UNIVERSITÀ DEGLI STUDI DI BRESCIA

DOTTORATO DI RICERCA IN
INGEGNERIA MECCANICA E INDUSTRIALE

settore scientifico disciplinare
ING-IND/17

CICLO
XXXIII

THE ENTERPRISE 4.0 PARADIGM: STATE-OF-THE-ART, PROGRESSING AND CHALLENGES

TING ZHENG

Relatore:
Dr. ANDREA BACCHETTI

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Over the years, this thesis work has also been co-supervised by:

Dr. Marco Ardolino, Università degli Studi di Brescia, Italy

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München, 10th November 2020

Ting Zheng

Abstract

The current context of higher global competition and more complex customer demands pushes the manufacturing companies to provide value-added products to the market in a more fast and reliable way. According to this view, companies can exploit the outstanding improvements in digital technologies whose adoption has brought to the so-called fourth industrial revolution, also known as "Industry 4.0" (I4.0). Indeed, numerous literature has investigated I4.0 enabling technologies with regards to their technical specification, architecture, and domain of use, examples are Cyber-Physical Systems (CPS), Internet of Things (IoT), Big Data and Analytics (BDA), Cloud technology, Artificial Intelligence (AI), Virtual and Augmented Reality (VR & AR), Simulation and Modelling, Automation and Industrial Robots and Additive Manufacturing (AM). However, a comprehensive analysis of the adoption mode in manufacturing companies is of less concern, as well as the evidence from empirical studies on how companies are impacted by I4.0.

To fill this gap, this dissertation will make contributions from four perspectives (A, B, C, D). The first contribution is a systematic literature review (SLR), which explores 1) what are the I4.0 enabling technologies, 2) how they are applicated in the lifecycle processes of manufacturing companies, 3) what is the future research agenda based on SLR (contribution A). The second and third contributions are descriptive and longitudinal survey studies, which 1) investigate the state-of-the-art of I4.0 paradigm in Italian manufacturing companies (contribution B), 2) compare the I4.0 state-of-the-art advancement in a 2-year gap in Italian manufacturing sector (contribution C); these contributions are mainly to provide empirical evidence on how I4.0 are impacting on manufacturing companies and how it is evolved. Finally, logistics is selected as a vertical area of the I4.0 paradigm, to explore the Logistics 4.0 (Log 4.0) phenomena and figure out the determinants of successful adoption factors of Log 4.0 in the manufacturing companies through an exploratory survey.

The results of this research project contribute to I4.0 and Log 4.0 literature. In particular, the SLR for I4.0 applications in the manufacturing context provides a detailed and holistic description of the use cases of I4.0 enabling technologies in the lifecycle processes of manufacturing companies. Second, the descriptive survey of I4.0 state-of-the-art in Italian manufacturing companies provides a concrete description of how I4.0 is known and adopted by companies, as well as the corresponded benefits and obstacles. Third, through a dynamic state-of-the-art study, comparing with the data collected from 2017 and 2019, the evolvement feature of I4.0 is demonstrated. Finally, an exploratory survey of Log 4.0 tries to figure out the determinants of successful implementation of Log 4.0 solutions.

Keywords: Industry 4.0, digital transformation, digital technologies, business process, manufacturing, systematic literature review, descriptive survey, longitudinal survey, Logistics 4.0

Sommario

L'attuale contesto di elevata concorrenza globale e di richieste dei clienti più complesse spinge le aziende manifatturiere a fornire al mercato prodotti a valore aggiunto in modo sempre più rapido e affidabile. Secondo questa visione, le aziende potrebbero / dovrebbero sfruttare gli eccezionali miglioramenti offerti dalle tecnologie digitali, la cui adozione ha portato alla cosiddetta quarta rivoluzione industriale, nota anche come "Industria 4.0" (I4.0). Infatti, numerosi contributi in letteratura hanno identificato e investigato le seguenti tecnologie abilitanti I4.0 per quanto riguarda le loro specifiche tecniche, l'architettura e il dominio d'uso: Cyber-Physical Systems (CPS), Internet of Things (IoT), Big Data and Analytics (BDA), Cloud technology, Artificial Intelligence (AI), Virtual and Augmented Reality (VR & AR), Simulation and Modelling, Automation and Industrial Robots and Additive Manufacturing (AM). Tuttavia, un'analisi completa della modalità di adozione nelle aziende manifatturiere ancora manca, così come le evidenze di uno studio empirico su come le aziende sono impattate da I4.0.

Per colmare questa gap, il primo contributo è una analisi sistematica della letteratura scientifica (SLR), che esplori 1) quali sono per davvero le tecnologie abilitanti I4.0, 2) quali sono le loro aree di applicazione a supporto dei processi di business delle aziende manifatturiere, 3) l'agenda futura della ricerca (contributo A). Il secondo e il terzo contributo sono legati ad indagini (survey) descrittive e longitudinali, che 1) indagano lo stato dell'arte del paradigma I4.0 nelle aziende manifatturiere italiane (contributo B), 2) confrontano l'avanzamento dello stato dell'arte dell'I4.0 all'interno di un orizzonte temporale di 2 anni (contributo C); questi contributi servono principalmente a fornire evidenze empiriche su come I4.0 stia concretamente impattando sulle aziende manifatturiere e su come stia evolvendo nel tempo. Infine, la logistica è stata selezionata come processo / area di business su cui svolgere un approfondimento mirato, con l'obiettivo di esplorare il fenomeno della cosiddetta Logistica 4.0 (Log 4.0) e di capirne i fattori di successo che spingono verso l'adozione di tecnologie 4.0, attraverso un'indagine esplorativa dedicata.

I risultati di questo progetto di ricerca, opportunamente sintetizzati in paper, contribuiscono alla letteratura I4.0 e Log 4.0. In particolare, la SLR per I4.0 fornisce una descrizione dettagliata e olistica dei casi d'uso delle tecnologie abilitanti I4.0 nei processi di business delle aziende manifatturiere. In secondo luogo, l'indagine descrittiva dello stato dell'arte di I4.0 nelle aziende manifatturiere italiane fornisce una descrizione concreta di come I4.0 sia per davvero conosciuto e adottato dalle aziende, evidenziando i benefici di tale adozione e gli ostacoli che ancora ne limitano l'attecchimento. In terzo luogo, attraverso uno studio dinamico nel tempo, con dati raccolti nel 2017 e nel 2019, si dimostra l'evoluzione di I4.0. Infine, un'indagine esplorativa dedicata a Log 4.0 cerca di cogliere le determinanti del successo dell'implementazione delle soluzioni Log 4.0, anche qui evidenziando i principali benefici ed ostacoli.

Parole Chiave: Industria 4.0, trasformazione digitale, tecnologie digitali, processi di business, manifattura, descriptive survey, longitudinal survey, Logistica 4.0

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Abbreviations

I4.0	Industry 4.0
Log 4.0	Logistics 4.0
CPS	Cyber-Physical Systems
IoT	Internet of Things
BDA	Big Data and Analytics
CMfg	Cloud Manufacturing
AI	Artificial Intelligence
ML	Machine Learning
AR	Augmented Reality
VR	Virtual Reality
AM	Additive Manufacturing
DT	Digital Twin
IT	Information Technology
OT	Operational Technology
SMEs	Small-Medium Enterprises
RO	Research Objective
SLR	Systematic Literature Review
RQ	Research Question
RM	Research Methodology
AGV	Automated Guided Vehicles
IIoT	Industrial Internet of Things
R&D	Research and Development
CRM	Customer Relationship Management

Contributions

Contribution A

Zheng, T., Ardolino, M., Bacchetti, A. and Perona, M. (2020). The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. *In International Journal of Production Research*, available at: https://doi.org/10.1080/00207543.2020.1824085

Contribution B

Zheng, T., Ardolino, M., Bacchetti, A., Perona, M. and Zanardini, M. (2019). The impacts of Industry 4.0: a descriptive survey in the Italian manufacturing sector. *In Journal of Manufacturing Technology Management*, available at: https://doi.org/10.1108/JMTM-08-2018-0269

Contribution C

Zheng, T., Ardolino, M., Bacchetti, A. and Perona, M. (2020). Progressing and advancement of Industry 4.0 in the Italian manufacturing context: a dynamic state-of-the-art. *In Proceedings of XXV Summer School "Francesco Turco" – Industrial Systems Engineering*.

Contribution D

Zheng, T., Ardolino, M., Bacchetti, A. and Perona, M. (2020). The impacts of Logistics 4.0 on Italian manufacturing companies: an exploratory survey. *In proceedings of 27th EurOMA Conference* (pp. 1669-1678).

Other contributions

1. Bacchetti A., Zanardini M., Ardolino, M., Perona, M. and Zheng T. (2018). The impacts of Industry 4.0 paradigm in the Italian manufacturing sector: an exploratory survey. *In SCIENTIFIC WORKSHOP ON THE 4 TH INDUSTRIAL REVOLUTION*, Trento, Italy.

2. Zheng, T., Ardolino, M., Bacchetti, A. and Perona, M. (2018). Industry 4.0 revolution: state-of-the-art in the Italian manufacturing context. *In Proceedings of XXIII Summer School "Francesco Turco" – Industrial Systems Engineering* (pp. 338-394).

3. Zheng, T., Ardolino, M., Bacchetti, A. and Perona, M. (2019). Enabling technologies, impacts and challenges of "Industry 4.0" in the manufacturing context: some insights from a preliminary literature review. *In Proceedings of XXIV Summer School "Francesco Turco" – Industrial Systems Engineering* (pp. 27-33).

4. Ardolino, M., Bacchetti, A., Perona, M. and Zheng T. (2020). An exploratory survey of the impacts of Logistics 4.0 in the Italian manufacturing context. *(submitted to International Journal of Logistics, now under 2nd round revision)*.

5. Zheng, T., Bacchetti, A., Ardolino, M. and Perona, M. (2021). Road to Industry 4.0: evidence from a longitudinal survey in Italian manufacturing companies (*in preparation*).

PART I

EXECUTIVE SUMMARY

Since the proposal of the term "Industrie 4.0" by Germany in 2011, to promote digitalization for German manufacturers, it is then becoming an exceptionally hot topic across the industries and academic communities. Indeed, several countries have proposed their national initiatives for supporting companies in digital transformation, such as "Made in China 2025" by the Chinese government in 2015, "Impresa 4.0" by the Italian government in 2016. The high-speed diffusion of Industry 4.0 (I4.0) is because industrial enterprises are facing more challenges than ever for competing in the international market, delivering high-quality and customized products in a fast and reliable way. In response to that, the new trend of I4.0 is promptly attracting attention, which is also seen as the next industrial revolution/evolution for moving from previous industrial stages to a highly interconnected smart enterprise, achieving vertical integration, horizontal integration, as well as end-to-end engineering (Kagermann et al., 2013). Moreover, I4.0 provides a wide range of opportunities, such as increase in production and operations efficiency, improve product-service portfolio, enabling new business models, and getting more touching points with customers, and consequently, generating more revenue streams (Bustinza et al., 2018).

The industrial revolution/evolution is often characterized by its technology, which is the central element of such revolutions (Klingenberg et al., 2019). Indeed, the previous three industrial revolutions are separately characterized by mechanization, electrification, and computerization (Morrar et al., 2017). However, academics and practitioners attribute different technologies to I4.0, and there is no agreed list of I4.0 enabling technologies (Fettermann et al., 2018). In this dissertation, it investigates the I4.0 enabling technologies by considering the renown academic publications and diverse national initiatives. For example, Ghobakhloo, (2018) identifies 14 technological clusters and proposes a strategic roadmap towards I4.0. Klingenberg et al., (2019) reviews systematically the I4.0 technologies, and groups them according to data-driven principles. Oztemel and Gursev, (2018) contribute an extensive and detailed literature review of I4.0 technologies. On the other hand, national initiatives like "Industrie 4.0" and "Impresa 4.0" are referred. As a summary, Cyber-Physical Systems (CPS), Internet of Things (IoT), Big Data and Analytics (BDA), Cloud, Artificial Intelligence (AI), Blockchain, Augmented and Virtual Reality (AR&VR), Simulation and Modelling, Industrial and Automation Robot, Additive Manufacturing (AM) are considered as I4.0 enabling technologies. Indeed, I4.0 introduces novel opportunities that may disrupt the traditional processes of manufacturing companies, where some technologies could have transversal impacts, while others effect on a purely single process. However, current literature lack of linking between I4.0 and processes of manufacturing company in a holistic way.

More specifically, a comprehensive analysis of what are the I4.0 technologies application in manufacturing company's processes is required.

In this digital era, companies are facing up with significant challenges with high-speed advancement of technology evolution, whereas they need to reorganize their resources for digital transformation, understand what kind of benefits can be brought by I4.0, and what kind of obstacles are waiting for them. Such doubts are therefore deserving empirical studies for clarification. The existing literature is mainly focused on two streams of empirical studies, namely the I4.0 maturity model and survey of the I4.0 paradigm at the national/regional level. Regarding I4.0 maturity models, a summary of current models and their investigated dimensions have been summarized by (Pirola et al., 2019; Santos and Martinho, 2019). In fact, the I4.0 maturity models are not only explored by academic communities, but also by industrial associations, such as Acatech (Schuh et al., 2017) and VDMA (Lichtblau et al., 2015). On the other side, diverse survey-type studies are trying to explore how companies in different countries or regions are approaching I4.0. For example, Basl, (2017) investigates the readiness for implementing the main features of I4.0 in manufacturing companies in the Czech Republic, Tortorella and Fettermann, (2018) focus on the Brazilian manufacturing context with examining the relationship between lean production practices and I4.0 implementation. However, there is little research considering Italy as a target, who is the second most important country in the European Union (EU) referring to the sold production value (EC, 2020), following Germany. Moreover, existed researches are predominantly cross-sectional studies, and longitudinal type study is much less concerned.

Due to the I4.0 transformation in the manufacturing environment, the management of logistics process plays a vital role in the success of manufacturing firms, since it constitutes a significant cost in operations, and represents the image of the company through delivering the right products at both the right time and the right price (Fawcett and Clinton, 1997). However, it is questionable whether logistics systems can react quickly in the dynamic production environment and handling proficiently customized needs. A new term is therefore spreading in the literature to indicate the application of I4.0 within logistic processes, named Logistics 4.0 (Log 4.0), which stands in a broader sense of I4.0. Indeed, Log 4.0 promotes the realization of networking, automation as well as decentralized control in the supply chain through the adoption of digital technologies (Wang, 2016; Winkelhaus and Grosse, 2020). However, current literature for Log 4.0 studies is still in its infancy stage, focus is putting more on the conceptualization of Log 4.0 (Szymańska et al., 2017), and proposing a maturity model for Log 4.0 (Facchini et al., 2019; Oleskow-szlapka and Stachowiak, 2018) while lacking a comprehensive empirical investigation on a bigger sample size to understand how manufacturing companies are aware of Log 4.0, and what type of advantage in adopting Log 4.0 solutions, as well as what could be the potential factors that can impact such adoptions.

This dissertation contributes to filling the aforementioned research gaps by providing more clarity about the phenomenon of I4.0, its application cases, as well as the empirical evidence on how manufacturing companies are involved and proceeding towards I4.0. More specifically, this dissertation makes a holistic review of what are the use cases of I4.0 in the whole life cycle processes of manufacturing companies; provides empirical testimony on the state-of-the-art of I4.0 in the Italian manufacturing companies, investigating the companies' knowledge and utilization level of diverse I4.0 enabling technologies, and their corresponded benefits and challenges; explores the progressing character of I4.0, providing a dynamic state-of-the-art of I4.0 in Italian manufacturing companies; links I4.0 and Log 4.0, figuring out what are the factors that impact the implementation of Log 4.0 solutions. The overview of contributions is summarized in Figure 1.

From contribution A, it is found out that among the processes that have been investigated ranging from product development to after-sales management, researches are still intensively focused on production scheduling and control, which belongs to the domain of smart factory. And among the I4.0 enabling technologies that have been explored, IoT, BDA and Cloud are the technologies that appear normally together, implying that scholars are putting lots of efforts in synchronization of the information, and figuring out data-driven solutions for facilitating fast and precise decision-making in I4.0 context. Moreover, it is also figured out that I4.0 is not only a promotor for process efficiency improvement but can also act as a lever for optimising strategic configuration choices and achieving customer centricity. Besides, it is detected an increasing trend that scholars are exploring I4.0 as enabler of servitization and circular economy, the impact of I4.0 is extending from the 'smart factory' to the 'smart supply chain' concept.

From contribution B, it is found out that the Italian manufacturing companies are in different positions in their journey toward the I4.0 paradigm, mainly depending on their size and informatization level. Besides, not all the business functions are adequately involved in this transformation, production, IT are more involved among others. Company's awareness about this new paradigm seems quite low because of the absence of specific managerial roles to guide this revolution. Finally, there are strong differences concerning both benefits and obstacles related to the adoption of I4.0 enabling technologies, depending on the technology adoption level.

From contribution C, it figures out that the Italian manufacturing companies are more aware about I4.0 technologies and they have put more practice in adopting them in a two-year time slot. Indeed, there is an evident increase of adoption of BDA and IIoT. Moreover, the involvement of business functions is generally increased in 2019 compared to 2017, especially for IT, R&D and

Logistics. Furthermore, comparing the benefits perceived by companies with regarding the implementation of I4.0 enabling technologies, the greater number of technologies are used, the more benefits are obtained. And companies are generally perceiving more benefits in 2019 respect to 2017.

The contribution D figured out that the Italian manufacturing companies have very poor knowledge of Log 4.0 enabling technologies, and the adoption of technologies is very limited. On a practical level, the concept of Log 4.0 is still very weak as a paradigm aimed at integrating all the processes and technologies involved. Companies find it more difficult than expected to integrate new technologies with the structures and processes already existing within the company. In fact, the companies mainly focus their efforts on the implementation of technologies to improve the logistics operations, predominantly the efficiency of operations within the warehouse. Despite this, although still inadequately prepared, the companies that have started on the journey approaching Log 4.0 have generally perceived greater benefits than they expected before implementing new technologies. Moreover, this contribution reveals the fact without an adequate level of expertise and knowledge, it is really very difficult to implement digital technologies to support logistics processes.

Contribution A — ***The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review***

- **Methodology**: Systematic literature review
- **Output**: International Journal of Production Research
- **Status**: Published, ahead-of-print

Contribution B — ***The impacts of Industry 4.0: a descriptive survey in the Italian manufacturing sector***

- **Methodology**: Descriptive survey
- **Output**: Journal of Manufacturing Technology Management
- **Status**: Published, ahead-of-print

Contribution C — ***Progressing and advancement of Industry 4.0 in the Italian manufacturing context: a dynamic state-of-the-art***

- **Methodology**: Longitudinal survey
- **Output**: XXV Summer School "Francesco Turco" - Industrial Systems Engineering (2020)
- **Status**: Accepted for publication

Contribution D — ***The impacts of Logistics 4.0 on Italian manufacturing companies: an exploratory survey***

- **Methodology**: Exploratory survey
- **Ourput**: 27th EurOMA Conference
- **Status**: Published

Figure 1. Overview of contributions

This cumulative dissertation comprises of two parts. **Part I** provides an overview of the entire dissertation. More specifically, in chapter 1, a theoretical overview of the important concepts for this dissertation is provided. In chapter 2, the research design is described, strengthening from three perspectives, namely research gaps, questions, and methodologies. In chapter 3, a summary of overall findings and contributions are demonstrated, and discussions of the results are shown in chapter 4 from theoretical and practical aspects, as well as the limitations and future directions. And chapter 5 makes conclusions. **Part II** is overall composed of four research papers, which separately address the different aspects of the overarching research gaps and questions. The layout of the single publications has been unified into a common standard format and all references are consolidated in a common list of references. To be clarified, contribution A, B have been published at international peer-reviewed journals, while contribution C, D have been published or accepted for publication at international peer-reviewed conferences. The journal version of contribution C is in preparation, targeted at Journal of Manufacturing Technology Management, and the journal version of contribution D is under second round review at International Journal of Logistics Research and Applications.

1. THEORETICAL OVERVIEW

The literature review of this project is conducted from the following perspectives: 1) Concept and principles of Industry 4.0; 2) I4.0 enabling technologies; 3) I4.0 empirical studies in different countries; 4) I4.0 and Log 4.0. To be clarified, the literature review is an activity carried out during the whole Ph.D project, but with different focus during the different phases of the project. In the first year, the focus was put on understanding the concept of I4.0, the reason why it was proposed, and what are the principles of I4.0. Then in the second year, the focus was mainly to understand what the enabling technologies of I4.0 are, and how companies are impacted by I4.0, especially from the empirical point of view. In the third year, more attention has been put on investigating the relationship between I4.0 and Log 4.0, as well as the literature related to the critical success factors for the technology adoption model.

1.1 Industry 4.0

The term ‘Industry 4.0’ was first coined at the Hannover Fair in 2011, originated from a national project initiated by the German government, aimed at promoting the digitalization of manufacturing in Germany, in order to secure the future competitiveness of German industry (Kagermann et al., 2013; Lasi et al., 2014). Indeed, advances in digital technologies are changing the way products are designed and manufactured (Lee et al., 2013). Therefore, the main objective of this new paradigm is to create the so-called ‘smart factory’ where all the elements of the system, both humans and machines, are connected for better business and societal outcomes (Erol et al., 2016; Jiang, 2017; Wang, Wan, Li, et al., 2016). Generally, the term “Industry 4.0” is used interchangeably with the term “fourth industrial revolution”, differentiated from the previous three revolutions, which was separately characterized by mechanization, electronation, and computerization. The idea of Industry 4.0 is derived from the advancement of Cyber-physical systems (CPS), which can be controlled or monitored through software integrating computers, networks and physical processes (Khaitan and McCalley, 2014), and is the fundamental enabler of I4.0 (Kagermann et al., 2013). Though the issues of digitalization and the adoption of digital technologies in manufacturing enterprises have been debated from different perspectives in addition to ‘Industry 4.0’ (e.g. ‘Smart manufacturing’, ‘Smart factory’, ‘Factory of the Future’, ‘Intelligent manufacturing’), This study will put its focus on Industry 4.0. Indeed, this concept has been widespread for many years and acknowledged by several international academic communities.

Some fundamental principles can help to understand the concept of I4.0 better. Firstly, it is about the decentralization, based on the CPS, which is the integration of embedded computers, network monitors, and controllers (Alguliyev et al., 2018), different CPS can make decisions about their operations without using centralized control. The second principle is real-time support, which indicates the capability of gathering instantly manufacturing data, for quick decision-making. Then the modularity and interoperability, which offer the elasticity in expanding or altering existed modules for further requirements and communication ability among heterogeneous systems separately. Furthermore, there is also the principle of virtualization and service-orientation. Virtualization refers to the capability of generating virtual copies of physical items for evaluation and improvements, while service-orientation offers the capability of transforming the functions of manufacturing processes as a set of services, which can be accessed and utilized by other applications and systems (Mohamed et al., 2019).

Since the term 'Industry 4.0' has been coined, this concept has increasingly drawn the attention of academics, enterprises, and governments across the world. Indeed, several official documents and national industrial policies have been drawn up to push the whole manufacturing industry towards this new direction. Examples are Industrie 4.0 by Germany, Impresa 4.0 by Italy, Made in China 2025 by China, and Smart Manufacturing by the US (Governo Italiano-Ministero dello Sviluppo Economico, 2016; Kagermann et al., 2013; The State Council, 2015). In fact, industrialized countries are moving towards the I4.0 paradigm to exploit it as a lever for manufacturing revival. Catching up the opportunity of transforming 'traditional' manufacturing through the 4.0 paradigm may represent an important benefit in terms of increased revenue flows, lower operational expenditures, and more sustainable health and safety conditions (Gilchrist, 2016). At the same time, emerging economies are starting to approach I4.0 to develop specific and practical action plans for accommodating this innovative change (Luthra and Mangla, 2018; Sung, 2018). Therefore, I4.0 is the seed of the forthcoming transformation of the manufacturing industry landscape, for both developed and emerging economies.

1.2 Industry 4.0 enabling technologies

The previous three industrial revolutions are characterized by the rapid development of technologies. To better understand what I4.0 stands for, it is indispensable to make a screening on what are the enabling technologies of I4.0, and what are their applications. Meanwhile, it is also important for companies to be aware of how technologies can impact their business. Actually, I4.0 is featured by digitization, optimization, and customization of production; automation and adaptation; human-machine interaction (HMI); value-added services and businesses, and automatic data exchange and communication (Lu, 2017; Roblek et al., 2016). Thus, I4.0 encompasses peculiar technologies that can lead to important technical and organizational improvements (Albers et al., 2016). These technologies can make possible vertical (Almada-Lobo, 2016) integration, horizontal integration, and end-to-end integration of engineering (Brettel, Friederichsen, et al., 2014; Kagermann et al., 2013). However, there is no agreed list of I4.0 enabling technologies in literature, and there are some inconsistencies among the different literature domains (Fettermann et al., 2018; Riel and Flatscher, 2017). Indeed, there is also disagreement in official governmental documents regarding the I4.0 policies and enabling technologies. In this dissertation, a list of I4.0 enabling technologies is summarized based on the principles of I4.0, and other relevant literature (Ghobakhloo, 2018; Gölzer and Fritzsche, 2017; Hofmann and Rüsch, 2017; Mourtzis, 2020; Mourtzis et al., 2014; Rüßmann et al., 2015; Sokolov et al., 2020), namely Cyber-Physical Systems (CPS), Internet of Things (IoT), Big data and Analytics (BDA), Cloud computing, Artificial Intelligence (AI), Blockchain, Simulation and Modelling, Augmented and Virtual Reality (AR & VR), Automation and Industrial robots and Additive Manufacturing, such list covers both the Operations technology (OT) and Information technology (IT).

1.3 Empirical studies of I4.0

Current literature mainly contains two streams of empirical studies on the I4.0 topic, which are I4.0 maturity model building and I4.0 targeted survey at the national/regional level.

Regarding the I4.0 maturity models, several studies have tried to measure I4.0 readiness from diverse dimensions. For example, two professional associations in Germany have proposed the I4.0 maturity model considering different aspects, Lichtblau et al., (2015) take into account strategy, smart products, and data-driven services as measurable scales, while Schuh et al., (2015) provide a maturity matrix, concerning the corporate structure, process, and development as dimensions. Moreover, Pirola et al., (2019) put their target to the Italian Small-Medium Enterprises (SMEs) and develop the digital readiness model with regards to the company's strategy, people, process, and technology integration. Santos and Martinho, (2019) put their focus on the perspectives of smart factory, smart products as well as smart services. We can observe that, in this stream, researches are making contributions to measure the company's digital maturity, emphasizing on different directions.

Due to historical, political, and geographical features, each country is also characterized by its manufacturing pattern. Literature has shown some empirical investigations of the implementation of I4.0 in different countries through survey approach. For example, Jäger et al., (2016) try to understand how much the enterprises from the Rhine-Neckar region in Germany are familiar with I4.0 principles. Basl, (2017) and Veza et al., (2016) investigate the readiness for implementing the main features of I4.0 in manufacturing companies in Czech Republic and Croatia respectively. Luthra and Mangla, (2018) evaluate how to exploit I4.0 as a lever to achieve supply chain sustainability in the Indian manufacturing industry. Moreover, Tortorella and Fettermann, (2018) focus on the Brazilian manufacturing context examining the relationship between lean production practices and the implementation of I4.0. Besides, Beier et al., (2017) compare China and Germany with a focus on the expected changes brought by I4.0. Tortorella, Rossini, et al., (2019) consider Italy and Brazilian companies as targets for the comparison of I4.0 and lean practices implementation.

In this dissertation, due to the available resources and accessibility, the research target is focused on Italian manufacturing companies.

1.4 Industry 4.0 and Logistics 4.0

Based on the descriptive survey of I4.0 state-of-the-art in the Italian manufacturing sector conducted in late 2017, it is found out that the production area is mostly impacted by I4.0, and the logistics area is also one of the most involved areas for I4.0 technology implementation. Moreover, based on the SLR, which was aimed to investigate the impacts of I4.0 in different processes in manufacturing companies, we figured out that production is still the most studied area, and logistics is less focused. However, the management of the logistics process plays a vital role in the success of manufacturing companies, since it constitutes a significant cost in operations, and represents the image of the company through delivering the right products at both the right time and the right price (Fawcett and Clinton, 1997). Therefore, an attempt has been given to build up the relation between I4.0 and logistics management. Indeed, a new term is spreading in the literature to indicate the application of I4.0 within logistic processes, that is the Logistics 4.0 (Log 4.0). Amr et al., (2019) summarize the evolution from Logistics 1.0 to Logistics 4.0, reaching a definition of Log 4.0 as “a strategic technological direction that integrates different types of technologies to increase both the efficiency and effectiveness of the supply chain, shifting the focus of the organization to value chains, maximizing the value delivered to the consumers as well as the customers by raising the levels of competitiveness.” Wang, (2016) defined Log 4.0 as a collective term for technologies and concepts of value chain organization. According to Strandhagen et al., (2017), Log 4.0 stands in a broader sense of I4.0, and the key logistics activities of transportation, inventory management, material handling, information flow are effected by Log 4.0. Timm and Lorig, (2015) view Log 4.0 as a system consisted of autonomous sub-systems and a transformation from hardware-oriented to software-oriented logistics. Moreover, Facchini et al., (2019) consider Log 4.0 as the specific application of I4.0 in the area of logistics. Furthermore, Winkelhaus and Grosse, (2020) define Log 4.0 as “The logistical system that enables the sustainable satisfaction of individualized customer demands without an increase in cost and supports the development in industry and trade using digital technologies." Therefore, Log 4.0 promotes the realization of networking, automation as well as decentralized control in the supply chain through the adoption of digital technologies (Wang, 2016; Winkelhaus and Grosse, 2020).

2. RESEARCH DESIGN

To guarantee the quality of research, a suitable and rigorous research design is necessary. Thus, in this section, research gaps, research objectives (RO), as well as research methodologies (RM) will be presented. A research framework is designed as a guide, which is shown in Figure 2.

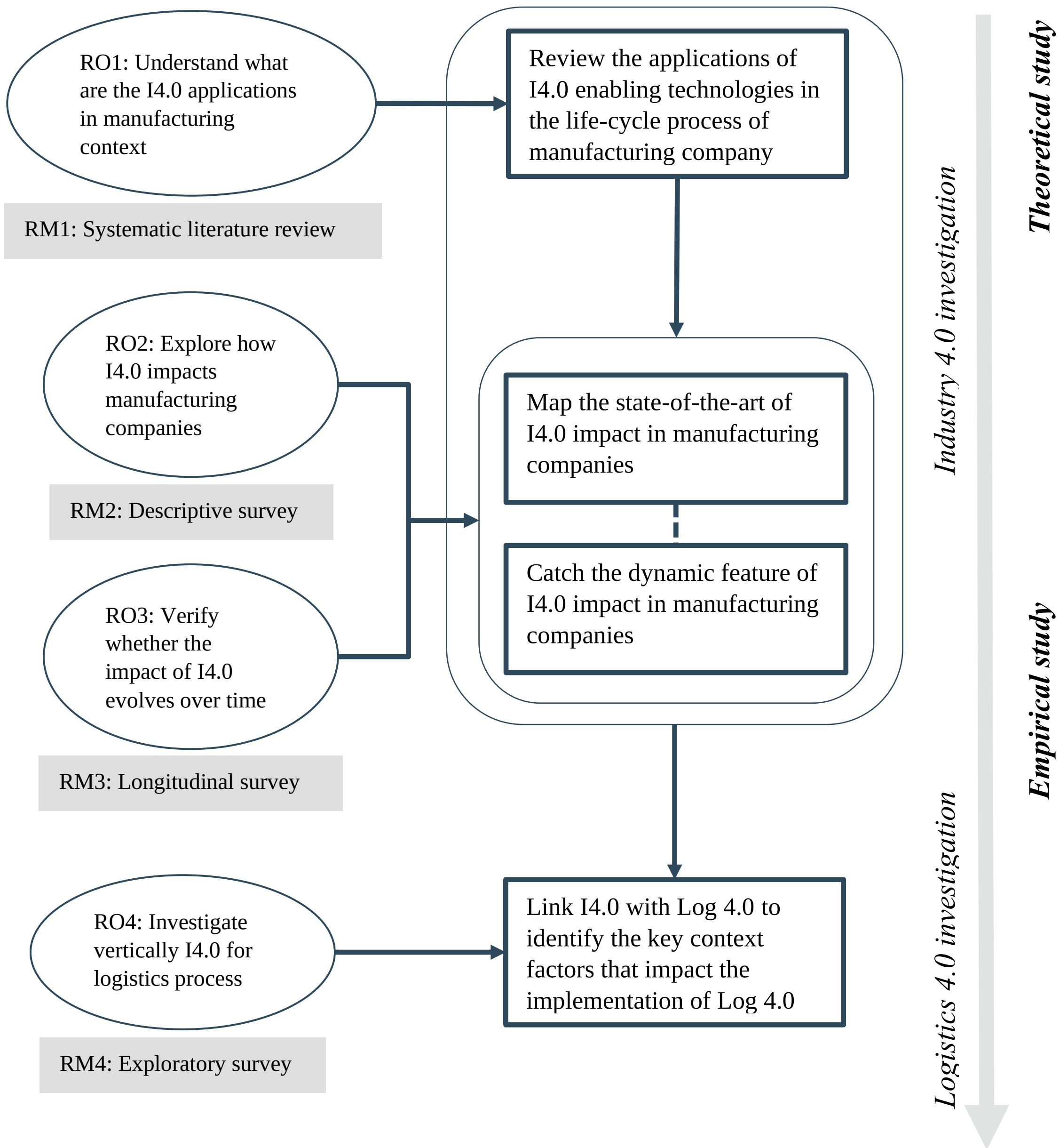

Figure 2. Research framework

2.1 Research gaps and questions

Industry 4.0 has undoubtedly attracted a lot of attention since its first proposal, not only for practitioners but also for academics. Meanwhile, technology advancement evolves constantly and rapidly. The requirement of customized products/services with high quality and fast delivery is becoming a doomed trend. As a matter of fact, companies are struggling with this challenging shift, and there is a demand for better comprehension of how companies can react to the I4.0 paradigm, how technologies can bring opportunities for them, and what kind of transitions should be made to embrace such transformation. For such reason, it becomes apparent, that the impact of I4.0 for manufacturing companies is worthy of further exploration.

GAP 1. Little attention to the cross-check of I4.0 enabling technologies and manufacturing company's life-cycle business process

The topic of industry 4.0 has been much debated in the literature and many of the published articles deal with the analysis of the single enabling technology and its technical function framework. Meanwhile, a lot of efforts are dedicated to the investigation of impacts of I4.0 technologies on a single specific business process of manufacturing company, while a comprehensive consideration of impact by I4.0 on both technical and managerial perspectives, as well as a holistic analysis of different processes of manufacturing companies, is missing (Piccarozzi et al., 2018; Schneider, 2018). Indeed, it is important to take a holistic analysis to map the relationship between I4.0 technologies and company's business processes, to provide companies with a clear vision on what are the use cases of I4.0, which process can be adopted, and how different technologies can be integrated for the optimal utilization. Hence, an attempt to narrow such a gap has been made by conducting a systematic literature review (SLR). Consequently, the following research question has been proposed, which is aimed to address the overall exposition of the I4.0 topic and introduces the convergence of I4.0 technologies and business processes of manufacturing companies:

- **RQ1: What are the applications of I4.0 enabling technologies on the processes of manufacturing companies?**

GAP 2. Limited empirical support to understand how I4.0 is impacting on manufacturing companies

After conducting the SLR, it is noticed that there are a few studies carried out to investigate the I4.0 phenomena from a national point of view empirically. The investigation on I4.0 readiness of Czech companies conducted by Basl (2017) proposed research questions such as how the companies are implementing the principles of I4.0, what are the motivating factors and impediments of applying I4.0 principles, and the existence of an appropriate strategy for I4.0. Tortorella and Fettermann (2018) raised the question of what the impact factors for I4.0 technology implementation are, intending to understand the connection between lean practices and I4.0 implementation in the Brazilian manufacturing sector. Besides, Jäger et al. (2016) put forward questions attempting to understand the I4.0 technologies' awareness and challenges faced by German SMEs. However, much less attention has been received by Italy, to investigate how Italian manufacturing companies are approaching the I4.0 paradigm. Moreover, since in Italy, the national initiative for Enterprise 4.0 (Governo Italiano-Ministero dello Sviluppo Economico, 2016) has been proposed in 2016, it is also of interest to understand how is the advancement of companies towards I4.0 transformation through a longitudinal study. Thus, to fill the gaps, descriptive survey research has been conducted in 2017 and 2019 separately, focusing on Italian manufacturing enterprises, aiming to have a deep overview on how the I4.0 paradigm is understood and diffused in Italian manufacturing companies, the main benefits achieved, the challenges faced, and the dynamic evolvement. Consequently, the second and third research questions are proposed, RQ2 is mainly aimed at mapping the state-of-the-art of I4.0 in the Italian manufacturing context, which is then composed by 5 sub questions. RQ3 is targeted to understand the dynamic change of state-of-the-art at different time slot through a two-wave longitudinal survey.

