automation flag. The impact of the fourth industrial revolution on jobs will be substantial, since its destructive factor is likely to take place much faster than during the previous revolutions and towards greater polarisation. A capitalisation factor will take place as well, but middle-income routine profiles, especially elder employees, will potentially lose their job first. At the end of the day, data security remains the most critical factor to consider IoT solutions. Without an almost complete certainty that CPS are secured, few companies will risk losing their confidential data along with that of their partners. Regarding this matter, blockchain technology is promising and proposes concrete solutions for cybersecurity, cooperation and data property. Its applications are still in early stages and will need further developments to become viable for pan-company integration.

Extensions

Thanks to a clear categorisation of concepts and centralisation of the literature, this paper constitutes a powerful tool for any researcher, manager or interested individual to better understand, historically and conceptually, the different opportunities and challenges that the fourth industrial revolution will bring on supply chains. It is especially valuable for managers and entrepreneurs who are not familiar with the subject or unaware of its importance for their businesses. Our analysis will help them conduct their own tailored business research, for it is on the field that in the end, the IIoT will really take place.

We hope that academics will want to use this paper to pursue future research. The concept is still very fresh, and many opportunities are at sight. First, the IIoT will impact all our SC model's categories, which makes each of them promising for additional exploration. They comprise their own complex management knowledge, know-hows and processes which can be used as further research material. For example, the impact of AM on a manufacturing ecosystem is a topic that could benefit from a paper on its own. This is also the case for technologies that find their way across each category such as RFID, blockchain or AI. Second, SCM is a broad topic that is most of the time industry-specific. This paper's categorisation may thus serve as benchmark to analyse each sector individually (e.g. oil, energy and food industries). Third, qualitative surveys might be done at a much larger scale with additional expert profiles targeting entrepreneurs, software engineers, legislative bodies and customer advocacy groups. Fourth, solid quantitative models would prove more tangible results pertaining to IIoT benefits and represent a more convincing call for action. However, due to the rare cases of IIoT implementations and corporate confidentiality, such analyses will be hard to conduct in a near future, outside of on-site participation projects. Finally, we saw that the fourth industrial revolution is also characterised by its impact on economic systems and social structures. There is thus much space left to assess how the future of governance and macroeconomic variables in an on-demand economy will impact supply chains.

In the end, what makes the topic so interesting is its novelty. New research will need to be conducted regularly to integrate new technologies, innovations and case studies. We are eagerly looking forward to see where it leads.

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