- **RQ2: How I4.0 is impacting on Italian manufacturing companies?**
    - RQ2.1: What is the company’s knowledge level of I4.0 enabling technologies?
    - RQ2.2: What is the company’s adoption level of I4.0 enabling technologies?
    - RQ2.3: Which are the business functions most impacted by I4.0 enabling technologies?
    - RQ2.4: Which are the most required roles for driving the I4.0 transformation?
    - RQ2.5: What are the main benefits and obstacles in adopting I4.0 enabling technologies?
- **RQ3: How is the progressing and advancement of the I4.0 impact in the Italian manufacturing context?**

GAP 3. Few empirical studies on how I4.0 impacts on logistics management in manufacturing companies

As depicted from the empirical state-of-the-art study in Italian manufacturing companies, logistics is one of the most impacted areas by I4.0 technologies, followed Production, Research and Development (R&D), and IT. However, there is a lack of empirical studies focusing on the evaluation of the effects of digital technologies on manufacturing logistics, which stands in a broader sense of I4.0, covering the key logistics activities of transportation, inventory management, material handling, and information flow, whose processes have a considerable impact in the cost structure of manufacturing companies (Strandhagen, Alfnes, et al., 2017). For this reason, it is relevant to investigate the Log 4.0 phenomena in manufacturing companies through an exploratory survey. The following research question is then proposed, which aims at describing and operationalizing the phenomenon of Logistics 4.0:

- **RQ4: How the Italian manufacturing companies are approaching I4.0 to support their logistics processes?**
    - RQ4.1: How manufacturing companies are aware of the Log 4.0 and which actions have been taken (or planned for the next future)?
    - RQ4.2: What are the main benefits and challenges perceived/measured by companies in adopting Log 4.0 solutions?
    - RQ4.3: What are the key factors that impact the adoption of Log 4.0 enabling technologies?

2.2 Research methodology

RM1. Systematic literature review

To address the RQ1, an investigation of academic publications has been undertaken, following the process of Systematic Literature Review (SLR). Indeed, SLR allows summarizing existing knowledge as well as evaluating available research works to a particular phenomenon to fill research gaps and strengthen the field of study (Petticrew and Roberts, 2006).

To clarify the paper selection purpose, a conceptual framework is proposed to guide the review process, where on the x-axis are the ten I4.0 enabling technologies, containing CPS, IoT, BDA, Cloud computing, AI, Blockchain, Simulation and Modelling, Visualization Technology, Automation, and Industrial robot and AM, while on the y-axis are the 10 business processes of manufacturing companies, containing new product development, supply chain configuration, integrated supply chain planning, internal logistics, production scheduling, and control, energy management, quality management, maintenance management, customer relationship management, and after-sales management.

To guarantee the rigor and generalizability, a structured selection process has been conducted and structured criteria have been utilized to include related papers and exclude unrelated ones. The management of the literature review process has been managed through Excel and Mendeley. To build the initial database, it has been started by searching the term “Industry 4.0” and its derivatives as the keyword in article title, abstract, keywords in Scopus and Web of Science (WoS) databases, which are the most referred scientific databases.

Indeed, in addition to “Industry 4.0”, other similar terminologies have already existed, e.g. “Smart manufacturing”, “Smart factory”, “Factory of the Future”. However, the term “Industry 4.0” and its derivatives are chosen as the keyword, because this concept has been diffused for many years and acknowledged by worldwide industrial and academic communities. The data source creation phase brought to 14784 papers, 9447 from Scopus, and 5337 from WoS. The data source is updated at the end of December 2019.

The selection of final papers for comprehensive analysis is mainly composed of three phases. The first phase uses the criteria from Scopus and WoS databases, including the paper language, document type, subject area. Then, after exporting selected papers from two databases, the exported articles are integrated, and duplications are then eliminated. Then the second phase is mainly to read the title and abstract of each article, excluding those not in scope, and those do not mention manufacturing. Then in the third phase, full paper reading is done, excluding those who investigate the I4.0 phenomenon in general, those who focus only on single technology without referring to applications, and those who have not related to any manufacturing business process. Finally, 186 papers have been considered to be suitable for a comprehensive literature review.

RM2. Descriptive survey

Descriptive survey research is to address the RQ2. Since survey research has been adopted to obtain information about large populations with a known level of accuracy (Rea and Parker, 1992; Rossi et al., 2013), and because limited empirical investigation on I4.0 impacts on manufacturing companies, and in particular in the Italian context, descriptive survey research has been adopted. Normally, different types of survey are distinguished, among which exploratory, confirmatory (theory-testing), and descriptive survey research (Filippini, 1997; Pinsonneault and Kraemer, 1993). The approach adopted in this study is the descriptive survey research since the aim is to understand the relevance of a phenomenon and describe its incidence in a population (Dubin, 1978; Malhotra and Grover, 1998; Wacker, 1998). Indeed, a descriptive survey is a suitable method when knowledge of a phenomenon is not too underdeveloped, the variables and the context can be described in detail and the objective is to understand to what extent a given relation is present. Therefore, the primary research objective is not theory development, but rather the investigation of the impacts of the I4.0 paradigm in the Italian manufacturing sector, by describing the knowledge levels, the achieved benefits and challenges, as well as the involvement of business functions in I4.0 transformation.

Firstly, a questionnaire has been designed to realize the objective. The questionnaire is structured in 8 sections. The first section is aimed at collecting general information about the company and the respondents. In the second section, the company strategy towards I4.0 is asked. In the third section, a series of questions regarding the role of IT and the current information system in the company have been projected. In the fourth section, questions regarding the role of HR and staff competencies are asked. Lastly, a section investigating six I4.0 enabling technologies is projected, aiming at evaluating the company's knowledge, relevance, adoption as well as related benefits and obstacles for each I4.0 enabling technology. The structure of the survey was modular since respondents can skip the module when he has no correspondent competences for filling it.

A web survey has been administered for conducting this research, since in respect to face-to-face and e-mail surveys, web surveys do not require responses to be manually transferred into a database, the cost is minimal with respect to other means of distribution and much more anonymity is guaranteed, helping in preventing interviewer biases (Dillman, 2007).

Concerning the survey sample, the unit of analysis in this survey refers to the Italian manufacturing enterprises and Italian sites of multinational corporations. Moreover, this research involves all types of companies, with no limits concerning their size (small-, medium- and large-sized companies are considered) and industry sector. The respondents were selected by several sources: the most relevant is the Italian database AIDA ('Italian company information and business intelligence' database), which collects the detailed accounts of about one million companies in Italy. Therefore, a sample of 956 companies was selected for this study.

After the projection of the questionnaire, a pilot testing was carried out, with firstly tested among researchers from the University of Brescia for checking grammatic and logical errors, and then tested by sending it to 3 potential respondents for checking readiness and clearance. with the aim of testing and possibly improving survey design and question-wording, as well as highlighting possible question biases (Forza, 2002).
In total, information of 103 manufacturing companies were collected with a response rate of about 11 percent. Overall, a sufficient heterogeneous classification has been achieved, since more than 50 percent of the sample is represented by SMEs, and the others are large and very large companies. Moreover, different manufacturing sectors have been included. Machinery, Metal product, and Electrical equipment are the top three sectors included. Regarding the respondent roles, Chief information officers (CIO) filled in the 37 percent of the questionnaires, followed by R&D Directors who provided 19 percent of the responses. Production and Operations Managers

represent the 18 percent of surveyed people, whereas, in 14 percent of cases, they were the General Managers to answer. The remaining 12 percent is related to other functions and roles.

RM3. Longitudinal survey

To address RQ3, which is designed to catch up with the evolvement feature of I4.0 impact in the Italian manufacturing companies, a two-wave longitudinal survey is then designed and conducted. With respect to the cross-sectional survey, the longitudinal survey has distinct analytical advantages, such as the analysis of gross change, as well as catching up with time-related characteristics of events or circumstances (Lynn, 2009).

As mentioned in RM2, the survey is targeted at all types of manufacturing companies with all sizes and sectors, with sample sources from the Italian database AIDA ('Italian company information and business intelligence' database). A static population based on the population at the time the first wave sample is selected, which implies that the second wave survey has the same population with respect to the first one. In this context, although there is a risk that some "birth" and "death" are ignored from the population, such determination considers the fact that there is a high industry engagement threshold for manufacturing companies and the availability of resources for conducting the survey. Moreover, a repeated-panel sample design is chosen, which guarantees the equivalent population of two waves, with two panels that may or may not overlap in time. Indeed, to obtain the optimal data collection period, the survey was launched at two-time slot, which is separately in the first semester in 2017 and 2019, such interval between waves is selected, because the Italian national initiative of Impresa 4.0 (Governo Italiano-Ministero dello Sviluppo Economico, 2016) was initiated in the late of 2016, the first survey was to generally to map the picture of how Italian manufacturing companies are aware of I4.0, and the second wave survey is launched after two years, which is a reasonable slot to capture the evolvement feature of I4.0 impact. Furthermore, to retain the ability to contact sample members at each wave, an administrative contacting system is regularly maintained and updated for tracking and tracing of contact details of close friends and the relationship of sample members (Lynn, 2009). Meanwhile, two panels share the same data collection methods, whereby the self-completion web-survey is administered. Then the follow-up telephone recall is conducted with the help of master thesis student, in order to reduce the non-response rate.

Overall, in the first-panel survey, a number of 103 responses have been considered as validated responses. The second-panel survey was carried out in the first six months of 2019, 102 validated responses are taken into consideration, among which, 40 companies have participated the survey both in 2017 and 2019.

RM4. Exploratory survey

To address RQ4, which aims to explore Log 4.0 in the manufacturing companies, an exploratory survey is designed to fill the gap. Literature shows few examples of investigating Log 4.0 phenomena. As proof of this, the topic of Log 4.0 is at an early stage of the investigation, thus we aim to provide preliminary insights on this domain, to collect evidence of the state-of-the-art of Italian manufacturing companies regarding Log 4.0, as well as to explore some relevant impact factors which can facilitate the Log 4.0 solution implementation.

The questionnaire is structured in 4 sections. The first section is aimed at collecting general information of the company. The second section asks about the supporting infrastructure and instrument for logistics activities. The third section inquiries about the company's perception of Log 4.0. Then the fourth section investigates six Log 4.0 enabling technologies, namely: Internet of Things (IoT), Big data and Analytics (BDA), Augmented Reality (AR), Collaborative Robotics, Automated Guided Vehicles (AGV), and Additive Manufacturing (AM).

Similarly, a web survey technique has been adopted for questionnaire distribution and data collection, then telephone recall is also organized with the support of a master thesis student to increase the response rate. As a result, a sample of 91 companies was surveyed for this study, where around 60% of the sample is represented by SMEs, while large companies belong to the other 40%. Moreover, 40% of respondents are logistics & supply chain managers, followed by production managers for around 21%, and top management for around 18%, who constitute approximately 80% of the surveyed sample.

3. SUMMARY OF RESULTS

This research project consists of four pieces of research that contribute to the overall goal of understanding I4.0 and Log 4.0, their enabling technologies, and how Italian manufacturing companies are involved in such a journey for the transformation of their organizations. Contribution A lays out the theoretical perspective, harmonizes the existing knowledge of I4.0 with its concept, principles, enablers, as well as the use cases in manufacturing companies; contribution B delineates the impact of the I4.0 paradigm in Italian manufacturing companies, describing the company's knowledge and adoption mode with regards to I4.0 technologies, as well as their perceived benefits and obstacles; contribution C makes a further step for a dynamic state-of-the-art comparison, with empirical analysis for I4.0 impacts in Italian manufacturing companies at two-time slots, one in 2017 and one in 2019, trying to depict the evolvement feature of I4.0 impacts; then contribution D tries to bridge I4.0 with logistics, providing detailed insights on how I4.0 effects on logistics area through an exploratory survey. In the following section, a more detailed illustration of results and discussions will be shown for each contribution.

3.1 The applications of the Industry 4.0 technologies in manufacturing context: a systematic literature review

Refer to RQ1, a systematic literature review is conducted, aiming at providing a holistic review of the main applications of Industry 4.0 enabling technologies for manufacturing companies. Indeed, 10 enabling technologies and 10 processes have been investigated and cross-checked. I4.0 enabling technologies included are Cyber-Physical Systems (CPS), Internet of Things (IoT), Big data and Analytics (BDA), Cloud technology, Artificial Intelligence (AI), Blockchain, Simulation and Modelling, Visualization technology, Industrial and Automation Robots, and Additive Manufacturing. Investigated processes are new product development, supply chain configuration, integrated supply chain planning, internal logistics, production scheduling and control, maintenance management, quality management, energy management, customer relationship management, and after-sales management. To be clarified, the results shown below are mainly taken from the paper published at International Journal of Production Research in October 2020.

From technology perspective, the results show that current literature focuses more on technologies like IoT, BDA, and Cloud technology, which reflects that scholars are putting efforts to find data-driven solutions for I4.0 implementation. While other technologies such as Blockchain, Industrial and Automation Robots are less studied. Concerning processes, production scheduling and control is ranked as the most investigated process and then followed by maintenance management. This result is not difficult to foresee, since the orientation of I4.0 is the production area, where efficiencies of production can be increased thanks to the utilization of I4.0 technologies. Besides, integrated supply chain planning ranks in the third place, which implies that planning issues have also been concentrated by scholars. Moreover, quality management, energy management have received much less attention, which is both within production and operations management domain among others.

Another finding is that there is an integrated mode of technology adoption. For example, IoT, BDA, and Cloud appear normally simultaneously, and their applications cover a wide range of processes. Since the main role of IoT is to connect various assets within and outside companies, the role of Cloud is to provide scalable data storage and computation capabilities, and the role of BDA is that of managing a large volume of data and retrieving useful information, the coupling of these technologies can maximally take advantage of collected data, and get useful information for decision-making. Moreover, technologies like AI, Industrial and Automation robot, and AM are usually coupled with one of the technologies mentioned above. Indeed, AI is usually applied in planning and process automation issues, while AM is more utilized in the product-related area. Besides, the use of Simulation and Modelling is mainly related to the decision-making process, since one of the principles of I4.0 is virtualization, and the research on virtualizing physical object for digital twin creation is exactly aiming to solve the problem of monitoring and evaluating process status for decision-making in the virtual environment, then for the coordination of physical environment.

3.2 The impacts of Industry 4.0: A descriptive survey in the Italian manufacturing sector

Refer to RQ2, a descriptive survey is conducted and results of a total of 103 respondents have been scrutinized. In this study, six I4.0 enabling technologies are considered, which are Industrial Internet of Things (IIoT), Big data and advanced analytics, Cloud Manufacturing (CMfg), Virtual and Augmented reality (VR & AR), Collaborative Robotics and Additive Manufacturing (AM). The knowledge and utilization level of these six technologies have been investigated, as well as corresponded benefits and obstacles. Moreover, the involvement of business functions and the required roles for the I4.0 transformation have also been researched. To be clarified, the following results are mainly taken from the paper published in the Journal of Manufacturing Technology Management in November 2019.

Concerning the company’s knowledge level towards I4.0 enabling technology, it reveals that the Italian manufacturing companies are characterized by very limited knowledge. Indeed, among the six technologies, only IIoT is known by more than half of the surveyed sample. In the meanwhile, Collaborative robotics and CMfg are much less aware of companies. The explanation of such low knowledge and utilization level could be that the management of complex technology calls for a structured approach for the management, and since the Italian national initiatives for Impresa 4.0 (Governo Italiano-Ministero dello Sviluppo Economico, 2016) is proposed in late 2016, and the survey was conducted in the first six months in 2017, companies are not completely aware of the characteristics and principles of I4.0. A similar finding is also adapted to the technology utilization level, which demonstrates a very low adoption level.

Moreover, the study indicates that larger companies tend to be more prepared than SMEs concerning the knowledge and utilization of I4.0 technology, such finding is explainable since SMEs usually have limited financial resources for new technology investment. Indeed, in the work of (Greve, 2008; Peslak, 2012), they have separately demonstrated that company size is related to the development of innovation-related activities and critical IT adoption issues, although the focus is not on digital technology adoption, it implies that a lack of resources for SMEs with respect to large companies. Besides, the survey result shows that companies with higher IT maturity, which indicates the adoption of informatization system, such as Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), Advanced Production Scheduling (APS), Product Lifecycle Management (PLM), Warehouse Management System (WMS), Business Intelligence (BI), Computer-Aided Design/Manufacturing (CAD/CAM), Manufacturing Execution System (MES), pretend to be better performed regarding I4.0 technology knowledge and utilization.

About the involvement of business functions for I4.0 technology adoption, it is found that Research and Development (R&D), Production, IT, and Top management seem to be the most involved business functions. The explanation of the high involvement of these business functions can be the following. For R&D, it's the function that goes normally at the frontier of novel technology exploration within the company. As for production, it is the business function where most of the technologies can be implemented. Besides, since IT has the role of collecting and sharing information for different departments of the company, and facilitates the new IT-related technologies, it is not surprising to see the high involvement of this function.

Finally, obstacles and benefits have been investigated. To be clarified, the investigated benefits include Time reduction, Cost reduction, Quality improvement, and Flexibility improvement. The investigated obstacles include High investment for technology, Missing of competencies, Immaturity of technology, and Absence of technology provider. The survey shows that companies who have already implemented at least one technology, perceive overall higher benefits than those who have not yet implemented any technology. Thus, it seems that the advantages of the adoption of I4.0 technologies are underrated before being applied. In parallel, the same goes for the obstacles. If comparing companies with no technologies implemented to companies with medium and high technology implementation levels, the former state to be less concerned about potential barriers, which may only come to light when the technologies are used.

3.3 Progressing and advancement of Industry 4.0 in the Italian manufacturing context: a dynamic state-of-the-art

Refer to RQ3, a survey conducted in two-time slots have been compared, the conduction time was separately in 2017 and 2019. The idea of such an analysis is to understand whether companies are more involved in the I4.0 journey, and what are the changes in a two-year period. To be clarified, the comparison result is based on the analysis taken from the paper presented at the XXV summer school of Francesco Turco in Industrial Systems Engineering. To be clarified, a journal version paper is work-in-progress, and it is expected to be submitted to Journal of Manufacturing Technology Management by the end of November 2020.

The comparison analysis is made from the perspectives of I4.0 technology knowledge distribution, utilization distribution, performance impacts, and obstacles. It is found out that the percentage of companies who have no knowledge and superficial knowledge has been both increased by 2% and 12% separately in 2019. Meanwhile, the percentage of companies that have medium and high knowledge has decreased in 2019. Overall, the proportion of companies who hold at least superficial knowledge remains almost the same in 2019 compared to in 2017. Moreover, it is noticed that there is an increasing trend of technology utilization in 2019, companies who implement more than three technologies has reached almost 10% of the total sample in 2019, meantime, companies who have no technology implementation has decreased by 12%. Moreover, the proportion of companies who have adopted at least one technology has surpassed half of the sample in 2019, while in 2017 this ratio is only 45%. When looking at the utilization distribution together with knowledge distribution, we may notice that although the company's knowledge level in 2019 is smoothly lower than that in 2017, the utilization level is alternatively higher. A reasonable explanation could be that in 2017, even if the companies have higher knowledge level, they were also facing high investment in technology and immature technology as barriers to further implementation, and indeed, these two factors are perceived higher in 2017 than those in 2019. Therefore, companies in 2017 take more action on economical and feasibility analysis of I4.0 solutions instead of putting into practice.

Regarding benefits, we observed that there is a relevant alteration for cost reduction, where companies in 2017 perceived it as one of the biggest benefits by I4.0, instead in 2019, it falls to the last place. Flexibility improvement is also demonstrated to lightly fall in 2019. On the contrary, Time reduction increases its position in 2019. The explanation of the above changes could be that since in 2019, the utilization level of technologies is generally increased compared to 2017, so even though the cost reduction brought by I4.0 implementation is reflected in process efficiency improvement, companies have still perceived the investment pressure on corresponded technologies. Comparing obstacles faced by companies in 2017 and 2019. It is found out that apparent reverse happens for High investment for technology, Missing of competencies, and Immaturity of technology. High investment for technology and immature technology is considered as smaller obstacles by companies in 2019 than in 2017, while Missing competency is perceived as the biggest barrier in 2019. Such transpose is predictable, since the more companies involved in implementing I4.0 technological solutions, companies require more technical and managerial competencies to manage such transformation. Moreover, as it has passed two years, companies are more familiar with the I4.0 national initiatives launched by the Italian government, and they may take the advantage of investment reimbursement, thus less investment barrier is perceived.

3.4 The impacts of Logistics 4.0 on Italian manufacturing companies: an exploratory survey

Refer to RQ4, an exploratory survey is conducted, trying to map the Log 4.0 state-of-the-art in the Italian manufacturing companies empirically, particularly from the perspectives from the awareness and the adoption of Log 4.0 enabling technologies, benefits, and obstacles the companies are facing up with, as well as the critical factors that impact the knowledge and adoption level. The results shown below are mainly taken from the paper published at the 27th EurOMA conference. To be clarified, a journal version paper submitted to the International Journal of Logistics Research and Applications is now under the 2nd round revision.

In this study, six technologies are selected for investigation, such as Internet of Things (IoT), Big data and Analytics (BDA), Augmented Reality (AR), Collaborative Robotics, Automated Guided Vehicles (AGV), and Additive Manufacturing (AM). Overall, the study shows that the Italian manufacturing companies have narrow knowledge of Log 4.0 enabling technologies, and the adoption of technologies is limited. However, IoT is demonstrated to be better known and applied by companies. Moreover, companies are found to have higher awareness and implementation level for Operation Technology (OT), such as the Collaborative Robotics and AGV, and less for Information Technology (IT). The explanation can be twofold: from one side, since there is a portion of companies who have adopted automation systems for logistics operations, they tend to be more familiar with the management and utilization of automated robots; from the other side, as the IT cluster adoption usually requires profound business and infrastructure transformation, it may require companies to put more time and investment for implementation. Indeed, this result is aligned with the findings from benefits and obstacles analysis, where companies state that they consider “High investment for technology” and “Missing digital competencies” as the biggest barriers for Log 4.0 technology adoption. Besides, companies perceive “Warehouse productivity improvement”, “Warehouse process cost reduction” and “Picking error reduction” as the biggest benefits brought by Log 4.0 enabling technology, which also confirms the fact that companies adopt more Log 4.0 solutions for Warehouse operations, and these solutions are mainly OT related. Another finding regarding the critical factors for Log 4.0 enabling technologies adoption reflects that companies who have already implemented automated warehouse system, and companies who have started staff training initiatives, tend to have higher Log 4.0 technology adoption level. Meanwhile, in this study, no relevant relationships are found between the size of companies and the technology adoption level.

4. DISCUSSION

4.1 Theoretical implication

In this research project, the phenomenon of I4.0 and Log 4.0 are explored. Four sections of contributions have been made to explain the theoretic bases of the topic, underlying the existed theory, and empirically study the phenomenon. The overall objective of this research is to add value to the body of knowledge regarding I4.0 and Log 4.0 topic, as well as to provide insights for practitioners for better understanding of the state-of-the-art and tackling practical challenges in the field of digital transformation under I4.0 context.

The first contribution is the systematic literature review of the I4.0 impact on manufacturing company's processes. This work is conducted by summarizing the use cases of I4.0 enabling technologies across the entire process cycle of manufacturing companies, from Product development to After-sales management. Although the goal of this study is ambitious, the idea behind is simple and relevant, which is to provide a comprehensive analysis of the applications of I4.0 technologies in manufacturing companies through reviewing existed literature, the detailed use cases can be referred to the contribution A in part II. Moreover, the contribution also figures out some typical integrative working mode of I4.0 technology. Then a research agenda is also arisen from the systematic literature review, suggesting that more industrial use cases should be conducted to test the effectiveness and benefits of adopting I4.0 solutions in real cases, more integral applications of I4.0 technologies worth further research to dig the huge value of data-driven solution. Besides, a more empirical study needs to be conducted, for showing evidence from the field why and how to use I4.0 for different types of companies. And more research focus should be put extending from production area to entire supply chain management, especially for circular supply chain and customer-centricity.

Based on the systematic literature review, a survey research approach is chosen for exploring the phenomenon of I4.0 empirically. In particular, it tries to close the research gap by mapping the company's knowledge and utilization level of companies of I4.0 enabling technologies, the benefits and obstacles companies have perceived, or faced up with, as well as the organizational readiness towards I4.0 transformation. This study is one of the first attempts in describing I4.0 state-of-the-art empirically in the Italian manufacturing context. It shows which technology is more acknowledged by companies, and which factors could impact the usage of I4.0 solutions. Some practical insights are also provided to help companies in understanding how to prioritize their actions towards such digital transformation. Indeed, to explore the progressing state of I4.0, a comparison of I4.0 impact on Italian manufacturing companies in 2017 and 2019 is analysed, which demonstrates some interesting insights. For example, more companies have started to adopt

I4.0 technologies, and they perceive more benefits brought by I4.0 technologies for time reduction, they require more competencies for management and use of technologies. Indeed, under the global smart economy context, the requirement of less lead time, and more competencies to manage complex systems becomes essential. Given the fact that the rapid rate of change and the influence of technology, companies need to settle their strategic plan for technological development and human resources development, to cope and thrive in this changing environment.

Finally, this research project tries to build the bridge between I4.0 and the logistics process, by investigating Log 4.0 in Italian manufacturing companies through an exploratory survey. In fact, the existing literature focuses more on the conceptual analysis of this phenomenon, and this study makes a pioneer attempt in understanding how companies are aware of Log 4.0, and what kind of context variables may be related to the adoption of Log 4.0 technology solutions. Indeed, this study concerns the adoption of L4.0 that is not yet adequately mature with respect to the theoretical developments found in the scientific literature. Contributions on Log 4.0 are increasingly popular in scientific literature as a natural element of the established I4.0 paradigm. However, there is a strong disparity between the two concepts of definition and practical implementation. In fact, in term of I4.0, the implementation of digital technology in production processes is much more mature with respect to the implementation in logistics process. And in order to achieve an adequate level of maturity, it needs to engage not just operational logistics processes, but extends to the entire supply chain, from demand forecasting to last-mile distribution, as well as scaling organically to the tactical and, above all, strategic processes more closely. The goal that scientific literature must pursue is to build an integrated framework that takes into consideration both production and logistical processes, favouring the full integration of all the structures and entities existing not only within the boundaries of the individual company, but at the level of the entire supply chain.

4.2 Practical implication

Firstly, the work of SLR does not only contributes theoretically to existent knowledge on I4.0 technologies applications in the manufacturing context, it also provides important practical implications for companies. The results of this work shed light on which are the most suitable areas in the manufacturing context that I4.0 solutions could be applied. Very often, the issue of I4.0 remains on an abstract level and it is very difficult for practitioners to understand exactly how to exploit this new revolution concretely. This research thereby provides insights for manufacturing companies to better understand and evaluate which are the best strategic choices to adopt and the possible repercussions. Indeed, for each business process, a table summarizing the use cases of I4.0 enabling technologies is associated, the company can refer to it as a guideline for their I4.0 solution selection and evaluation. Moreover, through a holistic review of I4.0 technologies and processes, companies can further have an outlook of what are the priorities of their optimization direction, since several technologies such as CPS, IoT, Cloud, and BDA are often operationalized simultaneously, and requires a structural transformation of data collection and processing systems. While other technologies such as AM, Collaborative Robotics can be adopted in the vertical process, such as production or prototyping, which may demand less change with respect to organizational structure. Thus, companies can choose their strategy on the adoption of one or several technologies at vertical or broad ranges of processes.

Second, regarding the empirical survey in the Italian manufacturing context, it demonstrates that manufacturing companies have generally limited knowledge and utilization of I4.0 enabling technologies. In this regard, large companies tend to be better prepared than small ones. Therefore, as regards adopting the I4.0 paradigm, the company size is an important matter. As SMEs usually have limited resources, they may not have enough capital for new technologies investment. However, it is also discovered that some SMEs are behaving as pioneers in the I4.0 transformation, who has a strong commitment to the company's top management. Indeed, I4.0 transformation requires appropriate integration of both pre-existing and new systems and infrastructure. In this regard, not all organizations have adequate IT maturity to embrace I4.0 (Leyh et al., 2017). It also reveals that IT function, R&D, and Production functions are actively involved in the utilization of I4.0 enabling technologies. Conversely, the HR function is much less involved. Nevertheless, since the HR function plays the fundamental role of selecting and recruiting people, and the I4.0 manufacturing environment calls for high-skilled managerial and technical labour with expertise in new materials, machines, and technologies (Grzybowska and Łupicka, 2017), it is of high importance that companies should attach importance to HR. As regards the benefits and obstacles in adopting the I4.0 enabling technologies, the survey results show that perceived benefits for companies that have already implemented at least one technology are overall higher than the benefits expected for those that have not yet implemented any technology. Thus, it seems that the advantages of the adoption of I4.0 technologies are underrated before being applied. In addition, the higher the number of technologies implemented, the higher the perceived benefits. In response to the SLR, I4.0 could bring great value for companies not only for the production area, but also for the supply chain, and generate new business models (Müller, 2019).

Third, the comparison between 2019 and 2017 demonstrate that companies are implementing more I4.0 technological solutions, meantime, they perceive more benefits regarding Lead time reduction and Product/service quality improvement, which implies that in the first stage of I4.0 practice, companies are capitalizing more on process improvement, while with the process maturity increases, they seek for generating new business model, which requires higher quality and service improvement. Moreover, the survey results show that they face more difficulties in finding adequate competencies in managing digital transformation. In fact, high-skilled managerial and technological workforce are of high relevance as mentioned previously. Companies should evaluate their workforce, plan proper qualifications, and update technical and managerial competencies of their workforce, to flexibly adapt the changing context.

Finally, the results of the exploratory survey of Log 4.0 provide numerous insights that can be very useful for practitioners operating in the logistics area of manufacturing companies. First of all, the result did not show any association between company size and Log 4.0 technology adoption level, which implies that the digitalization of logistics processes is currently possible by all companies regardless of size. This is an important issue since it underlines that there is no particular barrier to entry from a company size point of view. Besides, the benefits perceived by companies of adopting Log 4.0 technologies are often higher than expected, which demonstrates that companies who have already adopted at least one enabling technology, generally declare themselves to be well satisfied with the results pursued. In this regard, attention must be paid to obstacles which must be properly weighted. In fact, one of the main barriers that can undermine the success of a digitalization strategy in logistics is the risk of not being able to link new technologies with the existed infrastructures within the company. To overcome this constraint, it is therefore important to develop an integration strategy plan allowing to effectively blend the "old" with the "new", as well as offer proper training for its staff. In this way, it is possible to implement Log 4.0 successfully.

4.3 Limitations and future directions

The research area of Industry 4.0 is very broad and due to its top-priority nature and practical relevance, there is a fertile field for further research. Given the novelty of the phenomenon and the early stage of extant research, this research project has limitations that should be addressed in future research.

First, even though a rigorous step-by-step systematic literature review approach has been adopted for analysing the I4.0 topic, it still contains some limitations. This study is focused on academic peer-reviewed journal articles written only in English. The fact that papers in other languages, as well as other types of publications, such as conference papers might have circumscribed the findings. In addition to that, due to the keyword-based search method applied to the publications, it is possible that some papers related to the research focus, but which contained different keywords, were excluded. Moreover, having selected papers from only two databases, Scopus and Web of Science, albeit heavily populated, may have omitted a fraction of the literature. However, some of the immediate opportunities for future work are rooted in the limitations of this study. Since a comprehensive insight of how I4.0 technologies are impacting on life cycle processes of manufacturing companies, deeper analysis regarding what types of benefits and challenges of each use cases can be conducted, which would complement the findings, and lead to better practical suggestions for companies who are evaluating their selection of I4.0 solutions. Similarly, it would be immensely valuable to bring together researchers to debate and refine the understanding of the major research themes, since I4.0 is a huge research area, one systematic literature review cannot and would not cover all the areas, indeed, from the literature, we observed that recent publications not only focus on technological aspects of I4.0 but also on the managerial business model triggered by I4.0, such as the servitization and sharing economy. Thus, bringing academics from different domains to discuss future directions is highly valuable.

Second, our survey is targeted at the Italian manufacturing context, but no specific investigation has been designed for SMEs. Although we figured out that most of the SMEs are struggled in facing with I4.0 transformation, and meanwhile, the Italian manufacturing context is characterized by a high percentage of SMEs, where about 99% of companies are SMEs (EC, 2020), as a matter of fact, the results reported in this study tend to be more positive than the real situation. Another limitation is that despite the complete review conducted, no reference model and framework are proposed. A first attempt on providing a set of managerial roles for the I4.0 paradigm has been taken, but it still requires a more comprehensive and systematic approach in terms of theoretical guidelines, which can be used to support Italian manufacturing enterprises speeding up their I4.0 transformation. Another limitation is that, due to the limited sample number in this study, further sampling is required for generating more reliable theories. In addition, making significant comparisons with other countries, both industrialized and emerging economies, could provide a more robust understanding of the overall context (Kull et al., 2014). Future research should focus on developing case studies about pilot I4.0 practitioners to capture the root cause of successful cases. Both managerial and practical references should be developed, helping Italian manufacturing enterprises to consolidate and strengthen their position in the global competitive market. Indeed, such a study can be further compared with the result of a systematic literature review, which can illustrate the difference between theory and practice. Indeed, this attempt is undergoing, the case protocol is under projection, and studies will be done in the next months, possibly extending the Ph.D program period. Indeed, further case research will link I4.0 and Log 4.0 and provide a comprehensive understanding of what are the driving forces for a manufacturing company in moving towards 4.0 scenario.

5. CONCLUSION

This section is dedicated to making a summary of the efforts contributed to this dissertation. To this end, this section 1) revisits the research questions and objectives; 2) integrates the respective findings with research gaps; 3) assesses the value of the key findings in the light of existing literature; and finally, 4) synthesis new contributions to knowledge.

I4.0 is critical to the business of manufacturing companies and provides a range of new opportunities. Nevertheless, understanding the principles of I4.0, and initiating effective transformation towards I4.0 is not only a technological remoulding but also a complex and non–routine managerial mission. Therefore, the objective of this dissertation is to explore the I4.0 phenomenon by reviewing I4.0 applications in manufacturing companies through SLR, mapping empirically state-of-the-art of I4.0 impact in Italian manufacturing companies, and linking I4.0 with logistics area, exploring the Log 4.0 phenomenon in manufacturing companies, aiming at creating value for academia by adding to the body of knowledge in the field of I4.0, as well as for practitioners by offering systematic summaries of how I4.0 can be applied in companies, and providing inspirations to help them better tackle practical challenges. The following sets of research questions are strengthened again to reach the previously defined objectives and summarize the contributions of this dissertation.

RQ1: What are the applications of I4.0 enabling technologies on the processes of manufacturing companies?

In contribution A, based on an original framework developed, it provides a holistic and synthesized summarize of what are the application cases of I4.0 enabling technologies in the life-cycle business process of manufacturing company through a systematic literature review, analysing a total of 186 articles. This research harmonizes the existing knowledge, conceptualizing, and providing insights on what are the connections between technologies, how they can be applied vertically or cooperatively in different business processes, The results of this research show that, considering both technologies and processes, there are areas that have received more attention in the scientific literature. In particular, the utilization of CPS, IoT, BDA and Cloud is common for facilitating data-driven decision-making process, while the use of Industrial automation and robotics and AM is more vertically applied to specific business process. Indeed, the results of this research highlighted certain gaps in the literature on I4.0 that led to the identification of four recommended directions for future research, such as the wider range of impact by I4.0 in servitization and customer centricity, and extending horizontally from smart factory to smart supply chain. This study can be also helpful for practitioners, since it provides a summary for each single business process the catalogue of I4.0 technologies use cases, offering manufacturing companies the potentialities of selecting and evaluating their process and business features for the implementation of I4.0 solutions. Future research ought to place more effort in connecting each use case with its benefit and obstacles, thus combining richer information to facilitate companies in building up appropriate decisions of I4.0 implementation.

RQ2: How I4.0 is impacting on Italian manufacturing companies?

Despite that contribution A makes efforts from the scientific literature perspective, more evidence is needed from the field should be highlighted. In contribution B, the focus is put on studying how I4.0 impacts the Italian manufacturing companies, considering the company's knowledge level, utilization level, perceived benefits, and obstacles with regards to I4.0 enabling technologies, as well as the involvement of the company's business functions in I4.0 transformation. This research has actually investigated and assessed the position of Italian manufacturing companies in the I4.0 journey through a descriptive survey, scrutinizing a total of 103 respondents. The results of this study contribute to the body of scientific knowledge on whether and how the Italian manufacturing companies are approaching I4.0, it may help managers to assess the status quo of their organization and identify a new path of action. The association analysis shown in this study is simply used for discovering which factors are related to the knowledge and utilization level of I4.0 enabling technologies, nevertheless, each company needs to decide what kind of activities are appropriate, feasible, and relevant to its business model, digital transformation strategy and competitive environment.

RQ3: How is the progressing and advancement of the I4.0 impact in the Italian manufacturing context?

Based on contribution B, contribution C makes a further step by conducting a two-wave longitudinal survey in Italian manufacturing companies, comparing the results of the survey launched in two-time slots, separately in 2017 and 2019, which is one of the first attempt to capture the evolvement feature of I4.0 impacts. Sample numbers are 103 and 102 respectively, whereby the static population is chosen, and a repeated-panel sample design is determined to guarantee the rigor of survey design. Then the comparison is mainly derived from the following four aspects: 1) I4.0 technology knowledge level; 2) I4.0 technology utilization level; 3) company's performance impact by adopting I4.0 technologies; and 4) obstacles faced up by companies when adopting I4.0 technologies. It is figured out that the Italian manufacturing companies are still unripe towards I4.0 no matter their knowledge and utilization. Nonetheless, more companies are putting I4.0 solutions practically by adopting at least one I4.0 enabling technology. More interestingly, there is an altered perceived benefit, that companies consider more important the reduction of lead time and improvement of quality as prioritized benefits brought by I4.0 in 2019, while cost reduction was ranked in the first position in 2017. Meanwhile, similar to the findings in the 2017 version, companies still find it difficult to have technical and managerial competencies in managing the I4.0 realization. As both descriptive survey and longitudinal survey are trying to map the state-of-the-art of I4.0 in the Italian manufacturing context, future research should strive for developing theories, figuring out the working mechanism of why I4.0 could be successfully implemented by some pioneers, thus uncovering the how and why questions. Moreover, comparison among different countries and/or industrial sectors will be particularly important, especially with China and Germany.

RQ4: How the Italian manufacturing companies are approaching I4.0 to support their logistics process

As the last part of the dissertation, contribution D links I4.0 with the logistics process, investigating Log 4.0 in the Italian manufacturing companies through an exploratory survey, obtaining a total number of 91 validated responses. In particular, this study has considered specifically six Log 4.0 enabling technologies: IoT, BDA, AR, Collaborative robotics, AGV, and AM. Moreover, the benefits investigated are related to the following logistics processes: Demand planning and forecasting, Sourcing, Inventory Management, Warehouse Operations, and Distribution. As a summary, the concept of Log 4.0 is still very weak as a paradigm aimed at integrating all the processes and technologies involved. In fact, the surveyed companies find it more difficult than expected to make new technologies coexist with the structures and processes already present within the company. Indeed, it is found out that companies mainly address their efforts in the implementation of technologies aimed at improving the logistics operative activities, namely improve warehouse operations efficiency. Furthermore, this study demonstrates that staff training initiatives are positively related to operators' digital skills. Therefore, without an adequate level of competence and knowledge, it is very difficult to implement digital technologies to support logistics processes. Future research could derive from adopting the same research also in companies from other sectors such as third-party logistics players and firms operating in large-scale retail distribution.

6. REFERENCE OVERVIEW OF ARTICLES

This section provides the full bibliographical information of the articles included in this dissertation. They jointly address the formulated research objective and form the core part of the thesis. Full articles are presented in Part B.

6.1 The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review

Table 1 Bibliographic information of Article A

Title	The applications of the Industry 4.0 technologies in the manufacturing context: a systematic literature review
Authors	Zheng Ting, Ardolino Marco, Bacchetti Andrea, Perona Marco
Journal	International Journal of Production Research
Year	2020
Status	Published, ahead-of-print

Abstract

Industry 4.0 (I4.0) encompasses a plethora of digital technologies effecting on manufacturing enterprises. Most research on this topic examines the effects in the smart factory domain, focusing on production scheduling. However, there is still a lack of comprehensive research on the applications of I4.0 enabling technologies in manufacturing life-cycle processes. This paper is thus intended to provide a systematic literature review answering the following research question: What are the applications of I4.0 enabling technologies in the business processes of manufacturing companies? The study analyses 186 articles and the results show that production scheduling and control is the process most often investigated, while there is also an increasing trend in servitization and circular supply chain management. Moreover, there is extensive combined use of IoT, Big Data Analytics and Cloud, whose applications cover a wide range of processes. On the contrary, other technology like Blockchain is not as widely discussed in the domain of I4.0. This picture calls for a future research agenda extending the scope of investigation into I4.0 in manufacturing. Furthermore, the results of this research can prove extremely useful for practitioners who wish to implement one or more technologies, providing them with solutions for applications in manufacturing.

Keywords: Industry 4.0, manufacturing Systems, advanced manufacturing technology, manufacturing processes, smart manufacturing, literature review

In the present study, I have conducted the literature research, analysis, and interpret the result while the co-authors advised me during the journal paper formulation.

6.2 The impacts of Industry 4.0: A descriptive survey in the Italian manufacturing sector

Table 2 Bibliographic information of Article B

Title	The impacts of Industry 4.0: A descriptive survey in the Italian manufacturing sector
Authors	Zheng Ting, Ardolino Marco, Bacchetti Andrea, Perona Marco, Zanardini Massimo
Journal	Journal of Manufacturing Technology Management
Year	2019
Status	Published, ahead-of-print

Abstract

Purpose: This paper is aimed at investigating how much the Italian manufacturing companies are ready to be concretely involved in the so-called 'Industry 4.0' journey. In particular, this paper focuses on analyzing the knowledge and adoption levels of specific I4.0 enabling technologies, also considering how organizations are involved and which are the main benefits and obstacles.

Design/methodology/approach: A descriptive survey has been carried out on a total of 103 respondents related to manufacturing companies of different sizes. Data collected was analyzed in order to answer five specific research questions.

Findings: The findings from the survey demonstrate that Italian manufacturing companies are in different positions in their journey towards the I4.0 paradigm, mainly depending on their size and informatization level. Furthermore, not all the business functions are adequately involved in this transformation and their awareness about this new paradigm seems quite low because of the absence of specific managerial roles to guide this revolution. Finally, there are strong differences concerning both benefits and obstacles related to the adoption of I4.0 paradigm, depending on the technology adoption level.

Research limitations/implications: Future research should focus on developing case studies about pilot I4.0 practitioners in order to understand the root cause of successful cases. Both managerial and practical references should be developed, helping Italian manufacturing enterprises to consolidate and strengthen their position in global competitive market. Finally, it would be interesting to carry out the same study in other countries in order to make comparisons and suitable benchmark analyses.

Originality/value: Despite scholars have debated about the adoption of technologies and the benefits related to the I4.0 paradigm, to the best of authors' knowledge, only a few empirical surveys have been carried until now out on the adoption level of I4.0 principles in the manufacturing sector of a specific country.

Keywords: Industry 4.0, Digitization, Information technology, Technology, Advanced manufacturing technology, Manufacturing industry

In this work, I analysed the literature, conducted the results analysis, and enhanced the methodology, while the co-authors tutored me during the journal paper formulation.

6.3 Progressing and advancement of Industry 4.0 in the Italian manufacturing context: a dynamic state-of-the-art

Table 3 Bibliographic information of Article C

Title	Progressing and advancement of Industry 4.0 in the Italian manufacturing context: a dynamic state-of-the-art
Authors	Zheng Ting, Ardolino Marco, Bacchetti Andrea, Perona Marco
Proceeding	XXV Summer School "Francesco Turco" - Industrial Systems Engineering
Year	2020
Status	Accepted for publication

Abstract

Manufacturing companies are required to provide more value-added products in a faster and more reliable way in today's competitive market. Meantime, the rapid evolving of digital technologies is leading the fourth industrial revolution, also named as Industry 4.0 (I4.0). Although some contributions have been made in the literature to describe the state-of-the-art of I4.0 from national level perspective, it seems that there is still missing a dynamic evaluation over time concerning the evolution of the I4.0 paradigm, especially for the Italian manufacturing sector. This paper tries to fill this gap, by conducting a survey in 2019 with a sample of 102 companies and comparing the results with a first survey carried out in 2017.The results show that more companies are implementing I4.0 technologies compared to the 2017 survey, with an increase of 12%. It is also revealed that the large companies, characterized by a high level of informatization, still tend to behave better than small and medium ones. Companies consider lead time reduction and delivery of high-quality product/service as biggest benefits perceived from implementing I4.0 paradigm. As a conclusion, based on the results of the survey, authors show and describe the main levers to be adopted by practitioners in order to accelerate the 4.0 transformation.

Keywords: Industry 4.0, Disruptive technologies, Digital transformation, Survey, Manufacturing, State-of-the-art

In the present work, I have analysed the literature, co-project the survey protocol, enhanced the methodology and analysed the results, while the co-authors advised me during the paper formulation.

6.4 The impacts of Logistics 4.0 on Italian manufacturing companies: an exploratory survey

Table 4 Bibliographic information of Article D

Title	The impacts of Logistics 4.0 on Italian manufacturing companies: an exploratory survey
Authors	Zheng Ting, Ardolino Marco, Bacchetti Andrea, Perona Marco
Proceeding	27th EurOMA Conference
Year	2020
Status	Published

Abstract

This paper focuses on manufacturing logistics and explores how Italian companies are approaching the Logistics 4.0 (Log 4.0). The main purpose is to evaluate the state-of-the-art of Log 4.0 enabling technologies adoption, highlighting the main influencing factors, as well as an overview about the related benefits and obstacles. An exploratory survey has been carried out scrutinizing 91 Italian manufacturing companies. Statistical tests were used to demonstrate the significance of the influence of the factors analysed with respect to the level of adoption of the Log 4.0. The overall results indicate that the adoption of Log 4.0 in Italian manufacturing companies is still immature, but with huge potentials. Moreover, the few companies that have adopted at least one technology have sought benefits mainly related to warehouse activities and efficiency in process operations. In general, the awareness that Log 4.0 intends a choral and integrated implementation of digital technologies to support logistics processes has not yet been fully perceived.

Keywords: Information technology, Supply chain innovation, Logistics strategy, Logistics industry

In the present work, I have analysed the literature, enhanced the methodology and analysed the results, while the co-authors advised me during the paper formulation.

PART II

A. The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review

Title	The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review
Authors	Zheng Ting, Ardolino Marco, Bacchetti Andrea, Perona Marco
Outlet	International Journal of Production Research
Year	2020
Status	Published, ahead-of-print

Abstract.

Industry 4.0 (I4.0) encompasses a plethora of digital technologies effecting on manufacturing enterprises. Most research on this topic examines the effects in the smart factory domain, focusing on production scheduling. However, there is still a lack of comprehensive research on the applications of I4.0 enabling technologies in manufacturing life-cycle processes. This paper is thus intended to provide a systematic literature review answering the following research question: What are the applications of I4.0 enabling technologies in the business processes of manufacturing companies? The study analyses 186 articles and the results show that production scheduling and control is the process most often investigated, while there is also an increasing trend in servitization and circular supply chain management. Moreover, there is extensive combined use of IoT, Big Data Analytics and Cloud, whose applications cover a wide range of processes. On the contrary, other technology like Blockchain is not as widely discussed in the domain of I4.0. This picture calls for a future research agenda extending the scope of investigation into I4.0 in manufacturing. Furthermore, the results of this research can prove extremely useful for practitioners who wish to implement one or more technologies, providing them with solutions for applications in manufacturing.

Keywords: Industry 4.0, manufacturing Systems, advanced manufacturing technology, manufacturing processes, smart manufacturing, literature review

1. Introduction

Progressive globalization, mass customization and competitive business environments mean that "traditional" enterprise is facing new business challenges in today's turbulent economy (Simmert et al., 2019). The demand for faster delivery times, more efficient and automated processes, higher quality and customized products are driving companies towards the so-called fourth industrial revolution, known as Industry 4.0 (I4.0).

The previous three Industrial revolutions led to great increases in productivity driven by mechanization, electricity and information technology (Veza et al., 2015). For Industry 4.0, the underlying technology is represented by Cyber-Physical Systems (CPS), which make production systems modular and changeable, thus able to mass produce highly customised products (Kagermann, 2015; Nascimento et al., 2019). Indeed, when CPS communicate over the Internet of Things, they connect infrastructure, physical objectives, human actors, machines and processes across organizational boundaries, enabling the fusion between physical and virtual world, exploiting sensors, actuators, and computation power to transmit data in real-time for decentralized decision-making processes (Trappey et al., 2017). Meanwhile, there are other digital technologies that have emerged as enablers of I4.0. Chen and Lin (2017) investigate profit maximization in 3D printing within smart manufacturing systems, focusing on technical and managerial challenges to be overcome. There is also extensive exploitation of big data processing techniques and algorithms, with the goal of improving system scalability, security and efficiency (Xu and Duan 2019). In turn, Cloud technologies can help implement Cloud Manufacturing (CMfg), reducing costs and increasing scalability by leveraging virtual resources (Buckholtz et al., 2015). All these technologies can have repercussions not only in the manufacturing sector, but also in everyday life by transforming traditional appliances into smart products to implement sophisticated smart home systems (Aheleroff et al., 2020). In addition, the advent of new technologies has led to the emergence of new business models, such as what "multi-sided digital platforms", i.e. businesses capable of connecting two or more groups of users thanks to the support of a digital platform (Ardolino et al. 2020).

I4.0 is growing in both developed and developing countries. Choi and Choi (2018) study how Korean SMEs have implemented the smart factory concept and the main challenges in advancing to the next level of maturity. Expectations on digitization and I4.0 in the German metal and electric industry have been investigated by Weber et al. (2017), while Dalenogare et al. (2018) debated on the benefits of I4.0 related-technologies in the Brazilian industry. Zheng et al. (2019) also explored the current state of I4.0 in Italian manufacturing sector.

The area of greatest impact by I4.0 is manufacturing, with the areas investigated ranging from improving production processes to optimizing operational performance, developing products or services and supply chain planning. Studies have also covered worker skills (Kazancoglu and Ozkan-Ozen, 2018), sustainability and circular economy (Bressanelli et al. 2018) and the link between implementing I4.0 and lean thinking (Buer et al., 2018) as Lean Thinking has been implemented in many organizations (Amaro et al., 2019).

I4.0 is a topic much debated in the literature, and many studies analyse enabling technologies and their applications (Fatorachian and Kazemi, 2018; Kolberg et al., 2017). However, the existing literature pays more attention to the impacts on the processes of specific manufacturing companies, instead of considering transversally all the processes in a holistic way. These gaps are clearly outlined by Piccarozzi, Aquilani, and Gatti (2018), pointing out the need to analyse the impact of I4.0 considering all processes. The goal of bridging this gap leads to the development of a systematic literature review (SLR).

To date, there are some SLR-type articles investigating different perspectives of I4.0 already published. For example, some scholars have adopted systematic bibliometric analysis to review academic progress on the topic of I4.0 and summarize the areas of research and fields of application (Liao et al., 2017; Muhuri et al., 2019; Savastano et al., 2019; Strozzi et al., 2017). Kamble, Gunasekaran, and Gawankar (2018) have developed a sustainable I4.0 framework, incorporating sustainable aspects into machine-to-machine and human-to-machine integration enabled by I4.0 technologies, while Kerin and Pham (2019) summarize the use of Additive Manufacturing (AM), Internet of Things (IoT), Virtual Reality (VR) and Augmented Reality (AR) in the domain of remanufacturing. Kadir, Broberg, and Conceição (2019) review the ergonomics and human factors in the domain of I4.0, while Klingenberg, Borges, and Antunes Jr (2019) consider a data-driven approach for I4.0 technology classification. Ghobakhloo (2018) has classified building blocks and defined the technology trends of I4.0 by developing a roadmap for the I4.0 transition for traditional manufacturing companies. In addition, Moeuf et al. (2018) focused on SMEs, identifying the relationships among performance objectives, managerial capacities and I4.0 enabling technologies. Mittal et al. (2018) have tried to understand how the maturity models could be adopted to specific requirements by SMEs and what are the challenges. Da Silva et al. (2020) focused on empirical studies of I4.0, summarizing the concept, benefits, challenges and enabling technologies of I4.0. Furthermore, Piccarozzi et al. (2018) reviewed I4.0 from a managerial point of view. Buer, Strandhagen, and Chan (2018) try to map current literature investigating the link between I4.0 and lean manufacturing, while Pagliosa, Tortorella, and Ferreira (2019) investigate the key I4.0 technologies and link them to lean practices. Frederico et al. (2019) outline the relationship between supply chain 4.0 and I4.0 and propose a maturity framework for supply chain 4.0.

Although the literature mentioned above has covered different perspectives in relation to I4.0, it seems that there is a lack of comprehensive consideration of the impact of I4.0 from both a technical and managerial perspective, as well as the holistic analysis of the different processes of manufacturing (Piccarozzi et al., 2018; Schneider, 2018). Thus, the authors seek to fill this gap by performing a SLR, attempting to answer the following research question: What are the applications of I4.0 enabling technologies in manufacturing? The paper is composed of the following sections: Section 2 describes the conceptual framework that guides this research; Section 3 demonstrates the methodology adopted for the literature review; Section 4 reports the main results, and Section 5 provides discussions on our findings, also outlining a future research agenda; finally, Section 6 draws conclusions from the work.

2. Conceptual framework

I4.0 introduces new opportunities that may disrupt the traditional approach of manufacturing companies. Thanks to the growing number of new digital technologies, I4.0 has numerous repercussions and applications in all the main processes. At the same time, technologies can impact differently the various processes; there may be some technologies that have transversal impacts on all processes, while others may focus purely on single process.

This study adopts an inductive-deductive approach according to Seuring and Gold (2012). As a starting point, a conceptual framework was developed (Figure 1). Each of the intersections in the framework represents the impact of applying each of the technologies analysed on each of the processes. One of the objectives of this research is to measure the level of impact in each node based on the applications described in the scientific literature.

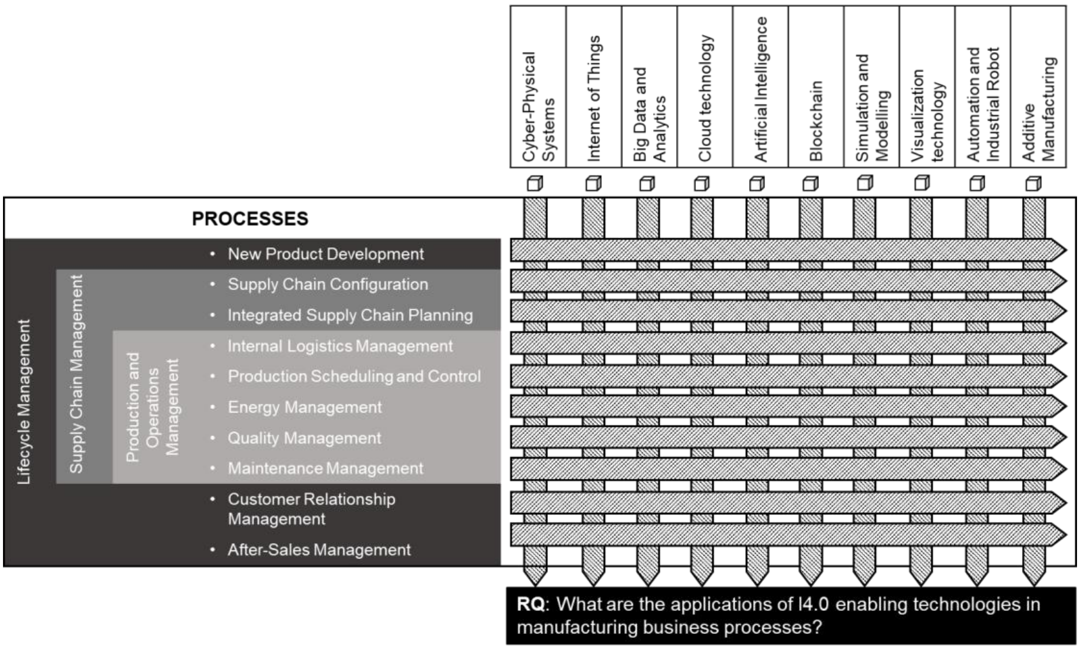

Figure 1. Conceptual framework

Using a conceptual framework can be very useful in a scientific study, since it 'explains, either graphically or in narrative form, the main things to be studied - the key factors, concepts, or variables , and the presumed relationships among them' (Miles and Huberman, 1994). Indeed, a conceptual framework can be defined as a tentative theory of the phenomena under investigation (Maxwell, 2012) and is a way of looking at a problem under analysis (Liehr and Smith, 1999).

This framework is mainly composed of two elements, namely: I4.0 enabling technologies and manufacturing company processes, which are used to guide the analysis of the scientific literature. The adoption of I4.0 technologies can have potential impacts on the various processes of manufacturing companies. Business processes might also be supported by the technologies according to different applications, affecting both the individual process and more broadly the whole value chain. The list of process covers the entire production flow, from product design through manufacture, service and, finally, recovery or disposal. Therefore, all the processes identified have an impact on the product during its lifecycle. Part of these processes refer more properly to Supply Chain Management (SCM), i.e. activities related to the management of suppliers and customers as well as planning and managing the flows of materials between the various actors. Finally, we also considered the processes intrinsically linked to operations and production, which represent the heart of the factory and manufacturing.

This framework therefore represents the context of the authors' research. A similar approach has been adopted by (Moeuf et al., 2018) published in International Journal of Production Research, who conducted a literature review of case studies on the application of I4.0 in SMEs.

2.1 I4.0 enabling technologies

The technological stream constitutes an important field concerning I4.0, and a combination of digital and manufacturing technologies can actually enable vertical integration of an organization's systems, horizontal integration in collaborative networks and end-to-end solutions across the value chain (Kagermann et al., 2013; Klingenberg et al., 2019). However, there is no agreed list of I4.0 enabling technologies in the literature; scholars lack mutual understanding and there are some inconsistencies among the different literature domains (Fettermann et al., 2018; Riel and Flatscher, 2017). In this paper, based on the fundamental design principles of I4.0, which are decentralization, real-time support, modularity, interoperability, virtualization and service-orientation (Alguliyev et al., 2018; Mohamed et al., 2019), the authors consider a list of 10 clusters of technologies, resulting from a critical review of those mentioned in acknowledged research in the literature (Ghobakhloo 2018; Oztemel and Gursev 2018; Ardito et al. 2019; Gölzer and Fritzsche 2017; Da Silva et al. 2020), namely: Cyber-Physical Systems (CPS), Internet of Things (IoT), Big data and Analytics (BDA), Cloud technology, Artificial Intelligence (AI), Blockchain, Simulation and Modelling, Visualization Technology, Automation and Industrial robot and, finally, Additive Manufacturing (AM). (Table 1).

Table 1. Summary of I4.0 enabling technologies

Technology	Description	References
Cyber-Physical Systems	CPS is a collection of transformative technologies that connects the operations of physical assets and computational capabilities. The main aim is to monitor physical systems while creating a virtual copy.	(Lee, Bagheri, and Kao 2015; Monostori et al. 2016; Alguliyev, Imamverdiyev, and Sukhostat 2018)
Internet of Things	Information network of physical objects (sensors, machines, cars, buildings, and other items) that enables the collection and exchange of data, allowing interaction and cooperation of these objects.	(Atzori et al., 2010; Oztemel and Gursev, 2018; Trappey et al., 2016)
Big Data and Analytics	Collection and analysis of large amount of available data using a series of techniques to filter, capture and report insights, where data are processed in higher volumes, with higher velocities and in greater variety.	(Buhl et al., 2013; Fosso Wamba et al., 2015; Vera-Baquero et al., 2014)
Cloud technology	System for the provision of online storage services for all applications, programs and data in a virtual server, without requiring any installation.	(Li et al., 2010; Tao et al., 2011; Xu, 2012a)

Artificial Intelligence	System that think humanly and rationally according to six main disciplines, including natural language processing, knowledge representation, automated reasoning, machine learning, computer vision and robotics.	(Kok et al., 2009; Monostori, 2003; Russell and Norvig, 2016)
Blockchain	A database that creates a distributed and tamperproof digital ledger of transactions, including timestamps of blocks maintained by every participating node.	(Ghobakhloo, 2018; Sikorski et al., 2017; Viriyasitavat et al., 2018)
Simulation and Modelling	Technologies that mirror the physical world data such as machines, products and humans in a virtual world, aiming for simplification and affordability of the design, creation, testing and live operation of the systems.	(Ghobakhloo, 2018; Higashino et al., 2016; Kocian et al., 2012)
Visualization Technology (Augmented and Virtual Reality)	Augmented Reality: a set of innovative Human Computer Interaction (HCI) techniques that can embed virtual objects to coexist and interact in the real environment; Virtual Reality: application of computer technology to create an interactive world, allowing the user to control the virtual object and whole virtual scene in real time.	(Azuma, 1997; Mujber et al., 2004; Regenbrecht et al., 2005; Reif and Walch, 2008; Wang, Ong, et al., 2016; Yew et al., 2016)
Automation and Industrial Robots	Machinery and equipment that automize operational processes, containing also Collaborative Robotics, which allows humans and machines to operate in a shared learning environment.	(Cherubini et al., 2016; Ghobakhloo, 2018; Oztemel and Gursev, 2018)
Additive Manufacturing	Process of joining materials in successive layers to make objects from 3D model data to 'unlock' design options and achieve great potential for mass-customization.	(Durão et al., 2017; Esmaeilian et al., 2016; Holmström et al., 2010)

2.2 Manufacturing company business processes

The scientific literature presents various frameworks and reference models listing typical default processes in companies. These models are often used for assessing and comparing performances among the process under analysis, possibly revealing best practices (Weilkiens et al., 2016).

In the literature, the most used model is the Value chain analysis by Michael Porter which includes a list of activities undertaken by a company in order to deliver a product or a service (Porter, 2011). The activities are divided into two categories: primary activities and support activities. Primary activities (Inbound Logistics, Operations, Outbound Logistics, Marketing and Sales, Service) add value to the goods and services delivered, while support activities (Infrastructure, Technological Development, Human Resource Management, Procurement) increase the effectiveness of primary activities. Another model is the Value Reference Model (VRM), developed and published by the non-profit organization *Value Chain Group* (Kirikova et al., 2012). It addresses three different level, namely: governance (strategical processes), planning (tactical processes) and execution (operational processes). In addition, the supply chain operations reference (SCOR) model developed by the Supply Chain Council includes five primary process: Planning, Sourcing, Making, Delivering and Returning. This model is generally used to evaluate and improve the performances and management of supply chain networks as well as to highlight the functional requirements of best practices (Stewart, 1997). The last example illustrated in this paper is the process classification framework (PCF) developed by the *American Productivity & Quality Center* (*APQC*) (APQC, 2019). This model includes 12 enterprise-level processes; the first five refer to operating processes and the other seven to management and support services. Even though this model can be seen as an extension of the famous Porter value chain, it has been poorly adopted in published research (Cragg and Mills, 2011).

Based on the models shown above, the authors have identified a list of business processes that characterize a typical industrial and manufacturing company. The list of processes is described in Table 2.

Table 2. Summary of manufacturing business processes

Process	Description
New Product Development	Design, testing and prototyping of a product before its production and marketing. This process also includes conceptualization well as the possible redesign of new product versions.
Supply Chain Configuration	Decision-making process linked to the strategic choices generally adopted at managerial level as regards both the configuration of the network (number of levels, selection of suppliers, make or buy strategy) and the factory layout including material flows management and asset positioning.
Integrated Supply Chain Planning	Mainly demand forecasting and planning (demand planning, demand forecasting), distribution (distribution planning), sourcing (purchasing planning), positioning of materials at various levels of the supply chain (inventory planning) and production (master production scheduling)
Internal Logistics	Factory operational logistics activities for the storage, internal handling of products and production enslavement.
Production Scheduling and Control	Process that includes both the scheduling (e.g. machine load management, batch allocation) within the factory and the monitoring and control of production.
Energy Management	Monitoring and control of all the resources used for the production and for the general functioning of the factory (e.g. raw materials, energy, utilities).
Quality Management	Factory activities to control production in terms of both products (e.g. product defects) and processes (e.g. production parameters).
Maintenance Management	Management of planning and maintenance for the assets found within the factory (including both breakdown and preventive or predictive maintenance).
Customer Relationship Management	Process including all activities involving interaction with customers (for example, to understand their habits or any product customizations). It also includes the design, management and provision of services (including customized services) directly connected to the physical product.
After-Sales Management	Management of the after-sales process including activities mainly concerning technical assistance and product maintenance, spare parts management, recovery and disposal of products at the end of the product lifecycle.

3. Methodology

3.1 Literature selection strategy

In this section, the authors present the adopted approach for selecting I4.0 related literature. To address the research question, academic publications were investigated, following the Systematic Literature Review (SLR) process. Indeed, SLR summarizes existing knowledge and evaluates available research works on a particular phenomenon in order to fill research gaps and strengthen the field of study (Petticrew and Roberts, 2006). Even though this approach is evolved from the field of medicine, in recent years systematic reviews have also been undertaken in the social and management sciences (da Silva Etges and Cortimiglia, 2019; Ülgen et al., 2019). To guarantee the rigor and generalizability, a structured selection process was implemented, and structured criteria adopted to include related papers and exclude unrelated cases.

To build the starting database, the authors began by searching the term "Industry 4.0" and its derivatives as keyword in article titles, abstracts, keywords in Scopus and Web of Science (WoS) databases. Despite the fact that issues of digitization and the adoption of digital technologies in manufacturing enterprises have been debated from different perspectives in addition to "Industry 4.0" (e.g. "Smart manufacturing", "Smart factory", "Factory of the Future"), publications data were taken exclusively considering the term "Industry 4.0" and its derivatives. Indeed, this concept has been widespread for many years and acknowledged by several international academic communities.

The data source creation phase led to the collection of 13,651 papers: 8,644 from Scopus and 5,007 from WoS. The data source is updated as at the end of December 2019. The creation of the initial database was followed by a screening phase of the papers using the standard filter fields provided by the databases. In this phase only English articles were included. In addition, only peer-reviewed journal articles were included; therefore, book chapters, conference papers, proceedings, and other non-refereed publications were excluded. This procedure is usual in a systematic review since this process acts as a quality control mechanism that confirms the knowledge provided by the included articles (Light and Pillemer, 1984). A filter was also applied to the subject areas in order to include only the most relevant articles based on the research question of this study. Figure 2 shows all the inclusion criteria adopted.

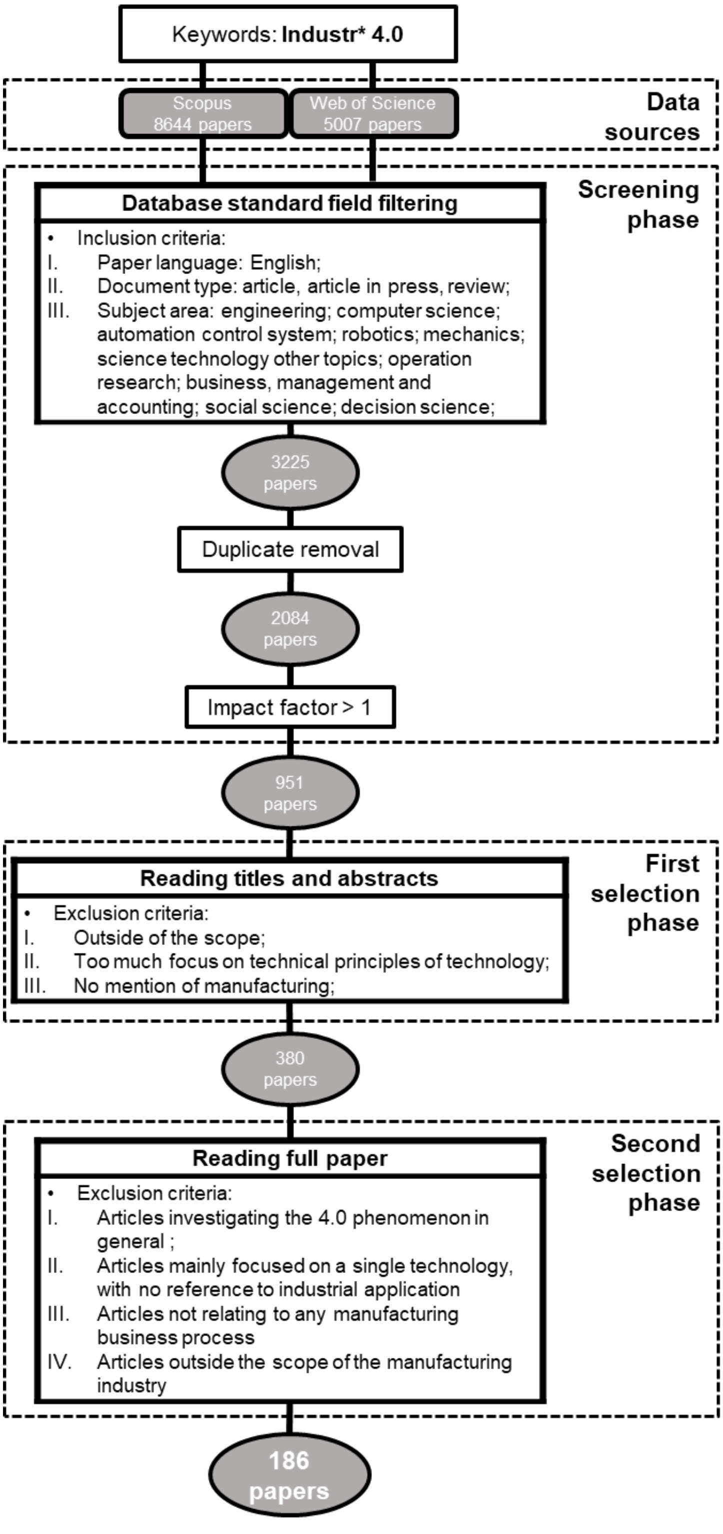

Figure 2. Literature review selection process strategy

The articles from the two different databases were merged and any duplicates were removed. The result was a single database consisting of 2,084 papers. After the abovementioned filtering, the impact factor was also considered, in order to assess the relevance of the journal in which the selected papers were published. This process ensures the inclusion of relevant and high-quality works. The advantages of citation-based ranking include high objectivity and wide acceptance and use of the Journal Impact Factor to assess the quality of individual papers is very common (Pagani et al., 2015). The screening phase have brought to 951 articles available for further analysis.

In order to achieve the research objectives, based on the developed conceptual framework, the authors carried out a first selection phase, which involved reading the titles and abstracts of each paper, in order to exclude the ones which were not within the scope of the research. In particular, works investigating the 4.0 phenomenon in general and with no explicit reference to an I4.0 enabling technology were not considered. In addition, all the articles mainly focused vertically on a single technology, with no references to any application in manufacturing, were also excluded. As a result, a total of 571 papers were considered "outside of the scope". Therefore, after this reading process, the sample was reduced to 380 papers.

The second selection phase involved reading the full paper. In this case, in addition to the criteria shown above, all the articles which did not refer to any process in the manufacturing business were also discarded. Finally, the articles outside the scope of the manufacturing industry were also excluded. In the end, 186 papers were considered suitable for this literature review. The selected papers were read and analysed with the support of Mendeley© and Microsoft© Excel. The articles were catalogued in Mendeley and, after a first reading, each of them was allocated a tag relating to both the technologies and the processes investigated. In addition, the parts of papers relating to potential applications to be mapped were highlighted. In a second step, all the highlighted parts were entered into a Microsoft© Excel spreadsheet, created according to the diagram in Figure 1. Each cell contained parts of the article highlighted in the previous phase. Then, the content of each cell was read, reasoning by single row, to identify the applications found and highlight the possible integrated use of two or more technologies. This enabled us to identify the various applications for each intersection of the table, as per the set objective.

3.2 Sample description

3.2.1 Year-wise publication analysis

In order to achieve a general view of the pieces of literature analysed, we conducted a primary mapping based on a year-wise publication analysis. Figure 3 shows an increasing trend in the number of published papers per year on I4.0 in manufacturing, which implies that the topic of I4.0 is attracting more and more attention from the academic community. From 2016, contributions began to increase rapidly, especially in 2019, resulting in almost twice the contributions of 2018 and three times those of 2017. Indeed, no significant contributions have been observed before 2016 according to our selection criteria. This trend can be explained by the fact that I4.0 is a relatively novel topic. Moreover, I4.0 was born in Germany in 2011 and first contributions were published mainly in Conferences proceedings, generally in German. Since this literature review excludes conference proceedings, it is reasonable to state that, due to the novelty of the topic, the papers published in peer review journals emerge mainly in 2016 and following years.

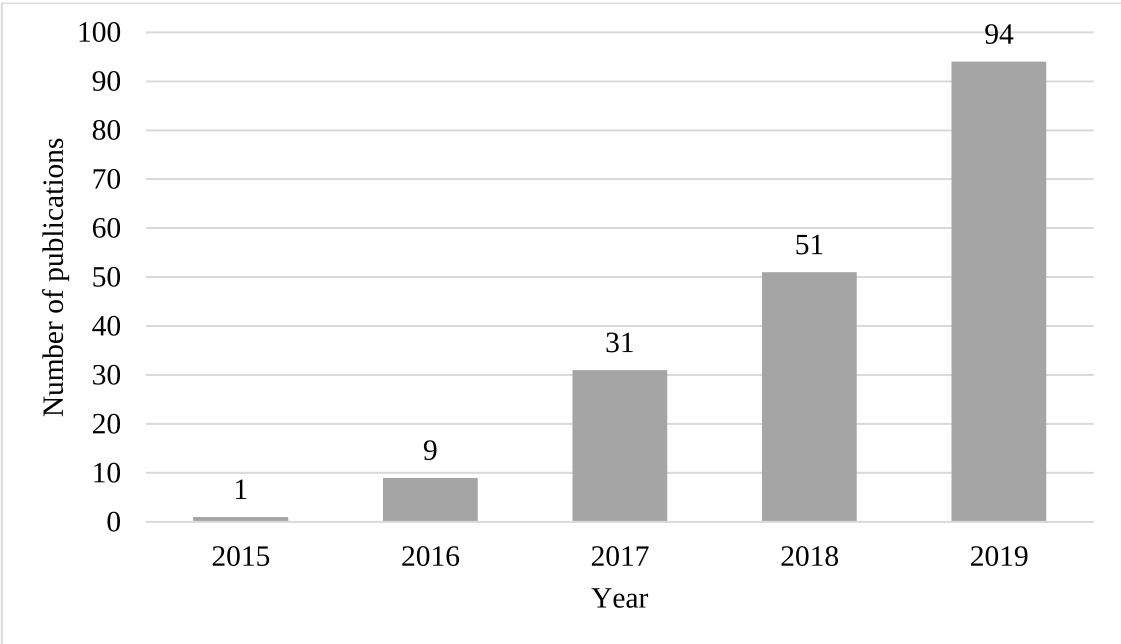

Figure 3. Year-wise publication

3.2.2 Journal contributions

Figure 4 lists the journals based on the number of articles published in this journal. Only Journals with at least 3 published articles are listed. IEEE Access, International Journal of Advanced Manufacturing Technology, International Journal of Production Research, Journal of Manufacturing Systems, Journal of Manufacturing Technology Management are the top five listed journals in which I4.0 related articles are published. Since I4.0 is enabled by advanced manufacturing technologies, including Operations Technology (OT) and Information Technology (IT), it is unsurprising to see that most articles have been published in technology-oriented and manufacturing-focused journals. Moreover, we noticed that a variety of journal types are covered, relating to business and sustainability, which indicates the multifaceted impact of I4.0.

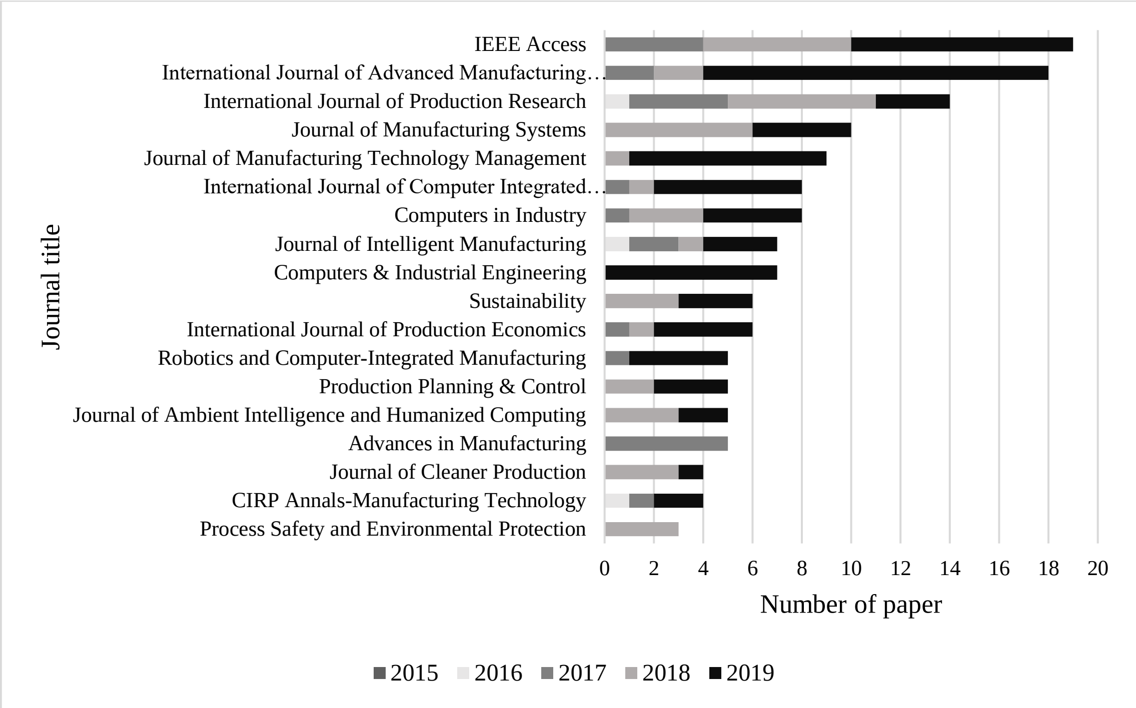

Figure 4: Journal contribution on the topic of I4.0

4. Content analysis result

4.1 New product development

New product development can mean the creation of new products by assessing all the characteristics and functions. In other cases, this activity may involve the modification of an existing product in order to achieve specific improvements and to satisfy new customer needs. The literature provides several contributions concerning the support of digital technologies in achieving this process.

Miranda et al. (2019) focus on the topic of smart product development according to a reference framework based on the adoption of CPS to create sensing, smart and sustainable products. Tao and Qi (2019) develop a Service-oriented Smart Network (SoSM), in which the IoT is used to connect all the users involved in the design phase of formalizing the product information model. The specific receiver and feedback mechanism enabled by the IoT improves the effectiveness of data source collection in New Product Development (NPD) (Chen et al. 2017). In addition, Bressanelli et al. (2018b) stress the capacity of the IoT and BDA in improving product design from a Circular Economy (CE) perspective. Indeed, the IoT allows data to be collected directly from the product in order to identify potential improvements in the design phase, which can be very useful when a new version of the physical product is to be launched.

In addition to collection, these data also have to be processed to underline any improvement trends; some works in the literature demonstrate the usefulness of BDA technology in this processing. Dalenogare et al. (2018) provide the evidence that operational big data collected from sensors has a positive impact on product design in CAD systems. Indeed, BDA is a lever for customized design, since more and more active or passive information on user behaviours are exposed to the internet (Qi and Tao, 2018; Tao and Qi, 2019), so designers can exploit these data to acquire information about potential design features and improvements in order to satisfy latent customer needs. This is further confirmed by Chen et al. (2017) who state that BDA can help designers to transform data into enlightening knowledge. Moreover, Ang et al. (2017) state that, combined with Machine Learning (ML), information collected from product lifecycle can be used to optimize product design.

Another interesting technology for NPD is Cloud technology, which provides an environment where data and functionalities are deployed; specific customer requirements across the global network can be transmitted to the Cloud for storage, computing and analysis, promoting distributed and collaborative product design (Ang et al., 2017; Rao and Prasad, 2018).

Automated simulation can support and accelerate virtual prototyping (Ang et al., 2017), while simulation is useful in technical assessment before the prototyping stage (Miranda et al., 2019). Digital Twin (DT) is also important in NPD as it replicates the digital representation of physical products for iterative optimization of personalized design (Qi and Tao, 2018).

Visualization technology, for example Augmented Reality (AR), can also support the product development process as it provides a concrete vision of the end product for assessing, in particular, the aesthetic details (Zhong et al., 2017).

Finally, additive manufacturing can also be implemented to enhance new product development. On the one hand, AM allows designers to achieve products featuring complex shapes that would not be feasible with traditional production techniques (Chen 2017; Ang et al. 2017). On the other hand, this production technology, characterized by reduced production lead time, guarantees rapid prototyping and obtains the product components quickly for subsequent testing (Chong et al., 2018; Ghobakhloo, 2018).

Table 3 shows the applications of I4.0 technologies in 'New Product Development'.

Table 3. Impact of I4.0 enabling technologies on "New Product Development"

Technologies	**Applications**	**Sources**
Cyber-Physical Systems	Smart product development	(Miranda et al., 2019)
Internet of Things	Data collection for product design improvements	(Ang et al., 2017; Bressanelli et al., 2018b; Chen et al., 2017; Tao and Qi, 2019)

Big Data and Analytics	Data processing and analysis for product design improvements	(Ang et al., 2017; Bressanelli et al., 2018b; Chen et al., 2017; Dalenogare et al., 2018; Qi and Tao, 2018; Tao and Qi, 2019)
Cloud technology	Distributed and collaborative design	(Ang et al., 2017; Rao and Prasad, 2018)
Artificial Intelligence	Data processing and analysis for product design improvements	(Ang et al., 2017)
Blockchain	-	-
Simulation and Modelling	Virtual prototyping	(Ang et al., 2017)
	Technical product assessment	(Miranda et al., 2019)
	Digital product representation	(Qi and Tao, 2018)
Visualization technology (Augmented and Virtual Reality)	Augmented design	(Zhong et al., 2017)
Automation and Industrial Robots	-	
Additive Manufacturing	Digital complex design	(Ang et al., 2017; Chen, 2017)
	Rapid prototyping	(Chong et al., 2018; Ghobakhloo, 2018)

4.2 Supply chain configuration

The supply chain configuration is a fundamental strategic activity as it includes both the choice of position of the various facilities, such as plants and warehouses, and the number of levels. Another aspect to be considered is the factory layout, as it can have a considerable impact on process efficiency. Clearly, factory layout design is inherent in the production system design, but it also forms part of those tactical choices that fall under supply chain configuration; therefore, we do consider factory layout in this section. In this case, BDA can play the important role of integrating data from different systems and, when combined with simulation, provide more accurate data for building sophisticate disruption scenarios for resilient SC design analysis (Queiroz and Telles 2018; Ivanov, Dolgui, and Sokolov 2019; Vieira et al. 2019; Vieira et al. 2019b). Therefore, BDA and simulation technologies can offer effective support in supply chain risk assessment. In addition, the use of IoT, BDA, Cloud, AI, Blockchain, AR and VR enable smart purchasing and supply management (Srai and Lorentz, 2019). Integrating these technologies makes it possible to digitize purchasing and supply management functions, improving coordination and control.

BDA can also be used in combination with AI and Simulation tools for evaluating and improving factory layout. Indeed, Kumar, Singh, and Lamba (2018) exploit a metal-heuristic approach to develop the framework for a sustainable and robust stochastic cellular facility layout, while

Z.Zhang et al. (2019) explore the simulation method for evaluating and optimizing the layout of the workshop and the dynamic performance of the manufacturing system. Supply chain configuration management also includes assessing what to produce and what to outsource if necessary. Although in recent years the trend has been to outsource to countries with low-cost labour, some technologies, such as AM, have given companies the opportunity to implement insourcing or back-sourcing strategies. Ivanov, Dolgui, and Sokolov (2019) highlight the potentialities of back-sourcing and in-sourcing strategies thanks to the higher flexibility and shorter lead times provided by 3D printing. In addition, Durão et al. (2017) investigate the relationship between central factories and distributed production sites when leveraging AM as a main production process for spare parts, in combination with CPS for full access to the monitored data. Savastano et al. (2019) also investigate the impact of I4.0 and competitive priorities on back-shoring decisions, discovering that advanced automation and additive manufacturing can act as effective levers. Indeed, AM-enabled spare part supply chain configurations can definitively exploit the flexibility advantages of local manufacturing (Zanoni et al., 2019).

Table 4 lists the main applications of I4.0 enabling technologies in 'supply chain configuration'.

Table 4. Impact of I4.0 enabling technologies on "Supply Chain Configuration"

Technologies	Applications	Sources
Cyber-Physical System	Distributed production of spare parts	(Durão et al., 2017)
	Supply chain risk management	(Ivanov et al., 2019)
Internet of Things	Smart purchasing and supply management	(Srai and Lorentz, 2019)
Big Data and Analytics	Supply chain risk assessment	(Ivanov et al., 2019; Queiroz and Telles, 2018b)
	Factory layout design and evaluation	(Kumar et al., 2018; Zhang, Wang, Wang, et al., 2019)
	Smart purchasing and supply management	(Srai and Lorentz, 2019)
Cloud technology	Smart purchasing and supply management	(Srai and Lorentz, 2019)
Artificial Intelligence	Factory layout design and evaluation	(Kumar et al., 2018)
	Smart purchasing and supply management	(Diez-Olivan et al., 2019; Ghadimi et al., 2019)
	Supply chain risk assessment	(Ivanov et al., 2019)
Blockchain	Smart purchasing and supply management	(Srai and Lorentz, 2019)
Simulation and Modelling	Factory layout design and evaluation	(Kumar et al., 2018; Zhang, Wang, Wang, et al., 2019)

	Supply chain risk assessment	(Ivanov et al., 2019; Vieira et al., 2019a, 2019b)
Visualization technology (Augmented and Virtual Reality)	Smart purchasing and supply management	(Srai and Lorentz, 2019)
Automation and Industrial Robots	Backshoring	(Savastano et al., 2019)
Additive Manufacturing	Distributed production of spare parts	(Durão et al., 2017; Zanoni et al., 2019)
	Insourcing / Back sourcing strategy	(Ivanov et al., 2019)
	Backshoring	(Savastano et al., 2019)

4.3 Integrated supply chain planning

The integrated supply chain planning process refers to the organization and management of various aspects, such as materials, suppliers, inventory, as well as demand forecasting. The support of digital technologies in managing all these aspects results in improved coordination and integration along the entire supply chain.

The simultaneous adoption of the IoT and BDA helps companies anticipate and shape future customer demands, leading to greater efficiencies in the distribution of end products. Indeed, a more accurate monitoring of customer demand may have an impact on different processes and make production planning more effective and aligned (Kamble et al., 2018).

On the other hand, with IoT and BDA technologies, inbound and outbound flows can be tracked more accurately, enabling automated and more precise demand planning and forecasting (Hofmann and Rüsch, 2017). These two technologies enable advanced demand assessment and forecasting. In this regard, Cloud technology can enhance the abovementioned mechanism, acting as an advanced data repository for planning and forecasting, allowing communications among all the players in the supply chain (customers, assemblers, suppliers and other service providers), facilitating the supply decision-making process for complying (or not) with customer-desired product varieties, volumes and times (Garay-Rondero et al., 2019; Strozzi et al., 2017; Wan et al., 2016; Yin et al., 2018). Indeed, Cloud technology not only promotes vertical integration within smart factories, but also horizontal integration along value networks, allowing interaction among consumers, design activities, manufacturing, and logistics (Wang, Wan, Li, et al. 2016). The Cloud also provides the opportunity to create collaborative instruments such as a service platform for coordinating regional manufacturing resources and achieving effective sharing and optimal allocations, even extended to multi-plants and logistics enterprises context (Bienhaus and Haddud, 2018; Rao and Prasad, 2018; Strandhagen, Alfnes, et al., 2017). Another aspect peculiar to integrated supply chain planning is the possibility of exchanging data for a complete visualization at all levels. Ben-Daya, Hassini, and Bahroun (2017) reinforce the idea of the visualization capacity of the IoT, which enables the virtual control of supply chains and, consequently, buyers can track and trace goods as they move through the supply chain, enabling advanced quality control and planning during the sourcing process. In addition, the real-time data capturing and exchange capacity provided by CPS, Auto-ID technology and BDA requires less manual interaction at inventory level between buyer and supplier, facilitating supply chain information exchange and visualization (Hofmann and Rüsch, 2017). BDA technology is also helpful in profiling and extracts the information important for marketing and SCM improves the matching of supply and demand processes (Kamble et al., 2018).

Moreover, the combined implementation of IoT, BDA and Cloud enhances supply chain integration and automation (Ardito et al., 2019; Garay-Rondero et al., 2019; Gružauskas et al., 2018; Manavalan and Jayakrishna, 2019), in which IoT can create a network of stakeholders along the supply chain (Schroeder et al., 2019) BDA play the role of data collector and processor along supply chain and the Cloud stores structured information for sharing and exchange. Bienhaus and Haddud (2018), Srai and Lorentz (2019) focus on procurement digitization, in which operational activities such as procurement transactions can be automatized through IoT, BDA and AI, in order to create more space for strategic human-performed initiatives. Indeed, companies using CPS and Big Data tend to have more efficient cooperation with their partners (Nagy et al. 2018).

Consequently, AI is also effective in supply chain integration and automation. Lolli et al. (2018) research the use of ML techniques, such as Support Vector Machines (SVM) and Deep Neutral Network (DNN), to solve multi-criteria inventory classification (MCIC) issues, generating excellent results.

BDA can also support distribution planning; Gružauskas, Baskutis, and Navickas (2018) adopted this technology for finding the trade-off between cost effective performance and sustainability in distribution planning. J. O. Strandhagen et al. (2017) consider real-time big data analytics as a lever for facilitating optimal material and product transportation routing within a Logistics 4.0 environment.

Integrated supply chain planning is a field in which Blockchain can be effectively applied with two main applications, namely: real-time materials identification and tracking (Ivanov et al., 2019), and cross-organizational automated collaboration among stakeholders (Ghobakhloo, 2018; Hofmann and Rüsch, 2017; Ivanov et al., 2019; Viriyasitavat et al., 2018). In particular, product information records can be traced transparently and authenticated (Alladi et al., 2019; Fernandez-Carames and Fraga-Lamas, 2019; Srai and Lorentz, 2019), and collaboration can be achieved through distributed smart contracts that enable trusted and autonomous relationship among different actors in the supply chain, both suppliers and customers (Alladi et al., 2019; Fernandez-Carames and Fraga-Lamas, 2019; Longo, Nicoletti, Padovano, et al., 2019). This kind of application is also confirmed by Viriyasitavat et al. (2018) who focus on business process management (BPM).

Table 5 shows the main applications resulting from the abovementioned contributions found in the literature.

Table 5: Impact of I4.0 enabling technologies on "Integrated Supply Chain Planning"

Technologies	Applications	Sources
Cyber-Physical Systems	Supply chain integration and automation	(Hofmann and Rüsch, 2017; Nagy et al., 2018)
Internet of Things	Data collection for advanced demand assessment and forecasting	(Hofmann and Rüsch, 2017; Kamble et al., 2018; Wan et al., 2016)
	Supply chain information exchange and visualization	(Ben-Daya et al., 2019; Gružauskas et al., 2018; Hofmann and Rüsch, 2017)
	Supply chain integration and automation	(Ardito et al., 2019; Bienhaus and Haddud, 2018; Garay-Rondero et al., 2019; Manavalan and Jayakrishna, 2019; Patel et al., 2018; Schroeder et al., 2019; Srai and Lorentz, 2019)
Big Data and Analytics	Advanced demand assessment and forecasting	(Garay-Rondero et al., 2019; Hofmann and Rüsch, 2017; Kamble et al., 2018; Patel et al., 2018; Wan et al., 2016)
	Supply chain information exchange and visualization	(Ben-Daya et al., 2019; Gružauskas et al., 2018; Hofmann and Rüsch, 2017)
	Supply chain integration and automation	(Ardito et al., 2019; Bienhaus and Haddud, 2018; Garay-Rondero et al., 2019; Manavalan and Jayakrishna, 2019; Nagy et al., 2018; Patel et al., 2018; Srai and Lorentz, 2019)
	Distribution planning	(Gružauskas et al., 2018; Strandhagen, Vallandingham, et al., 2017)
Cloud technology	Advanced data repository to carry out demand assessment and forecasting	(Ardito et al., 2019; Garay-Rondero et al., 2019; Moeuf et al., 2018; Strozzi et al., 2017; Wan et al., 2016; Yin et al., 2018)
	Supply chain information exchange and visualization	(Ben-Daya et al., 2019; Gružauskas et al., 2018; Hofmann and Rüsch, 2017)
	Supply chain integration and automation	(Garay-Rondero et al., 2019; Manavalan and Jayakrishna, 2019; R. Novais et al., 2019; Srai and Lorentz, 2019; Wang, Wan, Li, et al., 2016)

	Cloud manufacturing service platform for SC collaboration	(Bienhaus and Haddud, 2018; Chen and Tsai, 2017; Hofmann and Rüsch, 2017; Rao and Prasad, 2018; Strandhagen, Alfnes, et al., 2017; Wang, Wan, Li, et al., 2016; Yoon et al., 2019; Zhang, Ding, Zou, et al., 2019)
Artificial Intelligence	Multi-criteria inventory classification	(Lolli et al., 2019)
	Advanced demand assessment and forecasting	(Garay-Rondero et al., 2019)
	Supply chain integration and automation	(Bienhaus and Haddud, 2018; Srai and Lorentz, 2019)
Blockchain	Real-time materials identification and tracking	(Alladi et al., 2019; Fernandez-Carames and Fraga-Lamas, 2019; Ivanov et al., 2019; Srai and Lorentz, 2019)
	Cross-organizational collaboration among stakeholders	(Alladi et al., 2019; Fernandez-Carames and Fraga-Lamas, 2019; Ghobakhloo, 2018; Hofmann and Rüsch, 2017; Ivanov et al., 2019; Longo, Nicoletti, Padovano, et al., 2019; Viriyasitavat et al., 2018)
Simulation and Modelling	-	-
Visualization technology (Augmented and Virtual Reality)	-	-
Automation and Industrial Robots	-	-
Additive Manufacturing	-	-

4.4 Internal logistics

Internal logistics deals with the handling and storage of goods within the factory. This process encompasses the movement of materials and the support operations related to warehousing, stock control, material handling, and production feeding. In particular, the human resources involved in internal logistics are responsible for ensuring secure production supply, so cost and time efficiency are essential. I4.0 enabling technologies offer many ideas for improving internal logistics.

In the literatures, there are some contributions highlighting the identification and tracking capability of IoT technologies. Wan et al. (2016) describe the adoption of RFID for material identification and recording manufacturing information. Lee et al. (2017) investigate the implementation of IoT in tracking and tracing raw materials, semi-finished products and finished goods in inbound order inspections. K. Zhang et al. (2019) highlight the role of the IoT in making physical objects ‘smart’ and synchronizing information among production systems and warehouse systems for optimal dynamic lean control. These expedients may help reduce time and save resources. Indeed, incoming materials fitted with Auto-ID tags can be controlled by employees using scanning devices or automatic gate control systems (Hofmann and Rüsch, 2017). Automatic Guided Vehicles (AGVs) can read sensors in the factory, automating internal transportation, line feeding and material handling (R. Novais et al., 2019; Tang and Veelenturf, 2019). To demonstrate this, J. O. Strandhagen et al. (2017) show that Auto ID and RFID, together with AGVs and autonomous industrial robots, enable autonomous tracking and inventory control in warehouse management.

Fuzzy logic with incorporated machine learning algorithms can support and improve the order picking process (Lee et al., 2018). In addition, Hofmann and Rüsch (2017) discussed internal material flow optimization through simulation. Since there is an increase in the digitization of material flows, delivery processes may be simulated in relation to adjacent processes. Therefore, Simulation and Modelling might help in the assessment of collection and delivery processes.

As regards Visualization technologies, pick-by-vision is a promising concept within logistics (Strandhagen, Alfnes, et al., 2017). Work instructions for logistics operations can be given directly to workers using AR technologies for reducing the cognitive load and enabling better performance of various operations. Blanco-Novoa et al. (2018) illustrate the cases of use of Industrial Augmented Reality (IAR) for asset location and warehouse management.

As shown in Table 6, applications are found for technologies such as IoT, AI, Simulation and modelling, Visualization Technology and Automation and Industrial Robots in Internal Logistics processes. No relevant applications have been found concerning the other technologies considered.

Table 6. Impact of I4.0 enabling technologies on “Internal Logistics”

Technologies	**Applications**	**Sources**
Cyber-Physical Systems	-	-
Internet of Things	Material identification and tracking	(Hofmann and Rüsch, 2017; Lee et al., 2018; Wan et al., 2016; Zhang, Qu, Zhou, et al., 2019)
	Automation of internal transportation, line feeding and material handling	(R. Novais et al., 2019; Strandhagen, Vallandingham, et al., 2017; Tang and Veelenturf, 2019; Wan et al., 2016)
Big Data and Analytics	-	-
Cloud technology	-	-
Artificial Intelligence	Order picking management	(Lee et al., 2018)
Blockchain	-	-
Simulation and Modelling	Material flow simulation in factories and warehouses	(Hofmann and Rüsch, 2017)

Visualization technology (Augmented and Virtual Reality)	Pick-by vision	(Strandhagen, Alfnes, et al., 2017)
	Material allocation guidance	(Blanco-Novoa et al., 2018)
Automation and Industrial Robots	Automation of internal transportation, line feeding and material handling	(R. Novais et al., 2019; Strandhagen, Vallandingham, et al., 2017; Tang and Veelenturf, 2019; Wan et al., 2016)
Additive Manufacturing	-	-

4.5 Production scheduling and control

Production scheduling and control is the area that received most attention in the scientific literature. Table 7 shows that, apart from Blockchain technology, all the other I4.0 enabling technologies are found to have numerous applications in this process. CPS is observed to have considerable impact in production, with applications focused mainly on the scheduling and control of cyber-physical production systems, as well as the virtualization of manufacturing resources.

CPS, IoT and IoS constitute the architecture of smart factory, digitizing the processes, assets, products and operators (Wang, Wan, Li, et al. 2016; Wang, Wan, Zhang, et al. 2016; Ghobakhloo 2018; Diez-Olivan et al. 2019). According to Mittal et al. (2019) and Monostori et al. (2016), the applied form of CPS in production is CPPS, which is an interchangeable term for smart factory (Chen et al. 2017). Individual CPSs constitute the low-level control systems, powered by integration and interoperability, cloud computing, data analytics and cyber security, (Rojas and Rauch, 2019). CPPS can enable smart scheduling, ranging from physical operations to planning, evaluating and managing entire production processes (Kang et al., 2016; Rossit et al., 2019), and achieving mass personalization of production (Wang et al. 2017; Aheleroff et al. 2019). Indeed, several frameworks are proposed for achieving CPS-enabled smart scheduling. Wan, Chen, et al. (2018) propose an IoT-enabled framework for managing dynamic manufacturing resources based on CPPS. Fatorachian and Kazemi (2018) argue that the challenge of communication among different CPSs can be resolved by IoT, while BDA and Cloud enable overall control. Abidi et al. (2019) propose cloud-based CPS architecture for integrating heterogenous data for the purposes of shop-floor status monitoring and adaptive scheduling. Lu and Xu (2019), J. Zhang et al. (2019) also confirm that CPS enables smart production control through cloud-based platforms. Zhang, Wang, Zhu, et al. (2019) investigate the constitution of CPS through ubiquitous robots governed by Cloud. Jiang et al. (2018) also investigate CPS-based multi-agent systems (MAS) and contract net theory for task scheduling. Cruz Salazar et al. (2019) identify resources, processes, management and communication agents to create agent-based CPPS architecture. Tan et al. (2019) state that smart assembly units (SAUs), self-organized wireless sensors and actor/actuator networks (WSAN), MAS, edge computing and cloud computing can create CPS architecture for the dynamic coordination of shop-floor level material and information flow. CPS also enables shop floor digital twin, since the computational and physical capabilities are integrated by CPS, which makes physical resources capable of computing, communication and control (Longo, Nicoletti and Padovano, 2019; Tao and Zhang, 2017; Urbina Coronado et al., 2018). X. Xu (2017) consider cyber-physical machine tools an essential element of CPPS, where cyber twins of machines can be provisioned and coordinated. Turner et al. (2016) on the other side, investigate the function of VR and DES for shop-floor control. With regard to the virtualization of manufacturing resource, Shafiq et al. (2015, 2016) proposes the concept and framework of virtual engineering objects (VEOs) and virtual engineering process (VEPs) as a specialized form of CPS for providing engineering artefacts and processes with experience-based representation. Lu and Xu (2018) propose a framework of test-driven resource virtualization to guide industries in creating digital twins for smart factory, where technical properties, functional properties and real-time status can be virtualized in cyberspace by utilizing semantic web technologies, OWL and Jena modelling.

Regardless of the type of machinery or the type of processing, collecting the data of the production process is essential for effective monitoring. In this regard, IoT technologies provide valuable support in collecting data from production processes and resources (Qi and Tao, 2018; Tao and Zhang, 2017; Zhong et al., 2017). There are in fact several applications discussed in the literature. For example, the adoption of sensors and RFID can enable data to be extracted from multiple sources, guaranteeing up-to-date information on the progress of the production process (Wang, Wan, Li, et al. 2016; Y. Wang et al. 2017). Furthermore, Makris et al. (2016) discussed context-aware information processing for shop-floor application, in which sensors extract data from workpieces, machines and tools to synthesise the digital context of real production.

Production data can be used to increase the automation of certain crucial activities, such as resource allocation and scheduling. Mourtzis and Vlachou (2018) studied in detail how to integrate data from different sources such as machine tools, mobile devices as well as human operators for shop-floor job scheduling. Indeed, the adoption of specific optimization algorithms from AI systems can be combined with the IoT to achieve work in process (WIP) management, resource allocation, and production scheduling (Wang et al. 2017; Moussa and ElMaraghy 2019; Cohen et al. 2019; González Rodríguez, Gonzalez-Cava, and Méndez Pérez 2020). BDA can also be considered an enabler of dynamic scheduling in smart manufacturing (Qi and Tao 2018; Tao and Qi 2019; Kang et al. 2016; Wang, Wan, Li, et al. 2016; Wang, Wan, Zhang, et al. 2016; Kamble, Gunasekaran, and Gawankar 2018). Ang et al. (2017) state that through the IoT and the use of BDA, it is possible to monitor and control the workshop machinery autonomously for health monitoring or to change the workflow to allow “real-time” and flexible adjustment in case of machine breakdown or changes in work requirements. However, Moeuf et al. (2018) argue that, despite the fact that BDA has been largely recognised as a highly regarded method of optimizing the uses of resources, big data methods are difficult to implement in SMEs.

In addition to collecting real-time data for production monitoring, the IoT enables connections and information exchange among the different resources employed within the production environment. One of the main benefits of the IoT is to facilitate the communication among various objects (Wan et al. 2016; Wan, Chen, et al. 2018; Wang, Wan, Li, et al. 2016; Yao et al. 2019). Indeed, with IoT, it is possible synchronize the information collected from the shop floor in real time, and allow communication among man, machine, method and information systems in the factory (Fatorachian and Kazemi, 2018; Ghobakhloo, 2018; Lee et al., 2017; Lenz et al., 2018; Liu et al., 2020; Molano et al., 2018; Yoon et al., 2019; Zhang, Qu, Zhou, et al., 2019). Combining it with cloud technology can also amplify the effects and benefits of these relationships. Indeed, Zhong et al. (2017) view Cloud as a tool for synchronizing machine tools and their twinned services. Moeuf et al. (2018) and Strozzi et al. (2017) confirm the potential of the Cloud in providing access to shared pools for manufacturing resources and capabilities. Lalanda, Morand, and Chollet (2017) propose a Cilia framework to integrate automatically operation data with remote supervision assisted by the Cloud. Rossit, Tohmé, and Frutos (2018) and Saucedo-Martínez et al. (2018) highlight the fact that the high-performance computing capability of Cloud speeds up the computation of solutions. Moreover, the connectivity of complex physical machines, humans, and resources, through networked sensors and software, with Cloud technologies, can provide the foundation software as a service (SaaS) and platform as a service (PaaS) in smart factory solutions (Chen 2017). The IoT has the potential to extract the global state of the smart factory from the massive real-time system information, then coordinate distributed smart objectives with the assistance of powerful Cloud computing ability (Zhang, Ding, Zou, et al. 2019; Wang, Wan, Zhang, et al. 2016; Zhang, Wang, Zhu, et al. 2019). Therefore, IoT and Cloud computing enable the formulation of a smart connected network in the factory. Cloud computing can also be used in combination with ML techniques for implementing smart machining. In this way, machine tools become part of a Cloud-based platform that enable connection with other machines, systems, data sources and people, enabling the cyber machine tools to be readily provisioned as a Cloud service (Kim et al., 2018; Ritou et al., 2019).

Concerning AI, the literature discusses several types of semantic applications in production systems. Lu and Xu (2018) discussed in detail how to virtualize resources for the creation of DT, enabled by ontology, which can map machine status and operation at device, component and sub-component level. There are also other similar applications adopting ontology for mapping classes, properties, relation and instances of manufacturing resources, in order to formalize resource knowledge base (Wan, Chen, et al., 2018; Wan, Yang, et al., 2018). Pedone and Mezgár (2018) focus on industrial interoperability, comparing two of the major standardization frameworks for industrial Internet architectures. In addition, Jirkovsky, Obitko, and Marik (2017) identified the challenges of semantic heterogeneity, while Patel, Ali, and Sheth (2018) show the cases of vertical and horizontal integration empowered by a Semantic Web of Things for I4.0.

Another stream of AI application is Multi-Agent applications. Silva et al. (2018) tested a Multi-Agent System (MAS) composed of a component monitoring agent, subsystem monitoring agent and deployment agent, to investigate the acquisition of data at different levels of granularity, as well as to perform context-aware data analysis enabled by ML models for assisting predictive manufacturing at shop-floor level. In addition, as mentioned in CPS, agent-based CPPS architecture, empowered by semantics and the Cloud, could facilitate self-adjustment and dynamic resource allocation (Cruz Salazar et al., 2019; Jiang et al., 2018; Tan et al., 2019).

The Simulation and Modelling technologies are also useful for supporting production processes. Urbina Coronado et al. (2018) and Benotsmane, Kovács, and Dudás (2019) demonstrate how Simulation and Modelling can be adopted for virtualizing manufacturing resources. While Longo, Nicoletti, and Padovano (2019) stress the fact that digital twin enables the physical system and its submodules to feed the virtual representation of the physical space with real-time streams of data. Simulation and modelling can also be useful for previewing the evaluation of production planning and performances. Xu et al. (2016) highlight the importance of Simulation in decision-making within an Industrial internet environment by proposing a multi-fidelity approach to tackling the increased complexity of real-time simulation. Yoon et al. (2019) present a Smart Factory Information Service Bus (SIBUS) for seamless manufacturing information exchange, in which simulation is implemented to predict the expected total performance index (TPI) for the system. Moreover, Z. Zhang et al. (2019) describe explicitly the framework of simulation-based approaches for predicting production efficiency and equipment utilization rate before the construction of the production system. Kaihara et al. (2017) shift their research objective to the factory as a whole, considering each factory as an agent, and formulate a simulation model to forecast resource bottlenecks, in order to improve both the order fulfilment rate and resource use within the context of crowdsourced manufacturing. In addition, simulation techniques can verify the correctness and security of planning and scheduling decisions by comparing the actual job shop statement and digital twin job shop statement (Zhang, Ding, Zou, et al. 2019; Fei Tao and Zhang 2017; Guizzi, Falcone, and De Felice 2019; Cimino, Negri, and Fumagalli 2019).

As regards Visualization technology, two main applications are worth mentioning, namely: Shop-Floor Visualization, Automated Guidance for manual operator tasks and

Staff Training Simulation. On the one hand, virtual reality can act as a visualization platform for aligning physical production lines with virtual world (Turner et al. 2016). On the other hand, visualization technologies such as Industrial AR (IAR) can support operators by suggesting manufacturing tasks step-by-step, in particular for assembly instructions (Blanco-Novoa et al. 2018; Ang et al. 2017; Kamble, Gunasekaran, and Gawankar 2018; Wang, Ong, and Nee 2018; Cohen et al. 2019; Kadir, Broberg, and Conceição 2019; Mourtzis, Zogopoulos, and Xanthi 2019). In addition, VR enables immersive virtual environments for live on-the-job skill refinement, which enhance customized assembly training (Abidi et al., 2019; Pérez et al., 2019; Simões et al., 2019).
For Automation and industrial robots, two main applications emerged from the literature analysis, which are human-robot collaborative operations and production process automation. With respect to human-robot collaboration, Chen (2017) identified collaborative robots as one of the emerging technology trends for integrated and intelligent manufacturing (i2M), due to them being more flexible and smart in dealing with complex and challenging material-handling and manufacturing situations. Industrial robots can thus offer increased technological support for operators in production environment since manufacturing tasks are becoming more individualized and more flexible (Kamble et al., 2018; Moeuf et al., 2018; Strandhagen, Alfnes, et al., 2017). Human-robot collaboration can also improve safety for workers by reducing the risk of injuries (Benotsmane et al., 2019; Robla-Gomez et al., 2017). Obviously, increasing the number of robots used in a production environment facilitates and fosters the automation of production processes, thus reducing costs (Kamble, Gunasekaran, and Gawankar 2018; J. W. Strandhagen et al. 2017; Ghobakhloo 2018; Zhang, Wang, Zhu, et al. 2019).
Finally, AM can effectively support the management of advanced pull systems and, in particular, just-in-time techniques. In this regard, Chen and Lin (2017) investigate the relationship between AM and lean manufacturing, highlighting the fact that 3D printing conforms to the concepts of "pull systems" and "no inventory". Indeed, products can be manufactured in a print-on-demand manner, eliminating the need for product inventory. Manufacturing facilities with 3D printers can also be isolated from other facilities, thereby enabling factories to be downsized for leaner manufacturing (Cohen et al., 2019).

Table 7: Impact of I4.0 enabling technologies on "Production Scheduling and Control"

Technologies	Applications	Sources
Cyber-Physical Systems	Cyber-physical production system	(Abidi et al., 2019; Chen et al., 2017; Cruz Salazar et al., 2019; Diez-Olivan et al., 2019; Fatorachian and Kazemi, 2018; Ghobakhloo,

	scheduling and control	2018; Jiang et al., 2018; Kang et al., 2016; Lalanda et al., 2017; Longo, Nicoletti and Padovano, 2019; Lu and Xu, 2019; Mittal et al., 2019; Monostori et al., 2016; Rojas and Rauch, 2019; Rossit et al., 2019; Tan et al., 2019; Tao and Qi, 2019; Tao and Zhang, 2017; Turner et al., 2016; Urbina Coronado et al., 2018; Wan, Chen, et al., 2018; Wang, Wan, Li, et al., 2016; Wang, Wan, Zhang, et al., 2016; Wang et al., 2017; Xu, 2017; Zhang, Ding, Zou, et al., 2019; Zhang, Wang, Zhu, et al., 2019)
	Manufacturing resource virtualization	(Lu and Xu, 2018; Shafiq et al., 2015; Shafiq, Sanin, Toro, et al., 2016)
Internet of Things	Data collection from production processes and resources	(Lalanda et al., 2017; Makris et al., 2016; Mourtzis and Vlachou, 2018; Tao and Qi, 2019; Tao and Zhang, 2017; Wang, Wan, Li, et al., 2016; Wang et al., 2017; Zhong et al., 2017)
	Smart connected factory formalization	(Chen, 2017; Fatorachian and Kazemi, 2018; Ghobakhloo, 2018; Lee et al., 2017; Lenz et al., 2018; Liu et al., 2020; Molano et al., 2018; Rojas and Rauch, 2019; Simões et al., 2019; Strandhagen, Alfnes, et al., 2017; Tan et al., 2019; Wan et al., 2016; Wan, Chen, et al., 2018; Wang, Wan, Li, et al., 2016; Wang, Wan, Zhang, et al., 2016; Yao et al., 2019; Yoon et al., 2019; Zhang, Ding, Zou, et al., 2019; Zhang, Qu, Zhou, et al., 2019)
Big Data and Analytics	Automated resource allocation and scheduling	(Ang et al., 2017; Kamble et al., 2018; Kang et al., 2016; Liu et al., 2020; Moeuf et al., 2018; Qi and Tao, 2018; Rojas and Rauch, 2019; Tao and Qi, 2019; Wang, Wan, Li, et al., 2016; Wang, Wan, Zhang, et al., 2016; Zhang, Ding, Zou, et al., 2019)
Cloud technology	Storage and computation capacities for smart connected factories	(Chen, 2017; Fatorachian and Kazemi, 2018; Ghobakhloo, 2018; Lalanda et al., 2017; Liu et al., 2020; Moeuf et al., 2018; Molano et al., 2018; Mourtzis et al., 2019; Rojas and Rauch, 2019; Rossit et al., 2019; Saucedo-Martínez et al., 2018; Strandhagen, Alfnes, et al., 2017; Strozzi et al., 2017; Tan et al., 2019; Wan et al., 2016; Wang, Wan, Li, et al., 2016; Wang, Wan, Zhang, et al., 2016; Yoon et al., 2019; Zhang, Ding, Zou, et al., 2019; Zhang, Wang, Zhu, et al., 2019; Zhong et al., 2017)
	Smart machining implementation	(Kim et al., 2018; Xu, 2017)
Artificial Intelligence	Automated resource allocation and scheduling	(Cohen et al., 2019; González Rodríguez et al., 2020; Moussa and ElMaraghy, 2019; Sharp et al., 2018; Wan, Yang, et al., 2018; Zhang, Ding, Zou, et al., 2019)

	Smart machining implementation	(Kim et al., 2018; Ritou et al., 2019)
	Semantic applications for production systems	(Gorecky et al., 2017; Jirkovsky et al., 2017; Lu and Xu, 2018; Patel et al., 2018; Pedone and Mezgár, 2018; Turner et al., 2016; Wan, Chen, et al., 2018; Wan, Yang, et al., 2018; Xu, 2017)
	Multi-agent applications for production systems	(Cruz Salazar et al., 2019; Jiang et al., 2018; Kaihara et al., 2017; Peres et al., 2018; Rojas and Rauch, 2019; Tan et al., 2019; Wan, Chen, et al., 2018)
Blockchain	-	-
Simulation and Modelling	Manufacturing resources virtualization	(Benotsmane et al., 2019; Lu and Xu, 2018; Shafiq et al., 2015; Shafiq, Sanin, Szczerbicki, et al., 2016; Simões et al., 2019; Turner et al., 2016; Urbina Coronado et al., 2018)
	Production planning preview and performances evaluation	(Cimino et al., 2019; Guizzi et al., 2019; Kaihara et al., 2017; Longo, Nicoletti and Padovano, 2019; Tao and Zhang, 2017; Xu et al., 2016; Yoon et al., 2019; Zhang, Ding, Zou, et al., 2019; Zhang, Wang, Wang, et al., 2019)
Visualization technology (Augmented and Virtual Reality)	Shop floor visualization	(Turner et al., 2016)
	Automated guidance for operators' manual tasks	(Abidi et al., 2019; Ang et al., 2017; Blanco-Novoa et al., 2018; Cohen et al., 2019; Kadir et al., 2019; Kamble et al., 2018; Mourtzis et al., 2019; Pérez et al., 2019; Simões et al., 2019; Wang et al., 2018)
Automation and Industrial Robots	Collaborative operations with humans	(Benotsmane et al., 2019; Chen, 2017; Cohen et al., 2019; Kadir et al., 2019; Kamble et al., 2018; Moeuf et al., 2018; Robla-Gomez et al., 2017; Strandhagen, Alfnes, et al., 2017)
	Production process automation	(Ghobakhloo, 2018; Kamble et al., 2018; Moussa and ElMaraghy, 2019; Strandhagen, Alfnes, et al., 2017; Zhang, Wang, Zhu, et al., 2019)
Additive Manufacturing	JIT and advanced pull system management	(Chen and Lin, 2017; Cohen et al., 2019)

4.6 Energy management

Energy management has become an extremely important issue in a context of increasing attention towards emissions and sustainability. In recent years, in part driven by the growing focus on circular economy, there has been an increase in articles describing applications of I4.0 enabling technologies in support of energy management, although the field is still relatively unexplored (Table 8). According to Bonilla et al. (2018), although the implementation of IoT may increase the energy flow in manufacturing, it could also provide reliable data about energy flow, facilitating BDA technologies in combination with energy optimization algorithms to offset and partially reduce energy consumption. With an IoT platform connected by sensors and gauges, data can be further monitored and analysed to provide accurate energy consumption trends (Illa and Padhi, 2018). Indeed, CPS, in combination with IoT and Cloud, enables equipment to be adjusted, allowing energy consumption to be monitored in real-time, activating service-oriented energy management (Diaz C. and Ocampo-Martinez, 2019). Blockchain can guarantee the exchange of trusted information and automate the process of negotiating energy supply agreements among enterprises (Mohamed et al., 2019). Yan et al. (2017) propose a framework for structuralizing multisource heterogeneous industrial big data, and mining the regulatory energy-saving mechanism. Kumar, Singh, and Lamba (2018) consider electrical energy consumption (EEC) in factory layout design, in order to make the proposed layout environmentally sustainable. However, Mawson and Hughes (2019) concluded that there are few studies examining the concept of digital twin for energy analysis, and there is also a limited application of AR and VR to energy analysis.

Table 8: Impact of I4.0 enabling technologies on "Energy Management"

Technologies	Energy management	Sources
Cyber-Physical Systems	Service-oriented energy management	(Bonilla et al., 2018; Diaz C. and Ocampo-Martinez, 2019; Mohamed et al., 2019)
Internet of Things	Energy consumption monitoring	(Bonilla et al., 2018; Diaz C. and Ocampo-Martinez, 2019; Kumar et al., 2018; Mohamed et al., 2019)
Big Data and Analytics	Energy performance and consumption forecasting	(Bonilla et al., 2018; Illa and Padhi, 2018; Kumar et al., 2018; Yan et al., 2017)
Cloud technology	Service-oriented energy management	(Mohamed et al., 2019)
Artificial Intelligence	-	-
Blockchain	Smart contract for energy supply and consumption	(Mohamed et al., 2019)
Simulation and Modelling	Energy performance and consumption forecasting	(Kumar et al., 2018; Mawson and Hughes, 2019; Yan et al., 2017)
Visualization technology (Augmented and Virtual Reality)	-	-
Automation and Industrial Robots	-	-
Additive Manufacturing	-	-

4.7 Quality management

Few of the technologies investigated in this research are applied to quality management (Table 9). The adoption of an IoT platform can help to segregate clinically defect-related data, for the more effective prevention of quality defects and material savings (Illa and Padhi, 2018). Therefore, the main application of the IoT in quality management is quality defect detection in factory-made products. Tao and Qi (2019) also discuss the capacity of BDA applied to product quality and monitoring manufacturing processes. Indeed, BDA enables accurate data analysis from the production process, making it easier to detect subtle changes in the quality of products. Kucukoglu et al. (2018) tested the joint implementation of artificial neural network (ANN) and digital wearable gloves for classifying appropriate and defective operations in connector assembly though feedback signals on vibration and force in the fingers. Carvajal Soto, Tavakolizadeh, and Gyulai (2019) propose discrete event simulation to identify and assess different methods of product failure inspection by means of testing different ML techniques without disturbing physical production. AI-related technologies could thus specifically support the detection of defects in assembly processes (Peres et al., 2019). At the same time, augmented reality tools, such as visual wearables, may be used to compare the 3D CAD product model and the physical artefact (Blanco-Novoa et al., 2018; Ferraguti et al., 2019). In addition, Nagy et al. (2018) demonstrate an industrial case of using AR instead of paper-based checklists for quality checks. Avalle et al. (2019) proposes an AR-enabled method of detecting and placing industrial robot faults, while Muñoz et al. (2019) investigate a mixed reality approach for car body surface quality inspections.

Table 9: Impact of I4.0 enabling technologies on "Quality Management"

Technologies	**Applications**	**Sources**
Cyber-Physical Systems	-	-
Internet of Things	Product quality defect detection	(Illa and Padhi, 2018)
Big Data and Analytics	Manufacturing process quality monitoring and control	(Tao and Qi, 2019)
Cloud technology	-	-
Artificial Intelligence	Assembly defect detection	(Kucukoglu et al., 2018)
	Product quality defect detection	(Carvajal Soto et al., 2019; Peres et al., 2019)
Blockchain	-	-
Simulation and Modelling	Product quality defects detection	(Carvajal Soto et al., 2019)
Visualization technology (Augmented and Virtual Reality)	Digital visual quality control	(Avalle et al., 2019; Blanco-Novoa et al., 2018; Ferraguti et al., 2019; Muñoz et al., 2019; Nagy et al., 2018)
Automation and Industrial Robots	-	-

Additive Manufacturing	-	-

4.8 Maintenance management

The issue of maintenance is one of the most important areas within manufacturing company; a well-structured maintenance plan allows companies to achieve high efficiency in production with minimal downtime and reduce the consumption of resources.

CPS enables real-time monitoring of production assets in order to connect the physical world with virtual space (Ansari et al., 2019). These data are transmitted through IoT in order to develop smart solutions for condition-based maintenance (Fumagalli et al., 2019; Wan et al., 2017). With IoT, the monitoring of operating conditions is more efficient and sustainable, as it avoids the engagement of excessive resources (Lopes de Sousa Jabbour et al., 2018). To demonstrate this, Mourtzis and Vlachou (2018) focus on shop-floor scheduling and condition-based monitoring based on data collected from machines and stored on a Cloud platform, where machine tools and human resources are connected through the IoT. In addition, Li, Wang, and Wang (2017) propose a framework for fault diagnosis and prognosis in machine centres, which is composed of a data acquisition module enabled by the IoT and a data pre-processing module operated by a big data warehouse. The IoT guarantees the collection of big data from the operation of the various machines and Cloud technology provides the storage capacity and computation power to process them (Caggiano 2018; Diez-Olivan et al. 2019; Turner et al. 2019). A third technology supporting the maintenance process is BDA, which provides tools and models to highlight trends and patterns in order to develop an effective maintenance plan. Therefore, the combined use of the IoT and BDA can facilitate real-time monitoring of machinery for the early detection of anomalies and predictive maintenance (Neirotti, Raguseo, and Paolucci 2018; Chen 2017; Canizo et al. 2019). Indeed, BDA has been effectively applied to predicting the lifecycle of equipment, tools and robots (Tao and Qi 2019; Illa and Padhi 2018; Xu and Duan 2019; Yan et al. 2018). This application is also confirmed by Ang et al. (2017) who introduce the IoT, big data and automated simulation for machinery health monitoring in ship manufacturing. CPS is also the foundation for further virtual representation of digital twin and simulation tools to monitor effectively the health of the machinery workshop, using the data collected from the IoT gateway stored in Cloud (Guizzi et al., 2019; Longo, Nicoletti and Padovano, 2019; Redelinghuys et al., 2019). In this regard, it is possible to combine digital twin and BDA for smart MRO (Maintenance, Repair and Overhaul), so that the location and diagnosis can be displayed to users and technicians (Qi and Tao, 2018).

The use of AI techniques can also facilitate fault diagnosis and predictive maintenance (Sharp et al., 2018; Wan, Yang, et al., 2018). Zenisek, Holzinger, and Affenzeller (2019) propose a combined off and online model for identifying the condition of machinery and forecast deviations by examining different ML algorithms. Ansari, Glawar, and Nemeth (2019) propose a prescriptive maintenance model (PriMaf) for adapting maintenance activities within the context of CPPS, where deep learning is used to support decision making and learning from multi-dimensional data sources.

Regarding Visualization technology, Roy et al. (2016) and Nagy et al. (2018) highlight the potential of using AR to support maintenance training tasks, while Blanco-Novoa et al. (2018) evaluate the implementation of IAR in effectively detecting anomalies and identifying problems. Rao and Prasad (2018) also discuss the benefit of the ultra-low latency and high reliability offered by 5G for field personnel using AR devices for conducting maintenance and repair tasks.

The main applications of digital technologies to support maintenance processes are shown in Table 10. As shown, Blockchain and AM are found to have almost no cases of use in maintenance management.

Table 10: Impact of I4.0 enabling technologies on "Maintenance Management"

Technologies	**Applications**	**Sources**
Cyber-Physical Systems	Industrial data acquisition and structuralizing for maintenance analytics	(Ansari et al., 2019; Caggiano, 2018; Canizo et al., 2019; Fumagalli et al., 2019; Guizzi et al., 2019; Li et al., 2017; Longo, Nicoletti and Padovano, 2019; Lopes de Sousa Jabbour et al., 2018; Mourtzis and Vlachou, 2018; Redelinghuys et al., 2019; Turner et al., 2019; Xu and Duan, 2019; Yan et al., 2018)
Internet of Things	Industrial data acquisition and structuralizing for maintenance analytics	(Ang et al., 2017; Ansari et al., 2019; Caggiano, 2018; Canizo et al., 2019; Diez-Olivan et al., 2019; Li et al., 2017; Lopes de Sousa Jabbour et al., 2018; Mourtzis and Vlachou, 2018; Neirotti et al., 2018; Redelinghuys et al., 2019; Turner et al., 2019; Wan et al., 2017; Xu and Duan, 2019; Yan et al., 2018)
Big Data and Analytics	Diagnosis and predictive maintenance analytics	(Ang et al., 2017; Canizo et al., 2019; Chen et al., 2017; Chen, 2017; Diez-Olivan et al., 2019; Illa and Padhi, 2018; Kiangala and Wang, 2018; Qi and Tao, 2018; Tao and Qi, 2019; Wan et al., 2017; Yan et al., 2018, 2017)
Cloud technology	Storage and computation capacity for maintenance analytics	(Caggiano, 2018; Canizo et al., 2019; Diez-Olivan et al., 2019; Kiangala and Wang, 2018; Mourtzis and Vlachou, 2018; Redelinghuys et al., 2019; Wan et al., 2017; Yan et al., 2018)
Artificial Intelligence	Diagnosis and predictive maintenance analytics	(Ansari et al., 2019; Diez-Olivan et al., 2019; Li et al., 2017; Saufi et al., 2019; Sharp et al., 2018; Turner et al., 2019; Wan et al., 2017; Wan, Yang, et al., 2018; Yan et al., 2018, 2017; Zenisek et al., 2019)

Blockchain	-	-
Simulation and Modelling	Workshop machinery health monitoring	(Ang et al., 2017; Guizzi et al., 2019; Longo, Nicoletti and Padovano, 2019; Qi and Tao, 2018; Redelinghuys et al., 2019; Turner et al., 2019)
Visualization technology (Augmented and Virtual Reality)	Maintenance task guidance	(Blanco-Novoa et al., 2018; Nagy et al., 2018; Roy et al., 2016; Turner et al., 2019)
	Maintenance training guidance	(Roy et al., 2016)
Automation and Industrial Robots		
Additive Manufacturing	-	-

4.9 Customer relationship management (CRM)

CRM encompasses all processes that guarantee a personalized experience based on customer needs. For example, one of the distinctive elements offered by a manufacturing company is designing and delivering customized and advanced services connected to the physical product. This allows the manufacturer to acquire an important competitive advantage and build greater customer loyalty. This phenomenon is known in the literature as "servitization", which can be strengthened by the integration of digital technologies (Ardolino et al. 2018). In this case, CPS – applied to products - can form the basis for IoT-readiness to enhance smart interconnection throughout the product lifecycle (Kiel, Arnold, et al., 2017). At the same time, the user behaviour and products operation data collected can help the manufacturing companies to improve product design and production process and provide customer-oriented services (Tao and Qi 2019; Dalenogare et al. 2018; Bressanelli et al. 2018b; Müller 2019; Weking et al. 2020; Ardolino, Saccani, and Eloranta 2018). The IoT usually operates in combination with BDA to enable the application of smart services. Indeed, the status and operating data of the equipment and products can be gathered through the IoT, while BDA facilitates the prediction of equipment and product lifecycles, for the purpose of preventive maintenance (Ardito et al. 2019). This also facilitates customer profiling and service innovation (Anshari et al. 2018). Indeed, BDA offers an advanced form of customer segmentation that allow manufacturers to understand how to support the personalization and customization of sales and services (Anshari et al., 2018), as well as the redistribution of manufacturing (Zaki et al., 2019).

This mechanism can be amplified even further if it is supported by Cloud technology; to the Cloud enables real service platform where connections are established among organisations, suppliers and customers in order to offer bundles of products with related services according to data collected on consumer behaviour and improve customer satisfaction (Lopes de Sousa Jabbour et al. 2018; Dalenogare et al. 2018; Zheng et al. 2018; Frank et al. 2019). In this regard, Zheng et al.

(2018) highlight the power of digital twin-enabled service platforms for the provision of effective product-service systems (PSS) in which heterogenous sources of data and various factors are processed. Therefore, modelling and simulation technologies might also be useful in the development of Cloud service platforms.

Fraga-Lamas and Fernández-Caramés (2019) also demonstrate the potential use of blockchain for seamless service connection, enabling interconnection with IoT-connected vehicles, recording and executing agreements for digital retailing, usage-based insurance and monetary transactions. Furthermore, AM demonstrates its full potential in the customization and individualization of physical products; all this can significantly improve the level of service and increase customer perceived value (J. O. Strandhagen et al. 2017; Chen and Lin 2017). Indeed, the decentralized and high-performance of AM facilitate mass-customization (Ghobakhloo, 2018; Kamble et al., 2018; R. Novais et al., 2019; Yin et al., 2018).

Table 11 summarizes the main applications of I4.0 enabling technologies in CRM processes.

Table 11: Impact of I4.0 enabling technologies on "Customer Relationship Management"

Technologies	**Applications**	**Sources**
Cyber-Physical Systems	Advanced services	(Kiel, Arnold, et al., 2017; Lopes de Sousa Jabbour et al., 2018; Strandhagen, Vallandingham, et al., 2017; Weking et al., 2020)
Internet of Things	Customized and advanced services	(Anshari et al., 2018; Ardito et al., 2019; Ardolino, Rapaccini, et al., 2018b; Bressanelli et al., 2018b; Dalenogare et al., 2018; Frank et al., 2019; Kiel, Arnold, et al., 2017; Lopes de Sousa Jabbour et al., 2018; Müller, 2019; Tao and Qi, 2019; Weking et al., 2020)
Big Data and Analytics		
	Customer profiling & service innovation	(Anshari et al., 2018; Ardito et al., 2019; Bressanelli et al., 2018b; Frank et al., 2019; Zaki et al., 2019; Zheng et al., 2018)
Cloud technology		
	Cloud service platform;	(Ardito et al., 2019; Dalenogare et al., 2018; Frank et al., 2019; Lopes de Sousa Jabbour et al., 2018; Strandhagen, Vallandingham, et al., 2017; Zheng et al., 2018)
Artificial Intelligence	-	-
Blockchain	Customized and advanced services	(Fraga-Lamas and Fernández-Caramés, 2019)
Simulation and Modelling	Customized and advanced services	(Zheng et al., 2018)
Visualization technology	-	-

(Augmented and Virtual Reality)		
Automation and Industrial Robots	-	-
Additive Manufacturing	Product customization and individualization	(Dalenogare et al., 2018; Ghobakhloo, 2018; Kamble et al., 2018; Lopes de Sousa Jabbour et al., 2018; R. Novais et al., 2019; Strandhagen, Vallandingham, et al., 2017; Yin et al., 2018)

4.10 After-sales management

Table 12 lists the applications of I4.0 enabling technologies in After-Sales Management, an important phase that completes the loop of lifecycle management. In fact, the relationship with a customer of a manufacturing company generally does not end with the sale of the physical product. Furthermore, companies are increasingly responsible for managing disposal in the end-of-life (EOL) product phase.

Several contributions in the literature show that the IoT enables data to be collected from the physical product in order to monitor the different parameters of its usage throughout its lifecycle (Ben-Daya et al., 2019). This monitoring can be suitable for evaluating possible manufacturer responsibility for the operation and disposal of the product. Indeed, Gu et al. (2018) focus on investigating extended producer responsibility (EPR) for managing Waste Electrical and Electronic Equipment (WEEE). In this case, the cloud plays the fundamental role of repository of these data (Bougdira et al., 2019). For example, Roy et al. (2016) explore the service of product lifecycle maintenance, suggesting how to implement the IoT, Cloud and BDA to collect and interpret product-related data, in order to gather information on in-service degradation mechanisms and to plan appropriate maintenance operations. Moreover, the IoT, CPS and Cloud enhance the track and trace of post-consumption products, especially in the reverse logistics phase, enabling companies to reuse, remanufacture or recycle product components (Dev et al., 2020; Kerin and Pham, 2019) and speed up the transition towards a circular economy (Garrido-Hidalgo et al., 2019; Pham et al., 2019). Indeed, BDA, along with AI, is capable of isolating specific operating trends and assessing end-of-life product recovery (Bressanelli et al., 2018b; Rajput and Singh, 2019; Strandhagen, Vallandingham, et al., 2017). In addition, Goodall, Sharpe, and West (2019) investigate the data-driven simulation framework for dynamic remanufacturing operations, which is composed of adaptive remanufacturing simulation, remanufacturing information models and information system service layers.

In addition, blockchain can help manage remanufacturing operations by updating the relevant information of the spare parts on the shared ledger available to all the entities involved, such as car manufacturers or warehouse distributors.

With respect to Visualization Technology, Scurati et al. (2018) develop a glossary of symbols that can be used in the communication of maintenance instructions via AR. Blanco-Novoa et al. (2018) also show the similar application of IAR for augmented real-time collaboration and reporting. Finally, AM is shown to be an effective technology for spare parts management (Petr, 2018; Stock et al., 2018). Important ecological and social gains can be achieved by producing individual spare parts with 3D printing, exploiting flexibility and reduced production lead time to extend the lifecycle of components and products. Indeed, Kerin and Pham (2019) confirm that exploring the use of AM for low-value mass remanufacturing could be a future line of research.

Table 12: Impact of I4.0 enabling technologies on "After-Sales Management"

Technologies	**Applications**	**Sources**
Cyber-Physical Systems	Product-in-use monitoring	(Roy et al., 2016)
	Reverse logistics management and control	(Dev et al., 2020)
Internet of Things	Product-in-use monitoring	(Ben-Daya et al., 2019; Bressanelli et al., 2018b; Gu et al., 2019; Roy et al., 2016; Strandhagen, Vallandingham, et al., 2017)
	Reverse logistics management and control	(Ben-Daya et al., 2019; Dev et al., 2020; Garrido-Hidalgo et al., 2019; Pham et al., 2019; Rajput and Singh, 2019)
Big Data and Analytics	Product-in-use assessment	(Bressanelli et al., 2018b; Kerin and Pham, 2019; Roy et al., 2016; Strandhagen, Vallandingham, et al., 2017)
Cloud technology	Product-in-use data storage and processing	(Bougdira et al., 2019; Lopes de Sousa Jabbour et al., 2018; Pham et al., 2019; Roy et al., 2016)
	Reverse logistics management and control	(Dev et al., 2020; Garrido-Hidalgo et al., 2019)
Artificial Intelligence	Product-in-use assessment	(Bougdira et al., 2019; Rajput and Singh, 2019)
Blockchain	Spare part tracking	(Alladi et al., 2019)
Simulation and Modelling	Remanufacturing operations	(Goodall et al., 2019; Kerin and Pham, 2019)
	Reverse logistics management and control	(Dev et al., 2020)
Visualization technology (Augmented and Virtual Reality)	Remote maintenance support	(Blanco-Novoa et al., 2018; Scurati et al., 2018)
Automation and Industrial Robots	-	-

Additive Manufacturing	Spare part management	(Petr, 2018; Stock et al., 2018)
	Remanufacturing operations	(Kerin and Pham, 2019)

5 Discussion and research agenda

This article reviews the existing literatures on the application of I4.0 in manufacturing. Although several contributions have been published, it is clear that this is a growing area of research, reflecting the current trend in the manufacturing sector. This section outlines a future research agenda based on the results of the systematic literature review.

5.1 I4.0 enabling technologies: different levels of maturity and application potential

The adoption of I4.0 by manufacturing companies concerns, first of all, the implementation of digital technologies to support various businesses processes. As shown in the previous sections, the scientific literature includes many contributions investigating the role of technologies and their possible applications in the various business processes. However, for one reason or another, there are technologies that have been researched more than other ones. Figure 5 shows a heatmap of the articles analysed for this SLR. In particular, the horizontal axis shows the technologies investigated, while the vertical axis shows the different manufacturing processes.

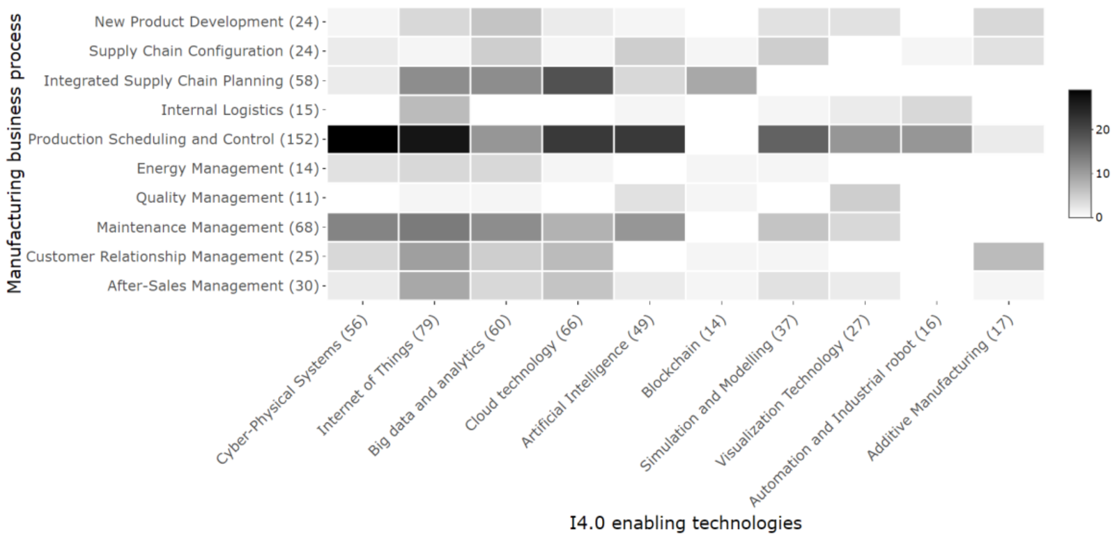

Figure 5: Research focus heatmap

Focusing on the technologies, this chart highlights the high interest in technologies such as IoT, BDA and Cloud. There are 79 papers investigating the impact of the IoT in different manufacturing processes, confirming the fact that the fundamental characteristic of I4.0 is connection, interaction and cooperation. In fact, IoT guarantees the connectivity and formulation of a network for gathering and transferring information. The IoT is followed by the Cloud, which is covered by 66 papers, and BDA with 60 papers, which strengthen the fact that academics are concentrating on finding smart data management solutions, facilitating the data-driven digital transformation of manufacturing companies. Then, there is a second group of technologies made up of CPS (56), AI (49), Simulation and Modelling (37) and Visualization Technology (27). From the analysis of the literature carried out in this paper, it appears that CPS, the founding technology for enabling I4.0, is a purely technological domain mainly applied to the production process. Furthermore, in many cases, CPS is not described as a technology, but as a working environment in which to build applications for supporting production activities. CPS is also the element on which the virtualization of the entire company is based, but the contributions are generally rather theoretical and still focus heavily on production. Future research should focus on investigating the opportunity of using CPS to support the entire factory and, more extensively, the entire supply chain.

In turn, AM (17), Automation and Industrial Robot (16) and Blockchain (14) are less debated in the literature, and their uses are associated with different aspects of manufacturing processes: AM is more product-related, with frequent discussion of rapid prototyping and customized product development; automation and industrial robot are adopted in process automation and human robot collaboration. On the other hand, blockchain technology is associated with information synchronization among the stakeholders along the supply chain. In fact, the roots of AM in product customization and robots in process automation are not new. The improvements offered by these technologies can be viewed as a continuation to previous developments. However, as blockchain is a relatively new technology for manufacturing companies, there is vast potential for using this technology for the entire supply chain; however, current literature is still in the early stage and it is difficult to understand for many practitioners. Future research should certainly examine this area in greater depth.

5.2 The integration of IoT, BDA and Cloud as the data-driven solution towards Industry 4.0

Considering the main applications of I4.0 enabling technologies in supporting business processes, it turns out that certain applications are supported by multiple enabling technologies. This shows how sometimes a transversal and integrated use of digital technologies, the full breadth of I4.0, achieves more effective results.

The IoT, BDA and Cloud account for large proportion of integrated implementation and their application covers a wide range of processes. Indeed, the IoT, BDA and Cloud are observed to appear simultaneously in many application scenarios, and they work together in the entire lifecycle from product development to end-of-life. The extensive use of these technologies can be explained by the fact that I4.0 seeks vertical, horizontal and end-to-end engineering. Such integration requires the interconnection of levels, from equipment to shop-floor, factory and even supply chain. Indeed, the IoT enables the creation of connected networks that contain huge amounts of data, then the Cloud offers computation and storage capacities for managing distributed data flow, and finally BDA serves to regulate and rationalize data. Another characteristic of these technologies is that they are IT technologies, which are mainly intended to employ data as raw material for process automation and integration. For instance, New product development, by incorporating the IoT and BDA, enhances product design, since BDA enables the processing and extraction of knowledge from product data, which are collected from the IoT. In addition, when the IoT is combined with the Cloud, the emphasis is placed on the creation of a platform for synchronizing information among stakeholders along the supply chain, facilitating efficient and precise planning, as well as collaboration among the different players. For maintenance management, the interplay among IoT, BDA and Cloud technology in predictive maintenance is evident. The role of IoT is to collect data from machines or processes that apply to maintenance. As the IoT connects with the Cloud, Cloud-based architecture can be formalized, serving as the foundation for the next step of big data pre-processing and pattern recognition assisted by BDA and, sometimes, Machine learning techniques. Finally, in CRM processes, the integrated use of the IoT, BDA and Cloud can effectively support digital "servitization" (Sklyar et al., 2019), gathering data on product operation and user behaviour through the IoT and processing them using BDA to generate a new service portfolio, encompassing advanced and customized services and increasing customer perceived value.

The synergistic use of IoT, BDA and Cloud has proven to be very effective in various individual manufacturing processes (Hofmann and Rüsch, 2017; Zhang, Ding, Zou, et al., 2019), their integrated use allows data to be analysed more effectively than ever, which is also in alignment with the objectives of I4.0 for real-time support and decentralized decision making. Future research should evaluate the integrated use of these technologies as a powerful element of I4.0. In general, this overview is relevant not only to manufacturing companies, but also to data management processes in general and is potentially applicable to all sectors in which data analysis is of strategic importance.

5.3 Industry 4.0 as a lever for optimizing strategic configuration choices and achieving customer centricity

The analysis of the heatmap (Figure 5) also shows which processes, among those listed in the framework presented in this article, have received attention in the scientific literature. Production scheduling and control ranks far ahead of other processes with 152 articles, almost all the reviewed papers. This result is perfectly in line with the principles that gave rise to I4.0, i.e. the wish to impact effectively the efficiency of production processes thanks to the power of digital technologies. Indeed, on the one hand, it is possible to reduce the time and costs in relation to production assets and machines and, on the other hand, the technologies applied to maintenance processes improve the performance and reliability parameters in the production department. There is less focus, however, on the other processes within Production and Operations Management: internal logistics is investigated by 15 papers, while Quality Management and Energy Management are investigated by only 11 and 14 papers respectively. Regarding the area of Supply Chain Management, we see that integrated supply chain planning ranked in third place with 58 papers, while supply chain network configuration was studied in just 24 papers. From this analysis, it seems that scholars concentrate more on studying the impact of I4.0 enabling technologies on planning, while the configuration of strategic supply chain network received much less attention. Based on the results achieved, it can be said that I4.0 mainly impacts the operating processes of manufacturing companies. In the last few years, literature has also begun to investigate more tactical aspects, mainly investigating the effects of 4.0 technologies supporting integrated supply chain planning. However, little has been said about the effects on strategic configuration choices at the level of individual company or supply chain. These choices can have strong repercussions both in terms of the efficiency of the operation in the entire supply chain and the effectiveness in ensuring an adequate level of service to customers. Future research in this direction would help increase knowledge in this area. Extending the perspective to include lifecycle management, there are 24 and 25 papers investigating separately New Product Development and Customer Relationship Management, whereas After-Sales gets more attention with 30 papers. This denotes an ever-increasing attention towards more customer-oriented processes. It is recommended that future research should make efforts to examine the role of I4.0 in supporting processes aimed at achieving customer centricity.

5.4 Industry 4.0 as enabler of servitization and circular economy: from the 'smart factory' to the 'smart supply chain' concept

Industry 4.0 has been considered since its inception the enabling element of what is known as Smart Factory, with particular emphasis on company manufacturing processes (Kagermann, 2015). Indeed, I4.0 was conceived for improving the efficiency and effectiveness of production processes. However, research developments are shifting more and more from the individual factory to a broader vision of the whole supply chain (Frederico et al., 2019). Likewise, the aims described in the literature are also changing. This is demonstrated by to the trend of associating

I4.0 increasingly with servitization and the concept of circular economy. These two strands, which are developed independently in the literature of I4.0, are increasingly interconnected (Frank et al., 2019; Lopes de Sousa Jabbour et al., 2018; Nascimento et al., 2019; Sklyar et al., 2019). It is therefore clear that the concept of 'smart factory' is evolving into that of 'smart supply chain'. The smart supply chain is enabled by the implementation of I4.0 and therefore of digital technologies enabling an increasingly "servitized" offer that favours the circular economy. This transformation has led to an increasing emphasis on the importance of the customer and environmental sustainability, promoting the focus on 'customer centricity'. On the one hand, putting the customer at the center, I4.0 thus favours the implementation and delivery of increasingly advanced and "servitized" solutions. One the other hand, thanks to the great savings achievable in terms of consumption of resources and emissions, I4.0 focuses on the sustainable aspect by stimulating increasingly environmentally friendly processes. Future research should concentrate more on this new Industry 4.0-enabled model.

6 Conclusions

This research sought to systematize the existing body of scientific knowledge concerning the impacts of I4.0 on the manufacturing industry. In particular, this paper aims to provide an overview of the main applications of I4.0 enabling technologies supporting business processes of manufacturing companies.

Despite the increasing number of contributions in the scientific literature, the authors found that there is a lack of a comprehensive overview of how I4.0 enabling technologies can be applied to support manufacturing life cycle processes. Moreover, reviews on these topics don't deal with holistic study about the impact of digital technologies on business processes. To fill this gap, the authors performed a systematic literature review, adopting an original conceptual framework to guide their research. A list of the main I4.0 enabling technologies was formulated and, for each of them, the impact on and main applications in the various business processes were assessed. The results of this research show that, considering both technologies and processes, there are areas that have received more attention in the scientific literature. Indeed, the results of this research highlighted certain gaps in the literature on I4.0 that led to the identification of four recommended directions for future research.

In addition to the theoretical implications, this work also has important practical implications. The results of this literature review shed light on the potential applications of digital technologies in I4.0 and the most suitable areas of application in manufacturing. Very often, the issue of I4.0 remains on an abstract level and it is very difficult for practitioners to understand exactly how to exploit this new revolution concretely. This research can provide insights for manufacturing companies to understand better and assess the best strategic choices to make and the possible repercussions.

As with any research, this study comes with some limitations. The first is the framework, since not all the technologies that can potentially be considered part of I4.0 have been examined. However, there is no agreed taxonomy in the scientific literature, thus the authors considered all the relevant research in order to formulate an exhaustive list. The same goes for the selected business processes. However, in this case too, the authors' selection involved in-depth examination of well-known models and classifications used in both scientific and managerial literature. A further area concerns the methodology adopted for this literature review. First, there could be a subjective bias in the reading and selection of papers. Indeed, the exclusion criteria adopted in the literature review strategy were set according to the objectives of the papers and they may have excluded useful articles for analysis. In this regard, having selected papers from only two databases (Scopus and WoS), despite them being heavily populated, we may have omitted a fraction of the literature. Moreover, some scientific articles published on the topic of I4.0, especially in the early years, are written in German and were therefore excluded from this work. Finally, the approach adopted to identify the applications of the technologies supporting the various business processes was qualitative and non-quantitative.

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B. The impacts of Industry 4.0: A descriptive survey in the Italian manufacturing sector

Title	The impacts of Industry 4.0: A descriptive survey in the Italian manufacturing sector
Authors	Ting Zheng, Marco Ardolino, Andrea Bacchetti, Marco Perona, Massimo Zanardini
Outlet	Journal of Manufacturing Technology Management
Year	2019
Status	Published, ahead-of-print

Abstract.

Purpose: This paper is aimed at investigating how much the Italian manufacturing companies are ready to be concretely involved in the so-called 'Industry 4.0' journey. In particular, this paper focuses on analyzing the knowledge and adoption levels of specific I4.0 enabling technologies, also considering how organizations are involved and which are the main benefits and obstacles.

Design/methodology/approach: A descriptive survey has been carried out on a total of 103 respondents related to manufacturing companies of different sizes. Data collected was analyzed in order to answer five specific research questions.

Findings: The findings from the survey demonstrate that Italian manufacturing companies are in different positions in their journey towards the I4.0 paradigm, mainly depending on their size and informatization level. Furthermore, not all the business functions are adequately involved in this transformation and their awareness about this new paradigm seems quite low because of the absence of specific managerial roles to guide this revolution. Finally, there are strong differences concerning both benefits and obstacles related to the adoption of I4.0 paradigm, depending on the technology adoption level.

Research limitations/implications: Future research should focus on developing case studies about pilot I4.0 practitioners in order to understand the root cause of successful cases. Both managerial and practical references should be developed, helping Italian manufacturing enterprises to consolidate and strengthen their position in global competitive market. Finally, it would be interesting to carry out the same study in other countries in order to make comparisons and suitable benchmark analyses.

Originality/value: Despite scholars have debated about the adoption of technologies and the benefits related to the I4.0 paradigm, to the best of authors' knowledge, only a few empirical surveys have been carried until now out on the adoption level of I4.0 principles in the manufacturing sector of a specific country.

Article classification: Research paper.

Keywords: Industry 4.0, digitization, information technology, technology, advanced manufacturing technology, manufacturing industry

1. Introduction

In recent years, the manufacturing context has been characterized by several phenomena such as the increase in competition among companies and the growing complexity of customer demands (Bozarth et al., 2009; Jäger et al., 2016; Tang et al., 2017; Vogel and Lasch, 2016; Wouters et al., 2005). Indeed, manufacturing companies are continuously stressed to meet the diverse preferences of customers (Stock and Seliger, 2016) and struggle for creating value through both time-to-market, and enhanced product reliability (Hirsch-Kreinsen, 2016; Kurilova-Palisaitiene et al., 2018; Tortorella and Fettermann, 2018; de Treville et al., 2014). For this reason, achieving the manufacturing of products in a batch size of one, while maintaining the economic conditions of mass production, has rapidly attracted the worldwide attention of both enterprises and governments (Lasi et al., 2014). Furthermore, industrial managers have started to adopt disruptive technologies in order to innovate business environment, leading to the creation of new sources for added value for both organizations and society (Almada-Lobo, 2016; Roblek et al., 2016).

Besides manufacturing processes, the application of digital technologies may have impact on other aspects related to the enterprises, such as supply chains organization (Ashour Pour et al., 2019; Pour et al., 2016; Vendrell-Herrero et al., 2017). logistic processes (Hofmann and Rüsch, 2017; Strandhagen, Alfnes, et al., 2017), business strategies (Bharadwaj et al., 2013), advanced services provision (Ardolino, Rapaccini, et al., 2018a; Mourtzis, 2018), sustainability (Beier et al., 2017; Bressanelli et al., 2018b; Luthra and Mangla, 2018) and product quality (Landscheidt and Kans, 2016). A wide range of sectors has been impacted by the Industry 4.0 (I4.0) paradigm, and the common attribute is that this smart ecosystem is fuelled by technology enablers (Almada-Lobo, 2016).

According to this line of reasoning, the 'Industry 4.0' paradigm has been created in Germany in 2011 and then translated and reinterpreted in both highly industrialized countries and emerging economies. All these initiatives build on a common paradigm shift in industrial production aimed at exploiting advanced digitalization for bringing intelligence into devices and systems (Lasi et al., 2014). Moreover, they all look for integrating Information Technology (IT) with Operational Technology (OT) to facilitate the connection among humans, machines and products in an intelligent way, for the purpose of satisfying customized demands (Beckmann et al., 2016; Chen, 2017; Zhou et al., 2016).

In recent years, several international organizations and governments have rapidly embraced this new paradigm providing national documents and industrial plans (European Commission, 2013; Germany's Federal Government-BMBF, 2010, 2014; Gouvernement Française-Ministère de L'économie, 2015; Governo italiano-Ministero dello Sviluppo Economico, 2016). Despite a realistic convergence and interdependence among the diverse policies across the different countries, there is no perfect agreement on their architectural definition, and misalignment with respect the enabling technologies is quite evident (Chiarello et al., 2018). Moreover, the perceived benefits and obstacles can significantly vary among the different countries. Indeed, each country is characterized by the specific peculiarities of its manufacturing landscape, leading to different adoption and implementation levels of the main principles of I4.0. Scholars have carried out disparate studies on how the I4.0 paradigm is pursued in different countries. However, the effect of I4.0 technologies on the organizations' performance and how this is perceived by different companies is an under-investigated topic (Echeveste et al., 2017; Fettermann et al., 2018). In addition, the assessment of impacts among the diverse business functions, highlighting possible different trends, is neglected by the literature (Bienhaus and Haddud, 2018). Indeed, the debate on the organizational effects of this paradigm shift is still underdeveloped (Mazali, 2018). As regards empirical studies on these topics, there is a lack of theories that can serve as guidance for organizations deduced by practical insights (Sung, 2018).

The literature shows that there are a few contributions of some studies carried out in other countries. The investigation on I4.0 readiness of Czech companies conducted by Basl (2017) proposed research questions such as how the companies are implementing the principles of I4.0, what are the motivating factors and impediments of applying I4.0 principles, and the existence of an appropriate strategy for I4.0. Tortorella and Fettermann (2017) have raised the question of what are the impact factors of I4.0 technologies implementation, with the aim of understanding the connection between lean practices and I4.0 implementation in Brasil. Besides, Jäger et al. (2016) put forward questions attempting to understand the I4.0 technologies awareness and challenges faced by German SMEs.

However, much less attention has been received by Italy, which is the second most important manufacturing country in Europe (EC, 2020). The only exception is the study by Rauch et al. (2017) who, focusing on a small region in northern Italy, investigate the relationship between I4.0 paradigm and the practices of lean product development. Italy is considered by authors as an interesting research target also because the 99% of its companies are SMEs who are struggling to implement I4.0 principles compared to the large ones who have already started to evaluate the opportunities and risks of digitization for their strategies and business models (Schröder, 2017).

This study is therefore trying to fill this gap by focusing on Italian manufacturing enterprises, aiming to understand how they are approaching the I4.0 paradigm, the main benefits achieved, and the challenges faced through a descriptive survey research. Therefore, to achieve a comprehensive understanding of the I4.0 phenomenon in Italian manufacturing context, the following main research questions are proposed:

- RQ1: What is the knowledge level of I4.0 enabling technologies?

- RQ2: What is the utilization level of I4.0 enabling technologies?
- RQ3: Which are the business functions most involved by I4.0 enabling technologies?
- RQ4: Which are the most required roles for driving the I4.0 transformation?
- RQ5: What are the main benefits and obstacles in adopting I4.0 enabling technologies?

These research questions have been set based on a reference scheme developed by the authors and presented in Figure 1.

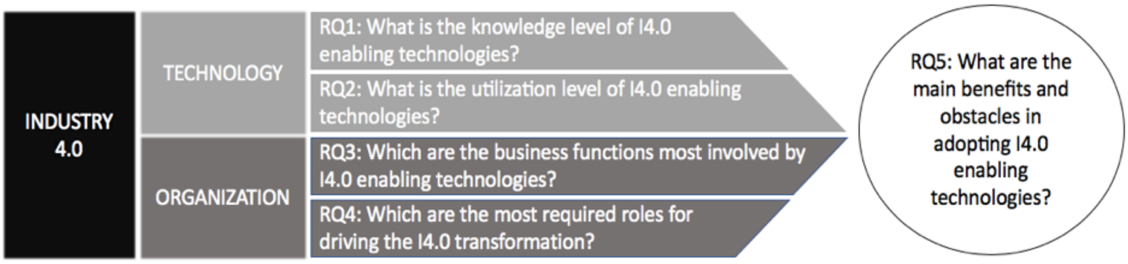

Figure 1. Reference scheme of the research

In particular, RQ1 and RQ2 aim at investigating the technological issues concerning Industry 4.0, while RQ3 and RQ4 are more related to the organization's business function and how it is involved in this transformation. Finally, RQ5 investigates the effects in terms of benefits and obstacles of the previous research questions.

The rest of paper is structured as follows. Section 2 presents the research background, Section 3 describes the adopted methodology, corresponded results are shown in Section 4, Section 5 discusses the results of the survey, and finally, Section 6 draws conclusions and indicates future perspectives both for researchers and practitioners.

2. Literature review

2.1 Industry 4.0 phenomenon

Advances in digital technologies are changing the way products are designed and manufactured (Lee et al., 2013). The term 'Industry 4.0' was first coined at the Hannover Fair in 2011, originated from a national project initiated by the German government, aimed at promoting the digitalization of manufacturing (Kagermann et al., 2013). Therefore, the main objective of this new paradigm is to create the so-called 'smart factory' where all the elements of the system, both humans and machines, are connected with each other for better business and societal outcomes (Erol et al., 2016; Jiang, 2017; Wang, Wan, Li, et al., 2016). Generally, the term 'fourth industrial revolution' is used interchangeably with Industry 4.0. Indeed, the worldwide manufacturing context has been characterized by disrupting breakthroughs leading to drastic changes in production and related processes.

Going back to the eighteenth century, the advent of the steam machine led to the first industrial revolution, with steam used to power old-fashioned machines (Lu, 2017). The second industrial revolution arose along with electricity, leading to the division of labor, mass production and faster means of transport (Schläpfer et al., 2015). In the 1970s, a third industrial revolution emerged due to the application of electronics and IT for 'flexible automation' in manufacturing (Schuh et al., 2015). Finally, the fourth industrial revolution refers to a further evolution, combining both IT and OT, enabling innovative data and information sharing between both inter-organizational and intra-organizational processes (Gronau, 2016).

One of the main enablers of Industry 4.0 has been the enhanced availability and affordability of sensors in parallel with boosted computer networks (Lee et al., 2015; Renu et al., 2013; Wang, Wan, Zhang, et al., 2016). All these technologies allow gathering a greater amount of data than in the past; the analysis of such data through innovative digital technologies potentially allows to increase knowledge for improving decision-making processes and to effectively meet the needs of customer markets (Tien, 2012). At the same time, management can be provided with more precise insights concerning the status of the factory (Dinardo et al., 2018). Furthermore, companies located in high-cost countries can make themselves independent of high labour costs by exploiting these new technologies (Kagermann et al., 2013).

Although embracing I4.0 generates positive outcomes, the increased complexity of collateral effects might be a non-trivial challenge (Alexopoulos et al., 2018). Indeed, since I4.0 strongly relies on on-line integration among several devices, machines and systems, another challenging aspect is IT security risk (Pereira et al., 2017). At the same time, adopting the I4.0 paradigm requires very large investments in new technology, with a suitable strategic plan and a strong commitment by the company's top management (Wolter et al., 2015). Finally, possible employment issues might emerge since workers will need to acquire different or even new set of skills and competences (Mourtzis, 2018).

Since the term 'Industry 4.0' has been coined, this concept has increasingly drawn the attention of academics, enterprises and governments all over the world. As a consequence, several official documents and national industrial policies have been drawn up in order to push the whole manufacturing industry towards this new direction. It emerged in fact that traditional manufacturing business models might not completely fit with these new emerging technologies (Adrodegari et al., 2018; Kiel, Müller, et al., 2017; Müller, Kiel, et al., 2018). The success of the implementation of this new paradigm strongly depends on both the adaptable integration of all the digital technologies implemented in the company and a strong commitment by all the involved functions, in particular the top management. Indeed, industrialized countries are moving towards this new paradigm in order to exploit it as a lever for manufacturing revival. Moreover, catching up the opportunity of transforming ‘traditional’ manufacturing through the 4.0 paradigm, may represent an important benefit in terms of increased revenue flows, lower operational expenditures and more sustainable health and safety conditions (Gilchrist, 2016). At the same time, also emerging countries are starting approaching I4.0 with the aim of developing specific and practical action plans for accommodating this innovative change (Luthra and Mangla, 2018; Sung, 2018). Therefore, I4.0 is the seed of the forthcoming transformation of the manufacturing industry landscape, for both developed and emerging economies.

2.2 Industry 4.0 enabling technologies

The spread of awareness on I4.0 has caused a huge hype on both scholars and practitioners. In particular, the technological stream constitutes an important research field concerning this new paradigm. Indeed, I4.0 encompasses peculiar technologies that can lead to important technical and organizational improvements (Albers et al., 2016). These technologies can in fact make possible both vertical (Almada-Lobo, 2016) and horizontal integration (Brettel, Bendig, et al., 2014; Kagermann et al., 2013).

However, there is no agreed list of I4.0 enabling technologies in literature; scholars lack mutual understanding and there are some inconsistencies among the different literature domains (Fettermann et al., 2018; Riel et al., 2017); moreover, some technologies seem to be much more promising than other ones (Dalenogare et al., 2018).

Indeed, this new paradigm is characterized by a wave of technologies that are basically dissimilar and not just an amalgamation of the previous ones (Chiarello et al., 2018). Furthermore, there is disagreement even in official governmental documents; as regards I4.0 industrial policies, in many cases technologies are different in number and type.

In this paper, the authors consider a list of six technologies, a sort of revision of the ones mentioned by the (Governo italiano-Ministero dello Sviluppo Economico, 2016), namely: Industrial Internet of Things (IIoT), Additive Manufacturing (AM), Big Data & Advanced Analytics, Virtual & Augmented Reality, Cloud Manufacturing (CMfg) and Collaborative Robotics (Table 1).

Table 1. Summary of I4.0 enabling technologies

Technology	Description	References
Industrial Internet of Things	An information network of physical objects (sensors, machines, cars, buildings, and other items) that allows interaction and cooperation	(Atzori et al., 2010; Lade et al., 2017; Wollschlaeger et al.,

(IIoT)	of these objects to reach common goals in industrial environments	2017; Zhang et al., 2017)
Additive Manufacturing (AM)	Process of joining materials in successive layers to make objects from 3D model data to 'unlock' design options and achieve great potential in mass-customization production	(Holmström et al., 2010; Khajavi et al., 2014; Mellor et al., 2014; Petrovic et al., 2011; Zawadzki and Zywicki, 2016)
Big Data & Advanced Analytics	Collection and analysis of large amount of available data using a series of techniques to filter, correlate and report insights not attainable with past data technologies, where data are processed in higher volumes, with higher velocities and in more varieties than before.	(Buhl et al., 2013; Fosso Wamba et al., 2015; Kambatla et al., 2014; Philip Chen and Zhang, 2014; Vera-Baquero et al., 2014)
Virtual & Augmented Reality	Augmented Reality: a set of innovative and effective human computer interaction (HCI) techniques which can embed virtual objects to coexist and interact with real objects in the real world; Virtual Reality: application of computer technology to create an effect of interactive, three-dimensional world, in which objects have spatial form. This interaction allows the user to control the virtual object and whole virtual scene in real time.	(Azuma, 1997; Mujber et al., 2004; Regenbrecht et al., 2005; Reif and Walch, 2008; Wang, Ong, et al., 2016)
Cloud Manufacturing (CMfg)	Manufacturing resources and specific customer requirements are linked via Cloud Computing for analysing and proposing service packages for utilizing resources and meeting the desired requirements.	(Li et al., 2010; Liu and Xu, 2017; Tao et al., 2011; Xu, 2012b)
Collaborative Robotics	A system intended to physically interact with humans and machines operating in a cooperatively shared learning environment.	(Cherubini et al., 2016; Khalid et al., 2018; Peshkin et al., 2001; Rozo et al., 2016)

Many enterprises still struggle to benefit from technology applications, facing difficulties in understanding the 'big picture' of the I4.0 paradigm (Sanders et al., 2016). This new paradigm in fact is not centred on the usage of individual technologies, but on their full integration for best exploiting their specific functionalities (Fettermann et al., 2018).

For instance, the integrated adoption of analytic tools such as machine learning and data mining with sensors and advanced computer networks can increase the knowledge about the efficiency of processes (Dinardo et al., 2018; Lee and Lee, 2015).

Moreover, the combination of robotization, automation and peculiar human–machine and machine–machine interfaces contributes to create a Cyber-Physical System (CPS) for merging the physical and digital worlds (Schuh et al., 2015). A CPS is in fact characterized by the combination between smart machines and production assets achieved through the integration of computation and physical processes (Lee et al., 2015). At the same time, the joint adoption of 'mobile devices' such as smartphones, tablets, smart glasses and innovative wireless and internet networks increases portability and facilitates information access (Guo et al., 2013; Reif and Walch, 2008). As another example, Additive Manufacturing is not only able to reduce time and cost for product development and manufacturing, but if combined with cloud technologies can open to totally new business models for manufacturing companies, exploiting the so-called Cloud Manufacturing (Modekurthy et al., 2015).

2.3 Industry 4.0 applications in different countries

Due to historical, political and geographical features, each country is characterized by its own manufacturing pattern. In order to benefit from I4.0, several governmental institutions have started to study and evaluate how to promote this new paradigm.

According to this line, the most recent literature has provided contributions concerning the investigation of the implementation of I4.0 in different countries, especially through surveys similar to the one proposed in this paper.

Bienhaus and Haddud, (2018) carried out a worldwide survey in order to understand the main impacts of digitization on procurement and within the area of supply chain management. In other cases, it is possible to find contributions focusing on a specific portion of the whole manufacturing sector. For example, Choi and Choi (2018) study how Korean SMEs are satisfied concerning their smart factory implementation and the main challenges in advancing to the next maturity level. Other studies focus on a specific industry sector such as the one of Mazali (2018) examining the change that smart digital factories enable in the work organization within the specific sector of train manufacturing. Expectations on digitalization and I4.0 in the German metal and electric industry have been investigated by Weber et al. (2017) while Dalenogare et al. (2018) debated on the benefits of Industry 4.0 related-technologies in the Brazilian industry.

There are also further studies focusing on how education programs at the university and job training have to be set or reorganized in order to fit the new principles of I4.0. For instance, Motyl et al. (2017) investigate the necessary skills and expertise to be developed in young students for them to be ready for the I4.0 paradigm in three Italian universities. Sackey et al. (2017) survey different universities in South Africa in order to identify the best didactic design parameters for creating a learning smart factory to support education in Industrial Engineering. A similar study has been conducted in Brazil to assess the effectiveness of a new programming course for making chemical engineering students able to face new problems typical of the I4.0 paradigm (Teles dos Santos et al., 2018). Similarly, Buasuwan (2018) investigates the effectiveness of higher education in Thailand for the implementation of the national policy 'Thailand 4.0'.

The literature presents a series of contributions focusing on the impacts of I4.0 in diverse countries. Indeed, there are studies concerning the investigation on the readiness for implementing the main features of I4.0 in manufacturing companies in Czech Republic (Basl, 2017) and Croatia (Veza et al., 2016). Moreover, Jager et al, (2016) try to understand how much the enterprises are familiar with I4.0 principles, focusing on the German Rhine-Neckar region. Beier et al. (2017) investigate the changes that digitalization is expected to bring by comparing a highly industrialized economy (Germany) with an emerging (China) industrial economy.

Besides, there are also some contributions aimed at understanding the development of I4.0 in non-European countries, such as the study by (Tortorella and Fettermann, 2018), who focus on the Brazilian manufacturing context examining the relationship between lean production practices and the implementation of I4.0. Moreover, I4.0 is a matter of interest also for emerging nations. Luthra and Mangla (2018) try to figure out the key challenges for achieving supply chain sustainability through I4.0 in the Indian manufacturing industry.

3. Methodology

Survey research has been adopted in order to obtain information about large populations with a known level of accuracy (Rea and Parker, 1992; Rossi et al., 2013). Moreover, scholars often distinguish between exploratory, confirmatory (theory-testing) and descriptive survey research (Filippini, 1997; Malhotra and Grover, 1998; Pinsonneault and Kraemer, 1993). The approach adopted in this study is the descriptive survey research, since it is aimed at understanding the relevance of a phenomenon and describing its incidence in a population (Dubin, 1978; Malhotra and Grover, 1998; Wacker, 1998). Indeed, descriptive survey is a suitable method when knowledge of a phenomenon is not too underdeveloped, the variables and the context can be described in details and the objective is to understand to what extent a given relation is present. Therefore, the primary research objective is not theory development, but rather the investigation of the impacts of the I4.0 paradigm in the Italian manufacturing sector, by describing the knowledge levels, the achieved benefits and the perceived challenges.

In order to reach the above-mentioned objectives, a survey research process consisting of three steps has been adopted, namely: Survey design, Pilot testing, Data collection & analysis.

3.1 Survey design

A questionnaire with 110 mixed open and closed questions has been sent to enterprises through web survey technique. The questionnaire was structured in 8 sections. The first section is aimed at collecting general information about the respondents. In the second section, a series of questions concerning the pre-existing level of enterprise's technologies in the company are asked. Since terminology related to technology issues might be subject to different interpretation (e.g., IoT, analytics, big data, etc.), description of each technology was provided through a 'link' button, helping respondents understanding main basic concepts. This allowed to make all respondents aligned with the same definition and avoid bias related to ambiguous questions (Choi and Pak, 2005). The following six sections investigate the identified digital technologies, aiming at evaluating the level of knowledge, relevance, adoption as well as benefits achieved and obstacles faced. The respondents were allowed to skip the section(s) if they had no knowledge about one or more of the technologies investigated in this study. Therefore, the structure of the survey was modular, in line with the aims of the research, so as to make each company able to involve different people to fill in the different sections at the same time, according to their specific competences. Indeed, for this reason, each company could involve (up to) 8 different respondents. Moreover, in order to make the language of the questionnaire consistent with the respondent's level of understanding, the questions were formulated both in Italian and English allowing also non-Italian people to participate to the survey.

A web survey has been administered for conducting this research, since this method has grown in popularity over the last 15 years (Couper, 2000; Shih and Xitao Fan, 2008). In respect with face-to-face and e-mail surveys, web surveys do not require responses to be manually transferred into a database, the cost is minimal respect to other means of distribution and much more anonymity is guaranteed, helping in preventing interviewer biases (Dillman, 2007).

Concerning the survey sample, the unit of analysis in this survey refers to the Italian manufacturing enterprises and Italian sites of multinational corporations. Moreover, this research involves all types of companies, with no limits concerning their size (small-, medium- and large-sized companies are considered) and industry sector. The respondents were selected by several sources: the most relevant is the Italian database AIDA ('Italian company information and business intelligence' database), which collects the detailed accounts of about one million companies in Italy. Therefore, a sample of 956 companies was selected for this study.

3.2 Pilot testing

A pilot testing was carried out before the survey, with the aim of testing and possibly improving survey design and question wording, as well as highlighting possible question biases (Forza, 2002).

Initially, a pre-test phase was set up providing the questionnaire to 3 colleagues of the same department. Colleagues helped understanding whether the questionnaire accomplished the study objectives (Dillman, 1978).

Subsequently, authors proceeded in two different steps, each one with different but complementary targets. In the first step we filled in the questionnaire when visiting 3 potential respondents in a face-to-face survey. The respondents completed the questionnaire as they would if they were part of the planned survey and we collected all their comments and feedback in order to understand if the questions were clear, as well as there were any problems in answering them. In the second step we administered the survey through the web survey application to a small pre-test sample, composed by 5 companies, which we had worked with in other projects in the past. Since we had quite knowledge about these companies, this pilot test helped us evaluating possible improvement areas in the questionnaire through the assessment of the content of the answers provided respect to what was expected by us.

3.3 Data collection & analysis

The survey was carried out in the first six months of 2017 and was sent to 956 companies. In total, 146 single responses belonging to 103 manufacturing companies were collected with a response rate of about 11%.

The characteristics of the sample group are shown in Table 2 while the characteristics of the respondent group are shown in Table 3 and Table 4. Overall, a sufficient heterogeneous classification has been achieved, since more than 50% of the sample is represented by SMEs, and the others are large and very large enterprises. This is quite in line with Italian manufacturing sector characteristics, where most companies are SMEs (Giunta and Trivieri, 2007). Moreover, different manufacturing sectors have been included.

Table 2. Enterprise size of sample group

Enterprise size	**Number**	**Percentage**	**Classification criteria**
Small-Medium	748	78.2%	Revenue < 50 mln euro
Large	143	15.0%	50 mln euro < Revenue < 300 mln euro
Very Large	65	6.8%	Revenue > 300 mln euro

Table 3. Enterprise size of respondent group

Enterprise size	**Number**	**Percentage**	**Classification criteria**
Small-Medium	58	56.3%	Revenue < 50 mln euro
Large	29	28.2%	50 mln euro < Revenue < 300 mln euro
Very Large	16	15.5%	Revenue > 300 mln euro

Table 4. Industrial sector of respondent group

Industrial sector	**Number**	**Percentage**	**Classification criteria**
Machinery	36	35.0%	NACE 28
Metal products	17	16.5%	NACE 25
Electrical equipment	14	13.6%	NACE 26/27
Metals	10	9.7%	NACE 24
Automotive	7	6.8%	NACE 29
Other industrial manufacturer	6	5.8%	NACE 32
Others	13	12.6%	Other

The analysis of the business areas to which the respondents belong shed light on the roles involved in filling in the questionnaire: CIOs filled in the 37% of the questionnaires, followed by R&D Directors who provided 19% of the responses. Production and Operations managers represent the 18% of surveyed people, whereas in 14% of cases they were the General Managers to answer. The remaining 12% is related to other functions & roles.

Actually, the initial response rate to our questionnaire was 6.3%. In order to improve this response rate, we adopted the approach proposed by (Forza, 2002) making telephone calls. Phone calls were aimed at understanding if the target respondent had received the questionnaire, better explaining the research and possibly helping the potential respondent. By doing this, the response rate increased to '11%', which is acceptable for the aforementioned purposes.

This phase has also concerned the evaluation of non-response biases in the questionnaire. In point of fact, one of the main issues with web-based surveys is patterns of non-participation and non-response bias that may substantially influence research results (Couper, 2000; Ritter and Sue, 2007). Possible non-response bias may emerge when there are systematic differences between respondents and non-respondents (Groves, 1989; Singleton and Straits, 2012). When respondents

differ from non-respondents, the respondent group might not correctly depict the population investigated and results achieved may result inaccurate, erratic and distorted (Lohr L., 2000; Wagner and Kemmerling, 2010). Therefore, bias is generated because those interested in the topic will appear different from non-respondents in terms of important variables (Groves et al., 2004). A growing amount of attention is being paid to the issue of non-response bias in survey research (Wagner and Kemmerling, 2010). One of the most commonly adopted techniques to evaluate non-response bias is the comparison of responses from early and late respondents. In reality, this method assumes that late respondents are most similar to non-respondents because their replies were induced through phone calls or took the longest time (A. Clottey and J. Grawe, 2014; Schniederjans, 2017). As regards this research, comparison between early and late respondents, weighing demographic variables such as revenue and number of employees, lead to no significant differences, with no substantial non-response bias issues.
Table 5 provides an overview of the variables adopted for the analysis and their characteristics.

Table 5. Definition and criterions of variables

Variable	**Type**	**Nr. of levels**	**Levels**
Company size	Categoric	3	SME; Large; Very large
Informatization systems coverage level	Ordinal	3	Low; Medium; High
Role of IT	Categoric	3	Frugal; Operational; Strategic
I4.0 technology knowledge level	Ordinal	4	Null; Superficial; Medium; Profound
I4.0 technology utilization level	Ordinal	4	Null; Low; Medium; High
Relevance of perceived benefits	Ordinal	4	Null; Low; Medium; High
Relevance of perceived obstacles	Ordinal	4	Null; Low; Medium; High
Business function’s involvement	Ordinal	4	Null; low; Medium; High

The variable ‘Company size’ follows the classification already depicted in Table 2, distinguishing among ‘SMEs’, ‘Large’ and ‘Very large’ companies.

The variable ‘Informatization systems coverage level’ evaluates the company informatization level and is built on the basis of the number of different IT systems implemented, namely: Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), Advanced Production Scheduling (APS), Product Lifecycle Management (PLM), Warehouse Management System (WMS), Business Intelligence (BI), Computer-Aided Design/Manufacturing (CAD/CAM), Manufacturing Execution System (MES). The corresponding evaluation level is ranged from low to high.

The ‘Role of IT’ variable investigates a specific organizational aspect of the IT function: ‘frugal’ indicates an IT function not formalized in the organization chart of the company; ‘operational’ is for an IT function which mainly performs operative activities, such as maintenance; ‘strategic’ means an IT function which contributes to product/process innovation and strategy definition.

As regards to ‘I4.0 technology knowledge level’, ‘Null’ means that the enterprise is not aware of the technology in question; ‘Superficial’ means that the company only investigated the general application field of the technology; ‘Medium’ means that the enterprise has examined the state-of-the-art and understood the potential benefits of technology, but has not yet investigated any specific application of it. ‘Profound’ means that the enterprise holds a deep knowledge of technology and has already evaluated all its benefits and costs. A percentage scale transformation has been conducted for the knowledge level variables used in the analysis for section 4.1, considering the cumulation of 6 technologies, ranging from 0 to 100%. Since a four-level order has been settled for each technology, 0 is considered as ‘no knowledge’ and 3 as ‘profound knowledge’. Thus, for example, if a company holds ‘superficial knowledge’ of all six technologies, it will get a score of 6, and consequently a percentage of 6/18 (33%).

Concerning ‘I4.0 technology utilization level’, since we totally investigated 6 technologies, companies adopting up to 2 technologies are considered to have ‘low’ utilization level, 3 or 4 technologies ‘medium’, and 5 or 6 technologies ‘high’. The level of companies adopting no technologies is ‘null’.

For ‘Relevance of perceived benefits’, authors investigated 4 types of benefits, which are named: cost reduction, time reduction, quality improvement and flexibility improvement. For ‘Relevance of perceived obstacles’, authors investigated 4 types of obstacles, namely: immature technology, high investment, missing competency and absence of technology provider. For both benefits and obstacles aspects of each technology, a four-level scale is used ranging from null to high, thus an ‘index variable’ is introduced to facilitate the analysis, which is the mean of the values of the six technologies.

Finally, the ‘Business function’s involvement’ variable evaluates the involvement of each company business function in the adoption of the single I4.0 enabling technology. Since for each technology investigated 4 levels of involvement (from 0-null to 3-high) of each business function were identified, authors also introduced an involvement index that is the mean value of the values obtained by each business function for all the technologies adopted by the company.

4. Results

This section reports the survey results. It is divided in 5 sub-sections, one for each of the research questions shown in 3.1.

4.1 RQ1: What is the knowledge level of I4.0 enabling technologies

Figure 2 provides an overview of the knowledge of surveyed respondent about the diverse I4.0 enabling technologies. It shows that companies generally hold limited knowledge of the surveyed technologies. There is also significant difference among each technology; Industrial Internet of Things (IIoT) is the only technology known by over half (64%) of the respondents at a superficial level at least. Indeed, Collaborative Robotics, Augmented & Virtual Reality and Cloud Manufacturing have been received far less attention than the other ones. 65% of respondents do not know the basic principles of Collaborative Robotics, and 70% do not even know what Augmented & Virtual Reality and Cloud Manufacturing are. The fact that many enterprises stated to have knowledge about IIoT is not difficult to explain, since this technology has been on the cusp of something because it is the pillar technology for I4.0 (Wilkesmann and Wilkesmann, 2018). Additive Manufacturing (AM) is also known by almost half of surveyed sample. It is not unusual that due to the upgrade of material and technology, more and more enterprise start getting in touch with AM. As regards Augmented & Virtual Reality, despite its no longer being in the initial stage, applications in the field are still really scattered. At the same time, for technology such as Cloud Manufacturing, it is still in its initial phase, thus lack of knowledge was easily predictable.

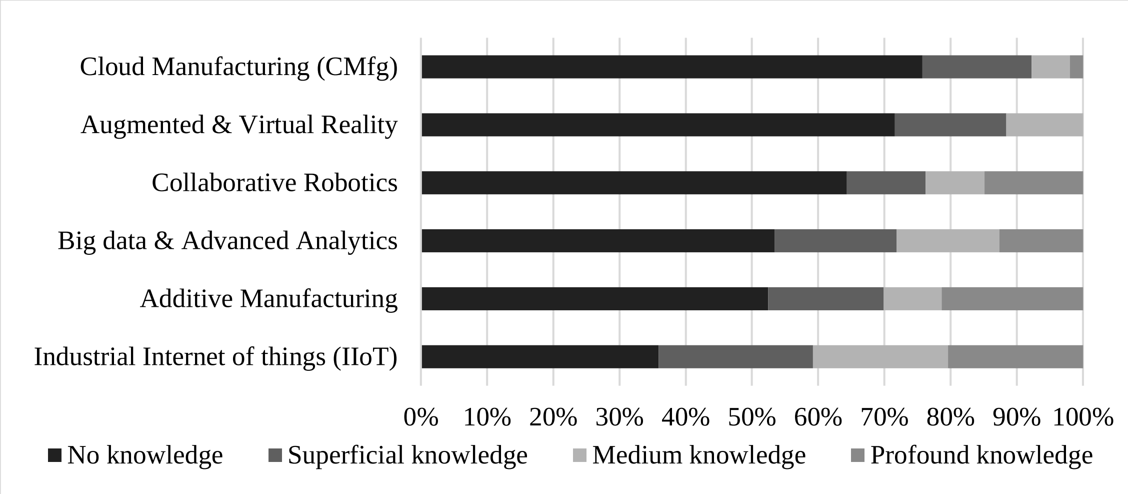

Figure 2. I4.0 technology knowledge levels

Figure 3 shows the relationship between company size and I4.0 technology knowledge level. The median of knowledge level increases as the company size increases; the median of small-medium companies only lays close but less than 0.2, whereas for large and very large companies it reaches 0.4. Though the lowest limit of three groups of company is 0, which corresponds to 'no knowledge', large companies and very large companies tend to have higher upper 50 quartiles, especially in the case of very large companies whose upper 25 quartile ranges from 0.67 to 1. Moreover, Table 6 presents the contingency table and the result of chi-square test for the combination of the two variables, showing a significant association.

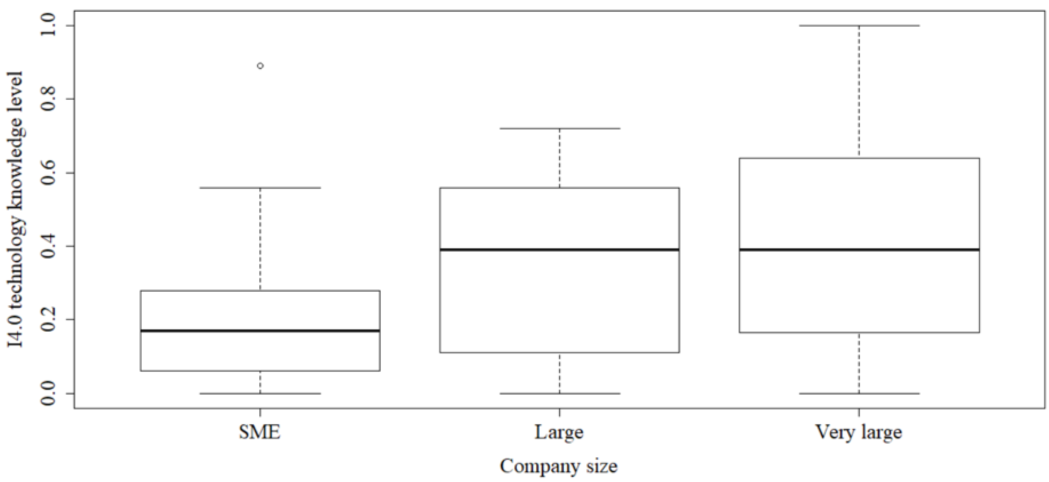

Figure 3. Relationship between I4.0 technology knowledge level and company size

Table 6. Chi-square test for company size and I4.0 technology knowledge level

	I4.0 technology knowledge level	Null	Superficial	Medium	Profound
Company size	SME	14	35	8	1
	Large	6	8	13	2
	Very large	3	2	8	3
Pearson's chi-square test: p-value = 0.0003913					

Besides the company size shown above, we found out that also 'Informatization systems coverage level' and 'role of IT', impact the knowledge level of I4.0 enabling technologies (Figure 4). When raising the management information system coverage level, a remarkable increase in knowledge level is achieved. A similar trend is shown in Figure 5, where an IT with a strategic role, mainly contributing to strategy definition and product/process innovation, has a more positive impact compared to an IT with an operational role which mainly focuses on maintenance activities. The chi-square test results shown in Table 7 and Table 8 also validate the significant association among these variables.

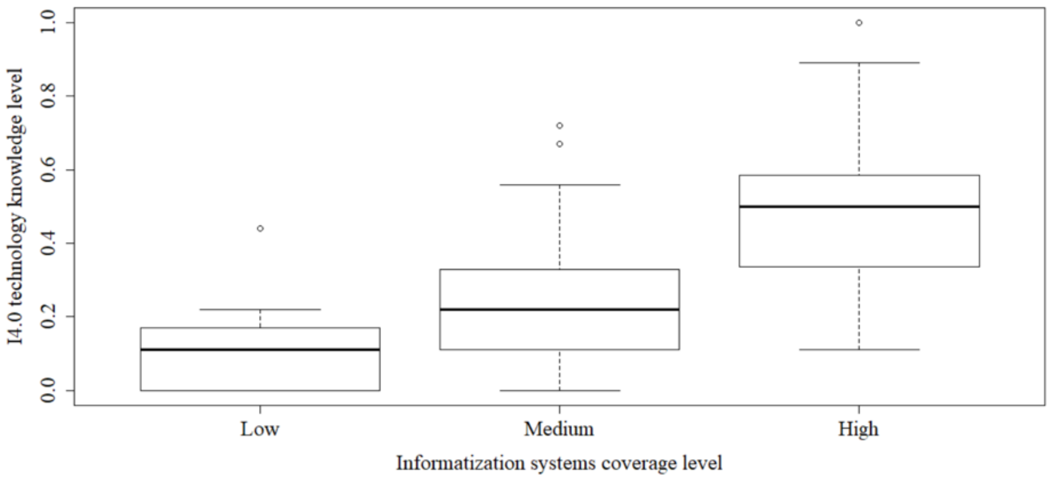

Figure 4. Relationship between Informatization systems coverage level and I4.0 technology knowledge level

Table 7. Chi-square test for Informatization systems coverage level and I4.0 technology knowledge level

	I4.0 technology knowledge level	Null	Superficial	Medium	Profound

Informatization systems coverage level	Low	4	8	1	0
	Medium	7	27	9	1
	High	0	8	18	5
Person's chi-square test: p-value = 3.932e-05					

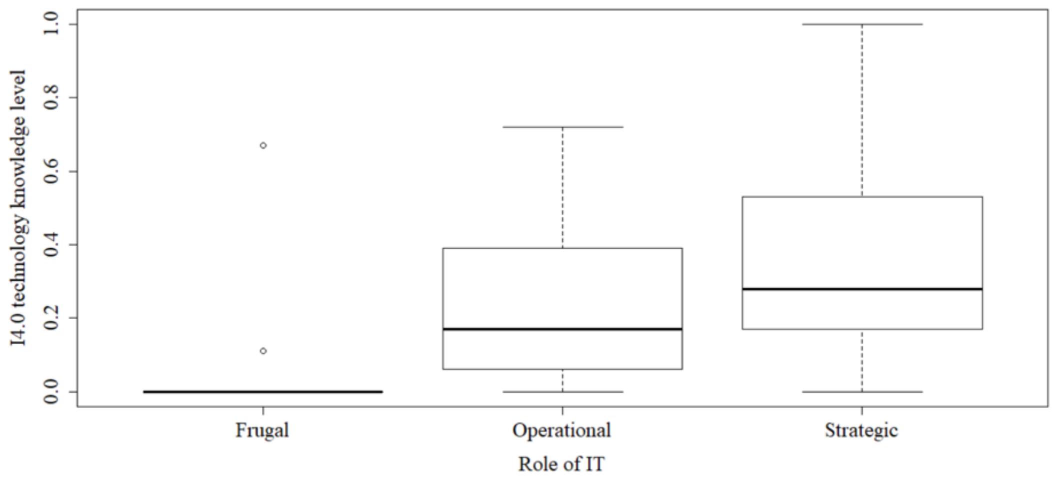

Figure 5. Relationship between role of IT and I4.0 technology knowledge level

Table 8. Chi-square test for role of IT and I4.0 technology knowledge level

	I4.0 technology knowledge level	Null	Superficial	Medium	Profound
Role of IT	Low	12	1	1	0
	Medium	8	19	10	1
	High	3	24	19	5
Person's chi-square test: p-value = 1.344e-07					

4.2 RQ2: What is the utilization level of I4.0 enabling technologies?

Figure 6 shows the adoption levels of the six I4.0 enabling technologies considered in the study. Additive Manufacturing is the most used technology, adopted by 22% of surveyed sample, slightly higher than IIoT, which reaches 21%. The utilization level of technology is different from the knowledge level mentioned in 4.1, where IIoT is the most known. Results of adoption level for Big Data & Advanced Analytics and Collaborative Robotics are coherent with the results concerning knowledge level. In addition, no concrete project enabled by Cloud Manufacturing has been activated up to date according to the surveyed sample, even though there are some enterprises stating to have knowledge about it. It is also interesting to point out the average number of technologies utilized by Italian manufacturing enterprises: 54% claim to have adopted only one technology, followed by 30% adopting 2 technologies, only 12% are using 3 technologies, and the rest 4% are applying more than 4 technologies. In summary, nearly 2 (1.8) technologies are been used by the surveyed sample.

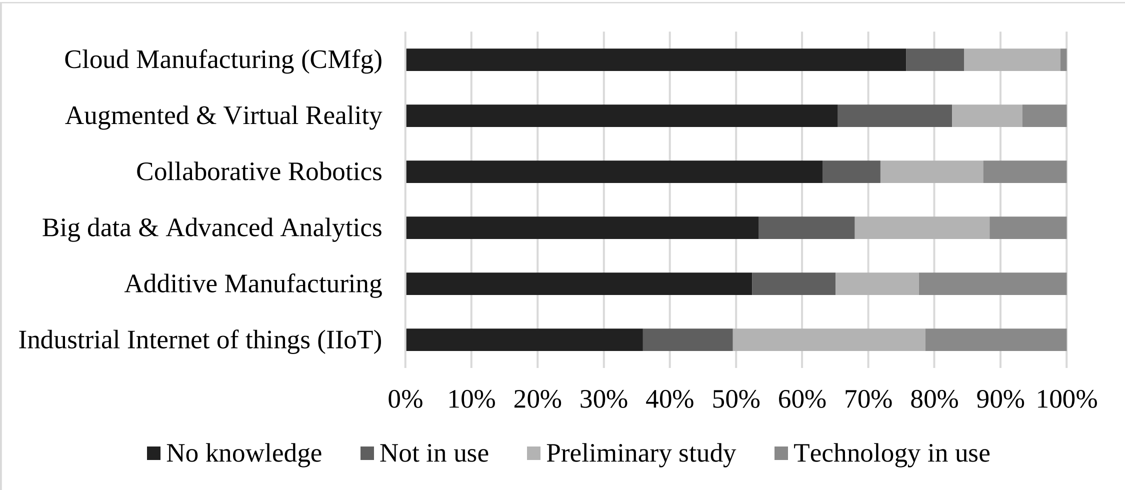

Figure 6. I4.0 enabling technology utilization level

Figure 7 displays the relationship between company size and utilization level for I4.0 enabling technologies. Looking at SMEs, which are more than half of the surveyed sample, the majority of them have not activated any new technology-related project. For large and very large companies, it seems that more than a half of them have adopted at least one technology, while no significant difference is demonstrated between large and very large companies. Although not always true, large companies generally have more resources available than SMEs. Therefore, we can state that a greater availability of resources favours the adoption of digital technologies.

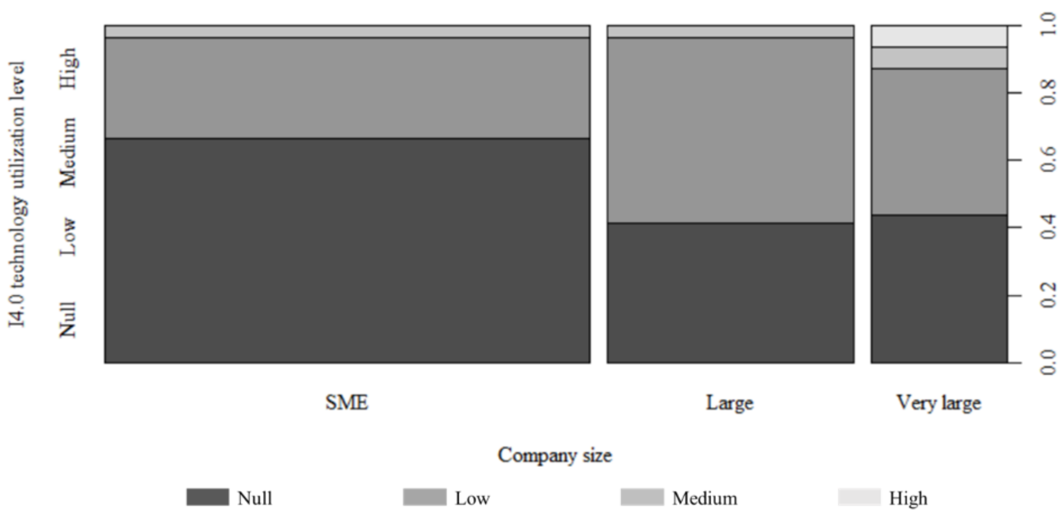

Figure 7. Relationship between company size and I4.0 technology utilization level

At the same time, a positive impact of Informatization systems coverage level is shown in Figure 8. Even though a portion of the sample has not implemented any technology regardless of diverse information system coverage level, the higher the coverage level of informative systems, the higher the technology adoption level.

Moreover, Figure 9 demonstrates that the usage of I4.0 enabling technologies changes depending (even) on the IT role. In particular, there is a little difference between companies who have IT playing strategic roles and operational roles. However, a substantial difference is found between non-existence ('frugal') and existence of the IT function in the company.

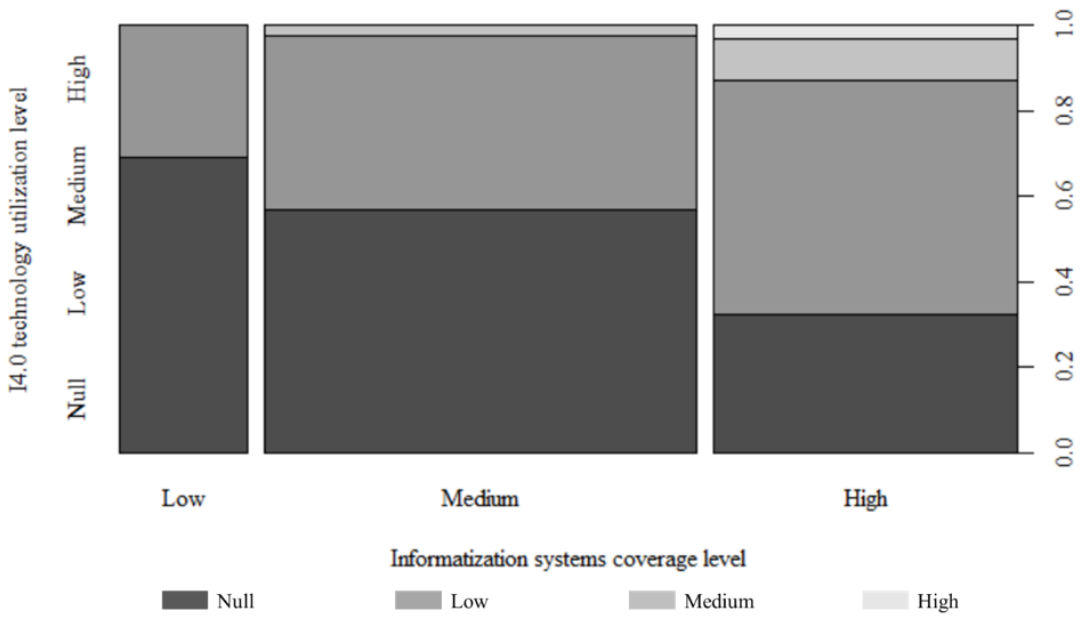

Figure 8. Relationship between Informatization systems coverage level and I4.0 technology utilization level

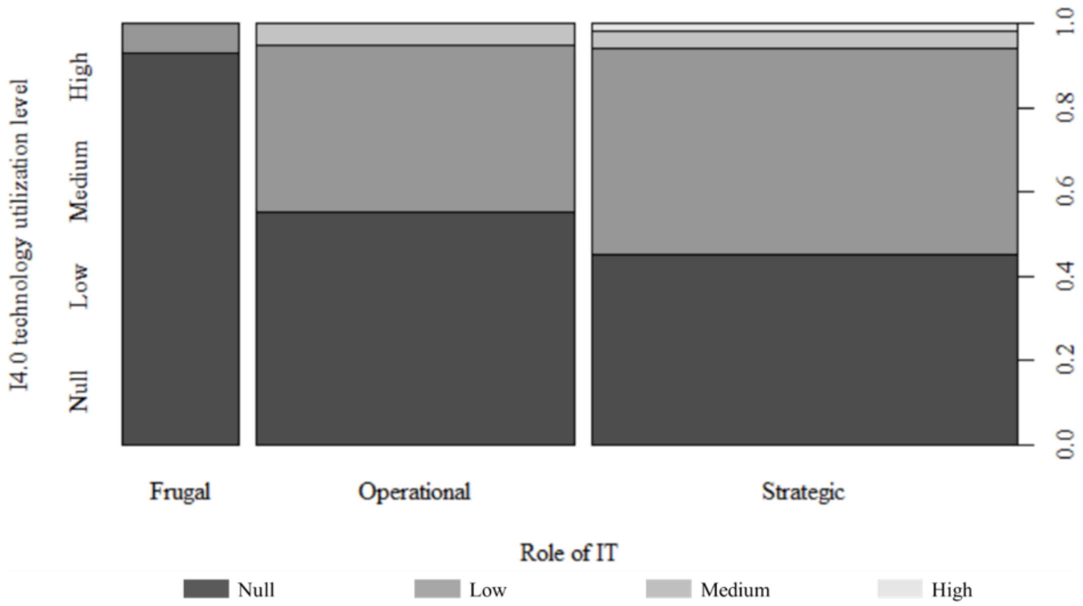

Figure 9. Relationship between role of IT and utilization of I4.0 enabling technologies

Another aspect that influences utilization of technology is the knowledge that the company has of technology. Figure 10 shows that the higher is the knowledge level of the company, the higher is the number of technologies it adopts. It is worth noting that only the company with profound knowledge reaches the total of 5 technologies in use, while the majority is between 1 and 4. As regards the portion of the sample with medium knowledge, 50% of these companies have implemented 1-3 technologies, and the number of technologies decreases for those stating to only have superficial knowledge. Table 9 shows the chi-square result of association between these two variables that has a very small p-value.

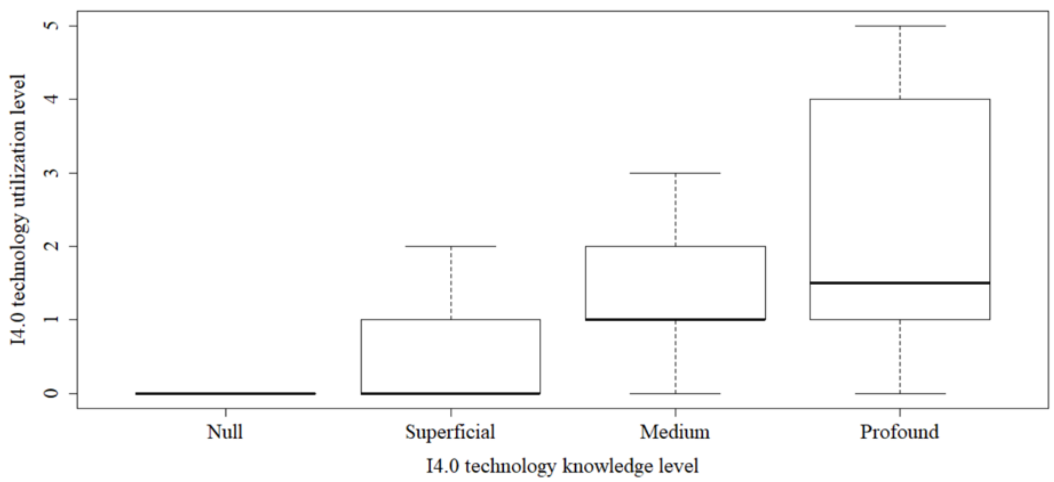

Figure 10. Relationship between I4.0 technology knowledge level and utilization level

Table 9. Chi-square test for company's I4.0 technology knowledge level and utilization level

	I4.0 technology utilization level	Null	Low	Medium	High
I4.0 technology knowledge level	Null	23	0	0	0
	Superficial	27	17	0	0
	Medium	6	21	3	0
	Profound	1	3	1	1
Person's chi-square test: p-value = 4.328e-09					

4.3 RQ3: Which are the business functions most involved by I4.0 enabling technologies?

A specific investigation on the business functions involved by I4.0 technologies has been conducted, aimed at understanding whether digital transformation is uniformly related to all business functions, or more related to some of them. Results are shown in Figure 11.

R&D, Production, IT and Direction seem to be the most involved areas by I4.0. Production, the function where most of the technologies are implemented, sometimes after some pilot tests in the R&D area, also has a high involvement index because of its role of putting enabling technology into practical production. For manufacturing companies, the process of transforming a 3D model into a real product is usually enabled by newest technology they have available.

Furthermore, it is not surprising to see that IT is another important involved area since it facilitates the utilization of new technologies in other business areas of the company. Indeed, IT holds the capability of collecting and sharing real-time information among different departments. Moreover, the survey results highlight a significant impact of digital technologies by the Direction function, obviously due to its primary role for leading technology implementation. Actually, radical technological changes are very hard to achieve without support from the Direction function.

In Figure 11 it is noted that as the number of technologies in use increase, the average involvement of each business function also increases compared to companies that utilize no technology; the increase recorded is by 24.6% for companies that use one or two technologies and 48.2% for those that use more than three technologies. Moreover, a remarkable low involvement of Controlling and, in particular, HR is found.

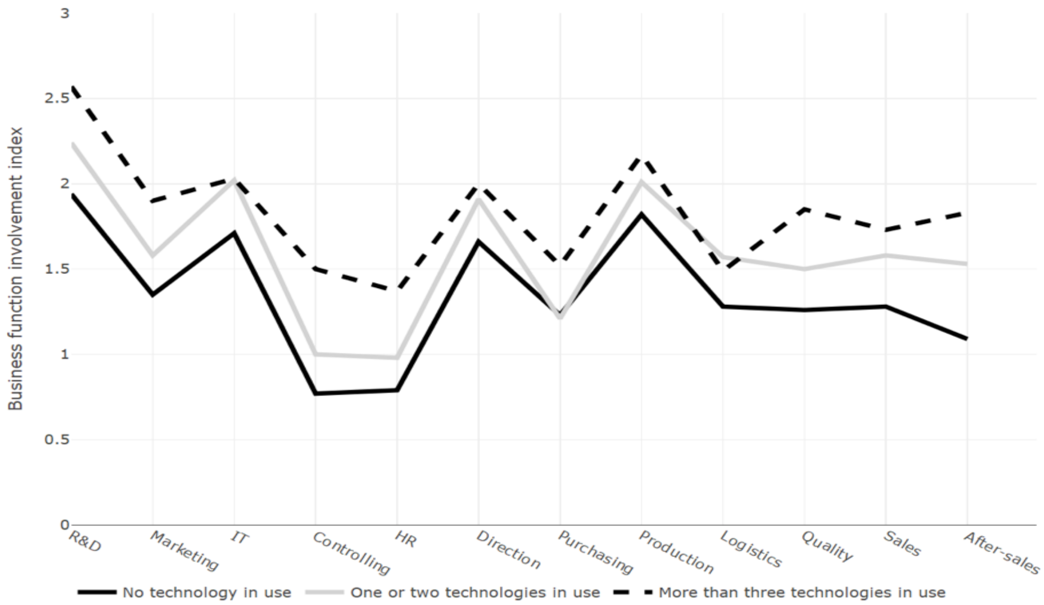

Figure 11. Relationship between I4.0 technology utilization level and business function's involvement

4.4 RQ4: Which are the most required roles for driving the I4.0 transformation?

It would be narrow minded to only consider the I4.0 paradigm as a technological phenomenon (Sanders et al., 2016). Though digital technologies are important enablers, adopting an optimized managerial structure is also crucial to facilitate planning, execution and decision-making activities of a company (Abramov et al., 2019). Concerning this aspect, authors tested presence and weight of the roles listed in Table 10, categorized in two main groups that are *technical* (specifics for each technology) and *managerial*. The table shows the most required roles in companies, selected by respondent from a long list included in the questionnaire.

Table 10. Technical and Managerial roles for each I4.0 technology

Technical roles	Required role
Industrial Internet of Things (IIoT)	IoT Strategist
	IoT Solutions Architect
	Software Development Engineer
Additive Manufacturing (AM)	3D Digital Designer/Modeler
	Material Engineer
	3D machine supervisor
Big Data & Advanced Analytics	Data Scientist/Architect
	Data Analyst

	Data Security Manager
Collaborative Robotics	Computer Vision/Perception Robotics Engineer Machine System Engineer Mathematical & Data Analyst
Augmented & Virtual Reality	AR/VR Software Engineer Augmented Reality Application Developer 3D Graphics Designer & Animator
Cloud Manufacturing	System / Infrastructure Architect Machine Supervisor Network Security Manager/Analyst
Managerial roles	Required role
For each I4.0 enabling technology	Digital Project Manager Strategy & Innovation Manager Chief Digital Officer

Figure 12 shows that the relevance level is higher than the presence level, indicating that companies are aware of the relevance of novel technical and managerial roles, but they still have not established them in their organization. Moreover, technical roles are considered to be more important than managerial ones. A reasonable explanation is that for the Italian manufacturing enterprises, with high prevalence of SMEs, I4.0 is still a technological revolution rather than an organizational one. Another issue to consider is the maturity stage of this revolution; given that for most companies the 4.0 revolution has just begun, it is reasonable that in the first instance they primarily require technical figures. The need for managerial figure will presumably emerge later, when the need to coordinate different technologies become stronger.

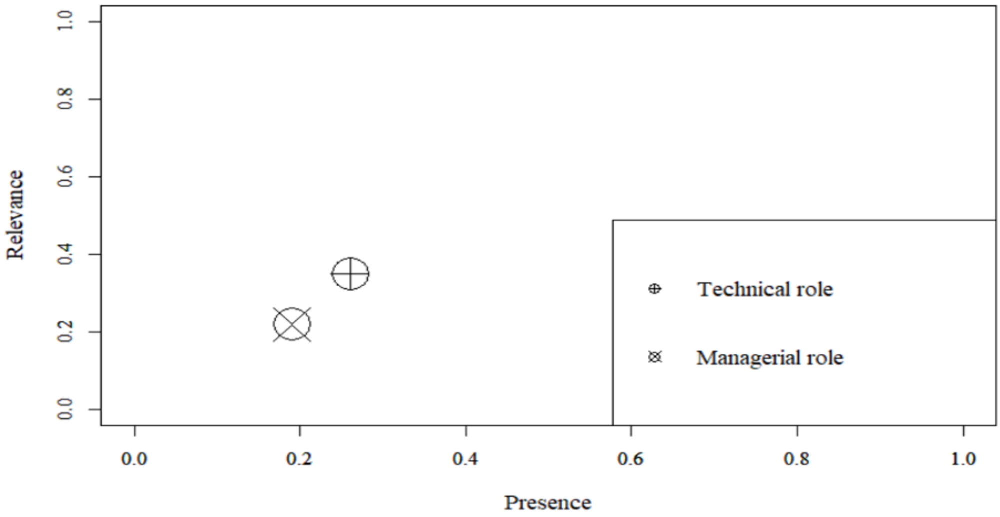

Figure 12. Presence & Relevance of technical and managerial roles

This message is also confirmed by Figure 13, in which the same analysis is carried out for each single technology; for no technology the need for managerial figures exceeds that for technical ones, confirming the average trend shown in the previous figure. It is also possible to clearly identify two clusters: AM, Big Data & Advanced Analytics and IIOT are significantly in higher positions compared to the other three technologies, in line with the findings regarding knowledge and utilization levels. Indeed, the most known and adopted technologies are also the ones for which the presence and relevance of the related roles is higher. In other words, it seems that only the development of an at least medium level of knowledge and utilization raises awareness of the need for developing new skills and roles within the organization. This analysis reinforces the theory about the low maturity stage of I4.0 revolution in the Italian manufacturing context.

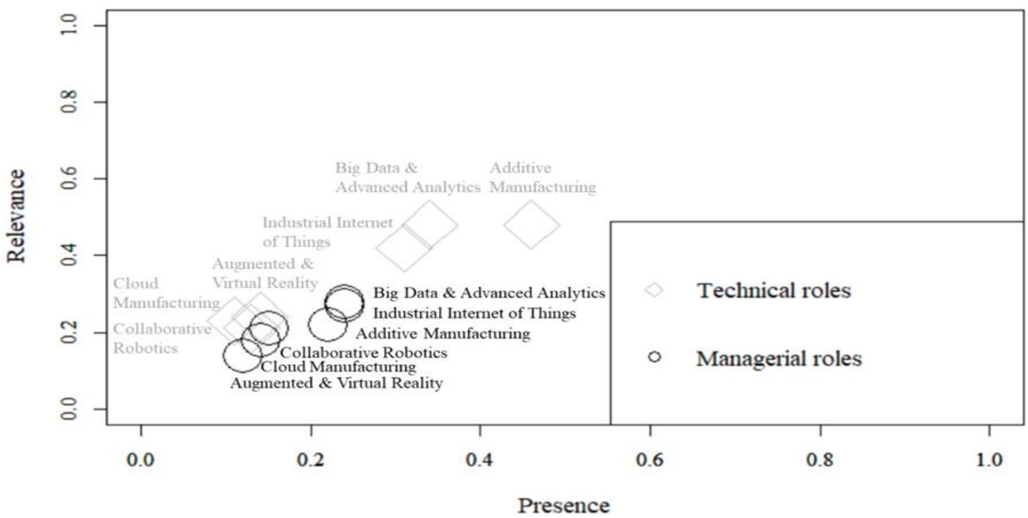

Figure 13. Presence & Relevance of technical and managerial roles, for each I4.0 technology

4.5 RQ5: What are the main obstacles and benefits in adopting I4.0 enabling technologies?

In this section, authors show what kinds of obstacles and benefits are perceived by companies regarding the I4.0 enabling technologies.

Figure 14 shows the results concerning the types and the relevance of the obstacles considered as such by the involved manufacturing companies. Comparing companies with no technologies implemented to companies with medium and high implementation levels, the former state to be less concerned about potential barriers, except for the risk of not finding a suitable technology provider. This might be justified by the fact that companies without any technology implemented are the ones that have not been able to find a technology provider with an adaptable and suitable offer. Another interesting finding is that among the four main categories of obstacles, high investment on technology is considered the most relevant barrier by companies with medium and high implementation levels. Indeed, companies using more technologies have experienced how many resources and investment have to be put on it. In addition, findings suggest that 'missing competency' is also considered as a big barrier, particularly by companies that have already implemented at least one technology. This reveals that when companies start to engage in I4.0 transformation by using more digital technologies, they gradually start feeling a lack of internal competences for the management and utilization of the novel technologies.

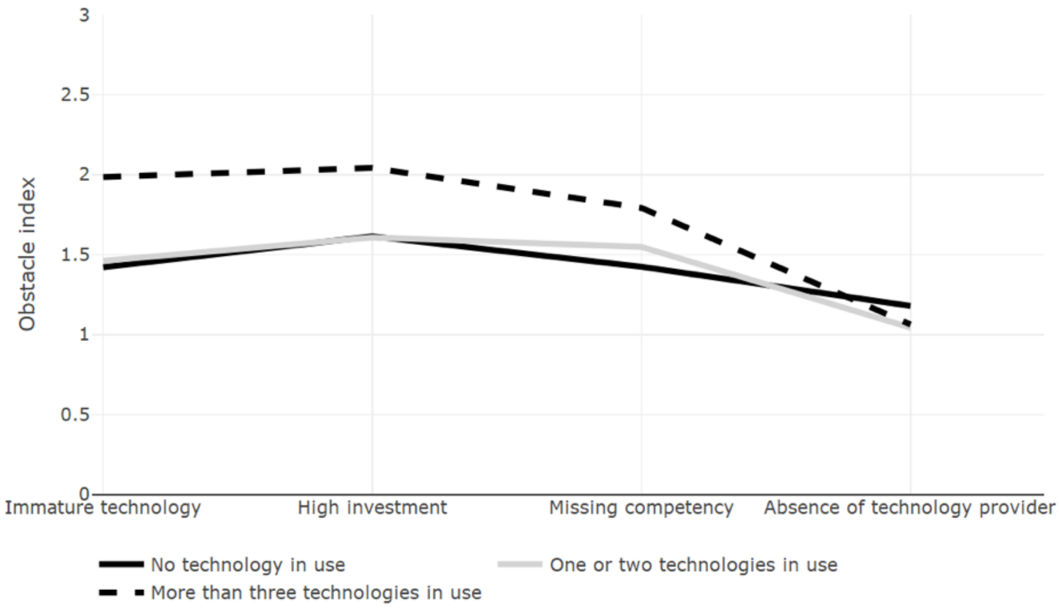

Figure 14. Obstacles in implementing the I4.0 enabling technologies

Figure 15 illustrates that the benefits perceived by companies that have already implemented at least one technology, are overall higher than the benefits expected by those that have not yet implemented any technology. Moreover, the higher the number of technologies implemented, the higher the perceived benefits, especially in terms time reduction, which is directly related to the capability of reducing time-to-market through providing customers a better service. Actually, a growth is noted in the relevance of the benefit attributable to quality in companies that adopt more than three technologies, reaching the same importance of cost reduction. Summing up, companies that adopt more technologies and therefore are more oriented towards the 4.0 paradigm, are more aware of the transverse nature and the relevance of the benefits they can achieve.

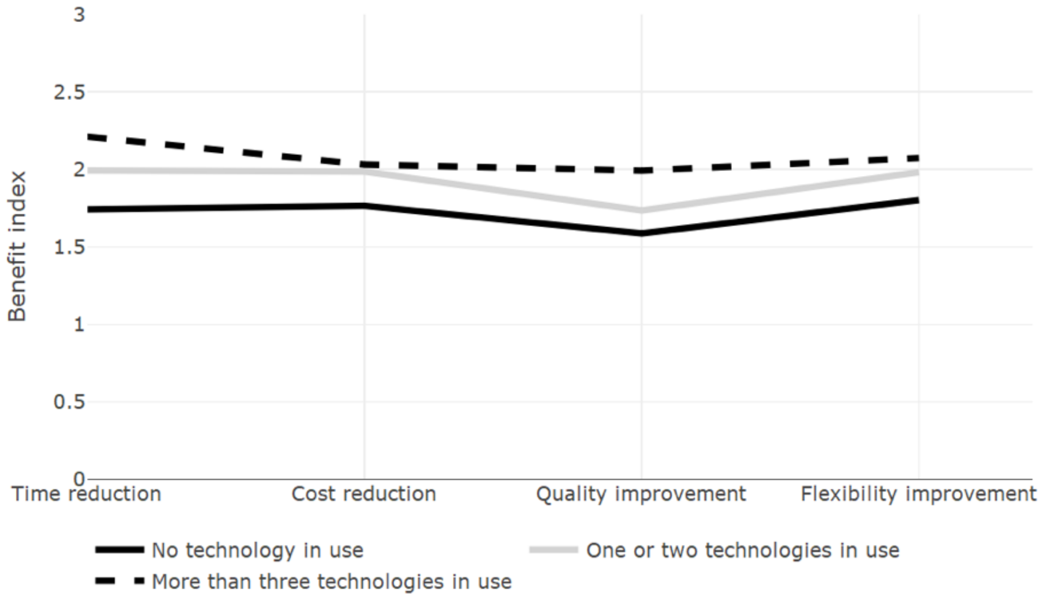

Figure 15. Benefits from implementing the I4.0 enabling technologies

5. Discussion

With the emergence of the I4.0 paradigm, the traditional philosophy of manufacturing systems is changing. Since the requisite of realizing individual requirements of diverse customers is increasing, traditional manufacturing systems may find it difficult to be efficient, flexible, responsive, together with searching quick appropriate management and control principles (Yin et al., 2018). Instead, a resilient manufacturing system may be able to quickly react to personalized customer orders based on connected resources and data under I4.0 environment (Schuh et al., 2015).

Concerning the knowledge of each I4.0 enabling technology, our survey reveals that manufacturing companies are generally characterized by a (very) inadequate level of knowledge. Only one of the six selected technologies, the Industrial Internet of Things, is known by more than a half of the sample. This is probably due to the fact that this technology is considered as the main enabler of the I4.0 revolution, since it opens new ways for the interaction of computational and physical capabilities with humans (Wilkesmann and Wilkesmann, 2018). As a matter of fact, it is deeply known by almost 40% of the sample. This notwithstanding, technologies that have by now become widespread, such as Big Data & Advanced Analytics, is completely unknown for more than a half of the sample. Even worse is the situation for the other technologies like Collaborative Robotics and Cloud Manufacturing. However, a possible excuse is that some of these technologies have not reached an adequate maturity level yet.

Investigating the technology adoption, the context does not change, though in some cases there is a misalignment. In fact, Additive Manufacturing is the most adopted technology, even though it is not the most known by the sample. This means that there are manufacturing companies that adopt this technology even though they do not adequately know its paradigm; in other words, the level of adoption is not aligned with the level of knowledge. However, these companies generally manage to fill this gap focusing on the so-called "on-the-job training". This behavior, apparently unjustified, is generally due to the availability of financial and tax incentives from national industrial plans. That brings companies sometimes to invest in this technology without having a full awareness and knowledge.

The increase in the number and complexity of technologies actually calls for structured methodologies for technology management (Santos et al., 2017). For this reason, several national technology roadmaps have been designed to support the outlining of specific strategic agendas (Mazali, 2018). This might induce pressure on companies to make investments while they are not completely aware about the characteristics and applications of the technology at issue (Schmidt et al., 2008).

In spite of the misalignments found for some technologies (e.g., AM), the company's knowledge level is anyhow positively related to its technology adoption as the higher the knowledge level, the higher the number of technologies implemented.

Moreover, our findings suggest that large enterprises tend to feel better prepared than small enterprises since it seems that SMEs still show some deficits. Therefore, as regards adopting this new paradigm, the company size is an important matter. Small-medium companies usually have limited resources and therefore, may not have enough capital or fell such a strong need to invest on new technologies. Moreover, SMEs might adopt a 'wait-and-see strategy' towards unfamiliar technologies, though the low level of knowledge found by our survey assumes that there is also a problem related to company culture.

In literature there are some studies investigating the role of company size for similar phenomena. For example, diverse studies related to IT adoption have been conducted. (Chen and Fu, 2001) demonstrate that the combination of company size and market nature can be an important indicator of the IT adoption pattern in manufacturing firms in China. A similar study has been conducted on Japanese companies, showing strong correlation between IT expenditure and company size (Griffy-Brown et al., 1999). Moreover, company size might affect the access to technology and the types of external sources of technological information used (Gomes et al., 2009). At the same time, several researchers have been trying to demonstrate the effect of the size of the businesses on the development of innovation-related activities (Boone, 2004; Greve, 2008). In addition, (Peslak, 2012) investigates whether and how the company's size matters in the recognition and prioritization of different critical IT issues.

Potential distortions might arise between the different size enterprises involved in the I4.0 transformation. Actually SMEs could become the victims and not the beneficiaries of this revolution because the pre-existing digitization-related gap between large and small businesses could increase (Sommer, 2015).

In spite of that, it is not true that only large companies can embrace this new paradigm. Scrutinizing the results of our survey, some SMEs are found to have successfully implemented the Industry 4.0 paradigm, by adopting profitably a considerable number of digital technologies. From this point of view, it is important to point out that all the companies in the sample does not belong to the "high-tech startup" category. In fact, one of the main causes of success in implementing the 4.0 paradigm was the strong commitment of the company management.

Besides company size, from both strategic and technologic perspectives, the manufacturers addressing this new paradigm have also to translate the transition process into a thorough project plan, detailing each phase and including a costs and benefits analysis (Bertrand and Zuniga, 2006; Sarvari et al., 2018; Schumacher et al., 2016). Indeed, I4.0 pursues the digital transformation through the appropriate integration of both pre-existing and new systems and infrastructure (Müller, Buliga, et al., 2018; Ustundag and Cevikcan, 2018). (Shelly Ping-Ju Wu, Detmar W.Straub, 2015) state that IT governance is typically the weakest aspect of corporate governance. In this regard, not all organization have the adequate IT maturity to embrace I4.0 (Gilchrist, 2016; Leyh et al., 2017). Furthermore, in order to successfully adopt the I4.0 paradigm, when the existing IT infrastructure does not effectively support the digitization of the company's business segments, appropriate IT development plans must be designed and implemented (Savtschenko et al., 2017).

In point of fact, several manufacturing companies stuck with technology, equipment, and processes, as well as lack of ICT integration, are struggling to move towards I4.0, especially in developing countries (Iyer, 2018).

Our results confirm this trend. The above-reported findings demonstrate that a high-informatized company tends to have a deeper knowledge on I4.0 enabling technologies. Indeed, when facing with new digital technologies, due to the existed accumulation on the informatization level, the company performs more actively on getting knowledge about new technologies. Moreover, a remarkable difference concerning both technology knowledge and adoption has been identified comparing companies with a 'frugal' IT function to companies with 'formalized' IT function. Therefore, in order to speed up the transition towards I4.0, the company must necessarily have already achieved full and complete informatization of its business processes. This certainly represents an essential foundation for the digital transformation of the company; companies which have not already completed this transformation, will unavoidably face more challenges and obstacles moving towards the new paradigm.

However, I4.0 does not only involve the IT function, since it calls for new strategies as well as organizational changes that concern not only manufacturing operations and technologies, but also management, human resources and other business processes (Gilchrist, 2016). Therefore, the new paradigm is a systematic evolution involving diverse business functions and envisages transformation throughout the entire value chain (Leyh et al., 2017; Zezulka et al., 2016).

Our results show that not only the IT function but also the R&D and Production functions are actively involved in utilization of I4.0 enabling technologies.

Since R&D is generally considered as the function capable of and responsible for stepping in the frontier of most innovative technologies, it is evident that when the enterprise is facing such digital transformation, R&D will be the first to get in touch with it and will take the role of understanding and testing possible solutions, especially in the case of non-fully mature technologies. Meanwhile, R&D is always required to incorporate new technologies and competences in the enterprise, predominantly through the re-projection or revision of existed products. In addition, Production is the business function where most of the technologies are implemented, sometimes after a pilot test in the R&D department.

Conversely, the result concerning HR is absolutely non-trivial since this function might play the fundamental role of selecting and recruit people, able to use novel technologies and providing adaptable training for the pre-existing employees.

Indeed, the novel manufacturing environment calls for high-skilled managerial and production labour with expertise in new materials, machines and technologies (Grzybowska and Łupicka, 2017). Overall, qualifications required of workers in an industrial plant are likely to rise. However, the existing discussions in the literature seem to take a rather economy- and technology-centered viewpoint, neglecting or considering very casually the social impacts (MAGRUK, 2016). Moreover, I4.0 is revolutionizing the rules of business, as well as the consumer market. In spite of that, several manufacturers continue operating under traditional marketing strategies that are not effective anymore (Ghobakhloo and Azar, 2018). Manufacturers who want to move towards the I4.0 paradigm must necessarily revise their marketing strategies and improve their level of digital market maturity (Bettiol et al., 2017). According to this line of thought, our survey shows that the Marketing function, not really involved, needs to be brought to the center of the I4.0 stage.

Finally, as regards the benefits and obstacles in adopting the principles of I4.0 transformation, interesting trends can be identified. In particular, our survey shows that perceived benefits for companies that have already implemented at least one technology, are overall higher than the benefits expected for those that have not yet implemented any technology. Thus, it seems that the advantages of the adoption of I4.0 technologies are underrated before being applied. In addition, the higher the number of technologies implemented, the higher the perceived benefit.

In parallel, the same goes for the obstacles. If comparing companies with no technologies implemented respect to companies with medium and high technology implementation levels, the former state to be less concerned about potential barriers, which may only come to light when the technologies are actually used.

These findings seem to validate the theory of the authors that this paradigm does not concern the application of single digital technologies (vertical evolution), but the full and harmonious integration of them to support the entire value chain (horizontal revolution).

6. Conclusions

The research carried out and presented in this paper has investigated and assessed the position of Italian manufacturing enterprises in the I4.0 journey. In particular, the purpose of this paper was to investigate how Italian companies are adopting the principles of Industry 4.0, which are the main benefits and obstacles achieved, as well as the gaps concerning skills and roles. A descriptive survey has been carried out and the results of a total of 103 respondents have been scrutinized. The sample was aligned with the Italian manufacturing context, which is mainly characterized by SMEs. The survey presented in this paper has considered specifically six specific I4.0 enabling technologies: Industrial Internet of Things (IIoT), Additive Manufacturing (AM), Big Data & Advanced Analytics, Virtual & Augmented Reality, Cloud Manufacturing (CMfg) and Collaborative Robotics.

In general, the information gained from the survey shows that Italian manufacturing companies have a different approach to I4.0 based on their size. Indeed, larger companies are much more aware of the potential of I4.0 and for this reason they show a higher level of both knowledge and adoption of I4.0 enabling technologies. On the contrary, it seems that SMEs still lack a specific strategy for gaining in-depth knowledge of the Industry 4.0 principles. In reality, within our sample interesting cases are found of SMEs that have successfully managed to implement the 4.0 paradigm and this must serve to also stimulate smaller companies to move towards the digital transformation. As SMEs have not the expending power of larger companies, they must carry out a comprehensive and thorough assessment about their need for undertaking the journey towards Industry 4.0, improving the efficiency of their current processes and prioritizing the required investments.

Furthermore, the investigation has demonstrated that there is large space for improvement in terms of involvement of employees in the I4.0 journey. The results of the survey have shown that there are some business functions, such as HR and Marketing, which are not still adequately involved. The low involvement of HR is a crucial factor. Indeed, the lack of interest in developing and acquiring specific managerial skills to superintend this transformation reveals that many companies have not a clear strategy map. Actually, specific training programs are needed in order to increase the commitment towards the adoption of the 4.0 paradigm, as the results of the survey revealed a general unbalanced focus on technologies respect to employee’s competences. Moreover, the HR function is generally not involved in the digital transformation projects of the company or, at best, it is only involved in late stages. Nevertheless, we have identified some best practices within the sample analyzed, developed digital academies in order to enhance the commitment towards the digital transformation of the company as well as to fill the gap concerning digital competences. These internal actions increase the odds of success related to the adoption of digital technologies. At the same time, the involvement of marketing is not of primary importance. This function is to be involved only in some special cases, such as when the implementation of new digital technologies brings an upgrading of the image of the company to be communicated to the market. A typical example could be the improvement in sustainability following the implementation of new technologies that improve business efficiency and processes (Bressanelli et al., 2018b).

Finally, the perceived benefits and experienced obstacles for companies implementing I4.0 enabling technologies are overall higher than those expected by companies that have not already embraced this new paradigm.

As any research does, this one also comes with some limitations. First, although the Italian manufacturing context is characterized by a high percentage of SMEs, no specific investigation has been designed for this group. Actually, the average company size in our sample is larger than Italy’s national level, where about 99% of companies are SMEs (EC, 2020); therefore, the results reported in this paper tend to be more positive than real situation. Another limitation is that, in spite of the complete review conducted, no reference model and framework are proposed. A first attempt on providing a set of managerial roles for I4.0 paradigm has been taken, but it still requires a more comprehensive and systematic approach in terms of guidelines/benchmarks in order to support Italian manufacturing enterprises speeding up their I4.0 transformation.

Indeed, due to the limited sample number in this study, further sampling is required for a comprehensive analysis of the current state of the matter, first of all in Italy and as a second step, also in other countries; this in order to be able to make significant comparisons and achieve more robust understanding of the overall context (Kull et al., 2014). Future research should focus on developing case studies about pilot I4.0 practitioners in order to capture the root cause of successful cases. Both managerial and practical references should be developed, helping Italian manufacturing enterprises to consolidate and strengthen their position in the global competitive market. The results of the survey presented herein combined with case studies on pilot I4.0 practitioners could definitely help formulating theoretical guidelines on how to successfully undertake the journey towards the Industry 4.0 paradigm. Examples of this kind of guidelines can be found by Ghobakhloo (2018), who has proposed a holistic roadmap for I4.0 transition which is mainly based on literature review, and by Fatorachian and Kazemi (2018) who have put their focus more on production process. However, a further empirical study is needed for theory modification or consolidation.

C. Progressing and advancement of Industry 4.0 in the Italian manufacturing context: a dynamic state-of-the-art

Title	Progressing and advancement of Industry 4.0 in the Italian manufacturing context: a dynamic state-of-the-art
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Outlet	XXV Summer School "Francesco Turco" – Industrial Systems Engineering
Year	2020
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Abstract.

Manufacturing companies are required to provide more value-added products in a faster and more reliable way in today's competitive market. Meantime, the rapid evolving of digital technologies is leading the fourth industrial revolution, also named as Industry 4.0 (I4.0). Although some contributions have been made in the literature to describe the state-of-the-art of I4.0 from national level perspective, it seems that there is still missing a dynamic evaluation over time concerning the evolution of the I4.0 paradigm, especially for the Italian manufacturing sector. This paper tries to fill this gap, by conducting a survey in 2019 with a sample of 102 companies and comparing the results with a first survey carried out in 2017.The results show that more companies are implementing I4.0 technologies compared to the 2017 survey, with an increase of 12%. It is also revealed that the large companies, characterized by a high level of informatization, still tend to behave better than small and medium ones. Companies consider lead time reduction and delivery of high-quality product/service as biggest benefits perceived from implementing I4.0 paradigm. As a conclusion, based on the results of the survey, authors show and describe the main levers to be adopted by practitioners in order to accelerate the 4.0 transformation.

Keywords: Industry 4.0, disruptive technologies, digital transformation, survey, manufacturing, state-of-the-art

1. Introduction

The process of globalization, mass customization and competitive business environment are driving "traditional" companies to face new business challenges in today's turbulent economy (Simmert et al., 2019). To adapt the novel competitive environment, companies are seeking digital approaches to moderate business processes and update technological solutions, which is normally known as Industry 4.0 (I4.0) transformation. According to Schumacher et al., (2016), I4.0 is enabled by the recent technological advances where the Internet of Things (IoT) serve as the backbone to integrate physical objects, human actors, intelligent machines, product lines, and processes across organizational boundaries. Meantime, other digital technologies also emerge as enablers of this new paradigm. Indeed, the effects of Big data & Analytics (BDA) for improving system scalability, security and efficiency is investigated by (Xu and Duan, 2019). Patel et al., (2018) explored the use of Artificial Intelligence (AI) for realizing autonomous resources scheduling. Turner et al., (2016) study the scenario testing and decision-making process enabled by Virtual Reality (VR) and Discrete event simulation (DES). Besides, Chen, (2017) identified Collaborative Robotics as one of the emerging technology trends for integrated and intelligent manufacturing (i2M). Furthermore, Chen and Lin, (2017) investigate on profit maximization of 3D printing within smart manufacturing system focusing on technical and managerial challenges to be overcome. In recent years, the manufacturing context has been tentative on investigation of specific technology application, while it seems that a global perspective is missing, especially from a national point of view. More concretely, the literature lacks an empirical study which focus on mapping the state-of-the-art of how I4.0 is adopted and implemented in manufacturing enterprises, as well as comparing two state-of-the-art at different time slot considering the evolving perspectives. This paper is thus trying to fill this gap by investigating the knowledge and adoption level of Industry 4.0 paradigm, the main factors that impact the I4.0 technologies application, the benefits and obstacles perceived by companies, as well as the dynamic comparison of the survey results at 2017 and 2019. Indeed, selecting Italian manufacturing companies as research target also derives from the fact that Italy is the second most important country in European Union (EU) with respect to the sold production value (EC, 2020). The rest of paper is structured as follows: Section 2 presents the literature review. Section 3 describes methodology, Section 4 show the survey results, and Section 5 draws conclusions and future directions.

2. Literature review and research gaps

2.1 Industry 4.0 enabling technologies and their impacts

The spread of awareness on I4.0 has caused a huge hype on both scholars and practitioners. In particular, the technological stream constitutes an important research field concerning this new paradigm, which make possible both vertical and horizontal integration (Almada-Lobo, 2016). In this paper, the authors consider a list of 6 technologies, resulting from a critical revision of the ones mentioned in acknowledged researches in the literature (Ghobakhloo, 2018; Oztemel and Gursev, 2018; Zheng et al., 2020), namely: Industrial Internet of Things (IIoT), Big data & Analytics (BDA), Artificial Intelligence & Machine Learning (AI & ML), Virtual & Augmented Reality (VR & AR), Collaborative Robotics and, finally, Additive Manufacturing (AM). The investigated technologies are also aligned with the survey conducted by authors in 2017 (Zheng et al., 2019).

2.2 Industry 4.0 empirical study

Literatures have shown mainly two streams of empirical studies for I4.0, which are I4.0 maturity model and survey of I4.0 paradigm at national level.

Regarding I4.0 maturity models, several studies have been conducted, measuring the I4.0 maturity levels from different perspectivs. Schuh et al., (2015) proposes I4.0 maturity matrix based on German companies, taking into account corporate structure, process and development as measurable dimensions. Lichtblau et al., (2015) concern strategy and organization, employees, smart factory, smart operations, smart products and data-driven services as dimensions. These two models are proposed by two associations in Germany, which are Acatech and VDMA. Moreover, from scientific communites, Schumacher et al., (2016) pose the I4.0 maturity model targeting for manufacturing firms, considering 9 dimensions. Pirola et al., (2019) measured digital readiness level of Italian SMEs from Strategy, people, process and technologie integration perspectives. Santos and Martinho, (2019) on the other side, take into account the dimension of smart factories and smart products and services.

From empirical survey side, Choi and Choi, (2018) studied how Korean SMEs are satisfied concerning their smart factory implementation and the main challenges in advancing to the next maturity level. Jäger et al., (2016) try to understand how much the enterprises from Rhine-Neckar region in Germany are familiar with I4.0 principles. Basl, (2017) and Veza et al., (2016) investigate the readiness for implementing the main features of I4.0 in manufacturing companies in Czech Republic and Croatia respectively. Luthra and Mangla, (2018) evaluate how to exploit I4.0 as lever to achieve supply chain sustainability in Indian manufacturing industry. Morover, Tortorella and Fettermann, (2018) focus on the Brazilian manufacturing context examining the relationship between lean production practices and the implementation of I4.0. The operational performance impact by I4.0 enabled lean practices is also investigated by Tortorella et al., (2019).

Besides, Beier et al., (2017) compare China and Germany with a focus on the expected changes brought by I4.0. Tortorella, Rossini, et al., (2019) consider Italy and Brazilian companies as targets for the comparison of I4.0 and lean practices implementation.

2.3 Research gaps and questions

The extant literatures show that some survey-type investigation have been carried out to study the I4.0 paradigm from national level as well as from international comparison level. Based on the study conducted by authors in 2017, which has provided a state-of-the-art of how Italian manufacturing companies are involved in I4.0 transformation (Zheng et al., 2019), the authors take another step forward, eager to understand how companies are advanced from 2017 to 2019. In order to fill this gap, the following research questions are put forward:

RQ1: How the Italian manufacturing companies are approaching and involved in the implementation of the I4.0 paradigm? RQ2: What are the critical factors that impact the knowledge and implementation of I4.0 enabling technologies?

RQ3: What are the main benefits achieved by the companies that are “on the move” and what are the obstacles they are facing?

RQ4: What are the differences between state-of-the-art in 2019 with respect to that in 2017?

3. Methodology

3.1 Survey design

Scholars often distinguish between exploratory, descriptive and confirmatory (theory-testing) survey research (Pinsonneault and Kraemer, 1993). The approach adopted in this study is the descriptive survey, since it is aimed at understanding the relevance of a phenomenon and describing its incidence in a population, more concretely, to understand the impacts of I4.0 paradigm in Italian manufacturing sector, through describing the knowledge level, utilization level of I4.0 enabling technologies, the perceived benefits and challenges, as well as the involvement of organization’s business area in the I4.0 transformation. The data collection window is opened in the first six months in 2019, which is as the same survey conduction period adopted in 2017 (Zheng et al., 2019). Concerning the survey sample, the unit of analysis in this survey refers to the Italian manufacturing companies and Italian sites of multinational corporations, with no limits of size and industry sector, and the sample group is controlled as the same with that in 2017. Moreover, web survey technique has been adopted for the survey data collection. The questionnaire is composed by 3 main sections, which cover the I4.0 strategy, organizational informatization level and competencies level, as well as I4.0 enabling technologies.

3.2 Sample description and variables

Overall, a sufficient heterogeneous classification has been achieved of the survey sample in 2019, around 54% of the sample is represented by SMEs, 29.4% are large companies and 16.7% are very large ones separately. Such data is pretty align with the data collected in 2017, where 56.3% belong to SMEs, 28.2% are large companies and 15.5% are very large ones Moreover, different manufacturing sectors have been included. Indeed, the front five sectors of the sample composition remains almost the same comparing 2019 and 2017, which counts for around 82% of the total sample. More concretely, manufacture of machinery equipment ranks in the first place both in 2017 (35.0%) and 2019 (32.4%). From second to fifth place are manufacturer of metal products, electrical equipment, basic metals and motor vehicles. Slightly difference is that in 2017, the manufacturer of metal products stands for 16.5%, while such proportion in 2019 is 18.6%. Furthermore, regarding to the role of respondent, Directors such as CIO, CTO, R&D director and Production and operations managers, as well as top management constitute the main respondent group. However, a smooth difference is that in 2019, the proportion of top management for filling the questionnaire increased from 14% to 18%.

Table1 demonstrate an overview of the variables adopted for the analysis and their characteristics. The variable ‘Company size’ follows the classification already depicted in Table 1.

The variable ‘Current informatization systems coverage level’ evaluates the company informatization level and is built on the basis of the number of different IT systems implemented, namely: Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), Manufacturing Execution System (MES), Advanced Production Scheduling (APS), Product Lifecycle Management (PLM), Warehouse Management System (WMS), Business Intelligence (BI) and Computer-Aided Design/Manufacturing (CAD/CAM), corresponding evaluation level is ranged from low to high.

For ‘I4.0 technology knowledge level’, ‘Null’ means that the enterprise is not aware of the technology in question; ‘Superficial’ means that the company only investigated the general application field of the technology; ‘Medium’ means that the company has examined the state-of-the-art and understood the potential benefits of technology without investigating any specific application. ‘Profound’ means that the enterprise holds a deep knowledge of technology and has already evaluated all its benefits and costs. Concerning ‘I4.0 technology utilization level’, since we totally investigated 6 technologies, companies adopting no technologies is levelled “null”, companies adopting up to 2 technologies are considered to have 'low' utilization level, 3 or 4 technologies 'medium', and 5 or 6 technologies 'high'.

'Business function involvement' variable evaluates the involvement of each company business function in the adoption of the single I4.0 enabling technology. Since each technology investigated 4 levels of involvement (from 0-null to 3-high) of each business function, authors also introduced an involvement index that is the mean value of the numbers obtained by each business function for all the technologies adopted by the company.

For 'Benefits', authors investigated 4 types of benefits, which are named: cost reduction, time reduction, quality improvement and flexibility improvement. For 'Obstacles', 4 types of obstacles are studied, namely: immature technology, high investment, missing of competency and absence of technology provider. For both benefits and obstacles, four-level scale is used ranging from null to high, thus an 'index variable' is introduced to facilitate the analysis, which is the mean of the values of the six technologies.

Table 1: Definition and criterions of variables

Variable	**Type**	**Nr. of levels**	**Levels**
Company size	Categoric	3	SME; Large; Very large
Current informatization systems coverage level	Ordinal	3	Low; Medium; High
I4.0 technology knowledge level	Ordinal	4	Null; Superficial; Medium; Profound
I4.0 technology utilization level	Ordinal	4	Null; Low; Medium; High
Business function involvement	Ordinal	4	Null; Low; Medium; High
Benefits	Ordinal	4	Null; Low; Medium; High
Obstacles	Ordinal	4	Null; Low; Medium; High

4. Results

4.1 How the Italian manufacturing companies are approaching and involved in the implementation of the I4.0 paradigm

To answer RQ1, the authors depicted the distribution of I4.0 enabling technology knowledge and utilization, as well as the involvement of organization's business functions. As shown in Figure 1, companies are found to have limited knowledge in general. Among the investigated six technologies, IIoT and BDA seem to be better known by companies, for which more than 40% of the companies have superficial knowledge and above. On the contrary, AI & ML seems to be the least familiar technology. The reason why companies are more aware of IIoT is aligned with the fact that IIoT is the pillar technology of I4.0.

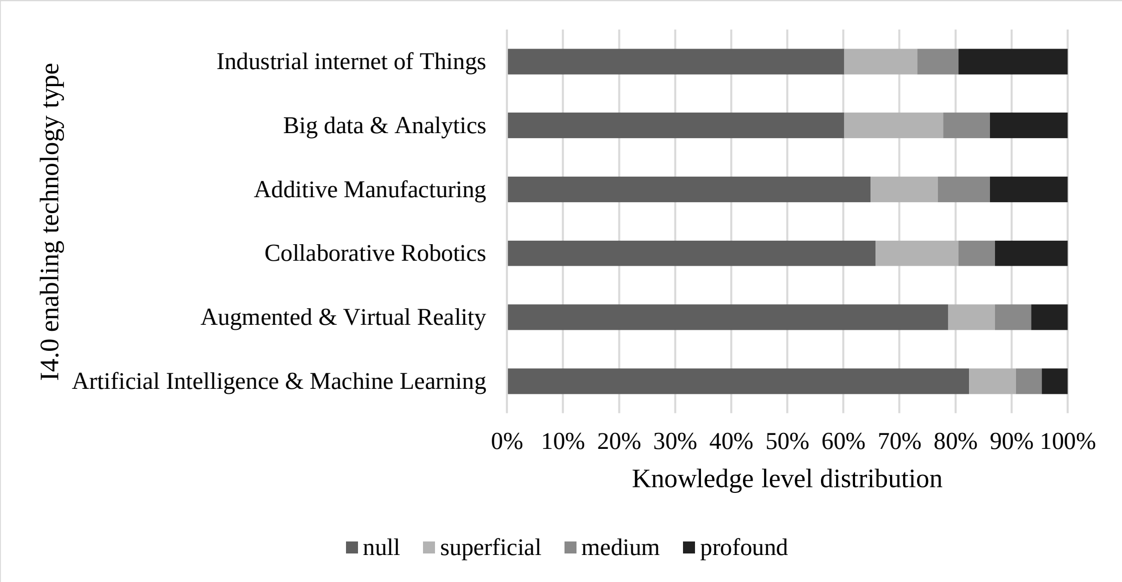

Figure 1: I4.0 enabling technologies knowledge distribution

In Figure 2, we find out that for all technologies, there is a proportion of companies who did not take any actions although they state to have at least superficial knowledge of the technology. Besides, we noticed that more than 30% of the surveyed companies have already implemented IIoT, and more than 20% for BDA. Similar implementation proportion can be found also for AM which is slightly lower than 20%. Regarding AR & VR and AI & ML, the result of utilization rate is coherent with the knowledge distribution. However, we detected that for AM, Collaborative Robotics and AR & VR, there are companies state to have used the technologies and then abandoned.

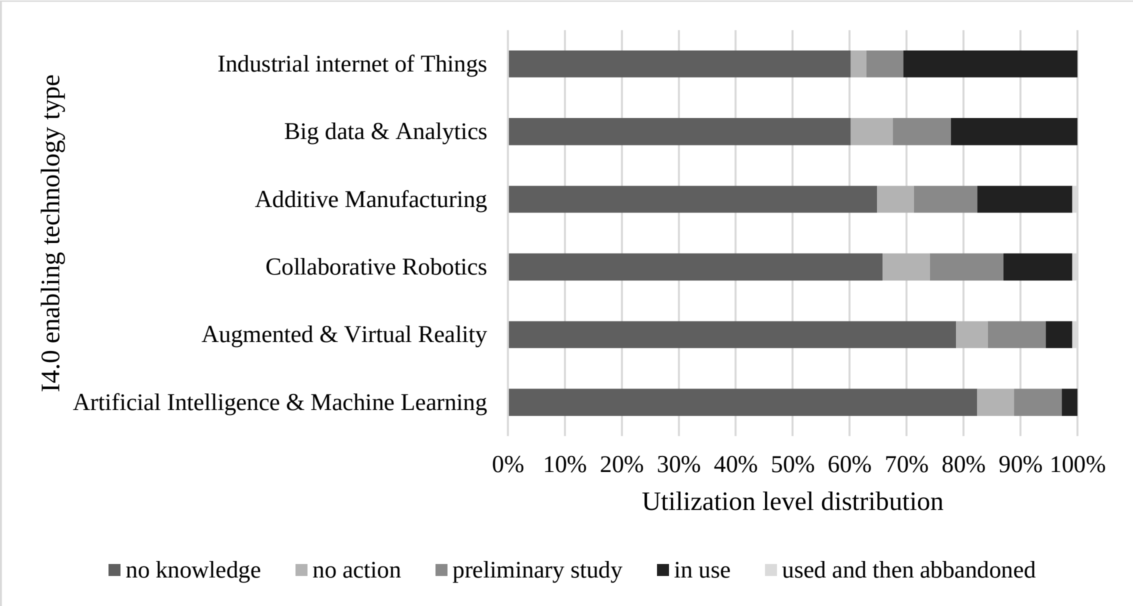

Figure 2: I4.0 enabling technologies utilization distribution

Figure 3 maps the relationship between technology utilization level and business function involvement. It shows that R&D, IT, Direction and Production are the highest impacted business areas by I4.0 technologies. Moreover, with the increase of technology utilization level, expands in the meanwhile the business area involvement, except for HR, Production and Quality, which all show to be slightly lower involved when comparing companies who implement no technologies and those who have implemented one or two technologies.

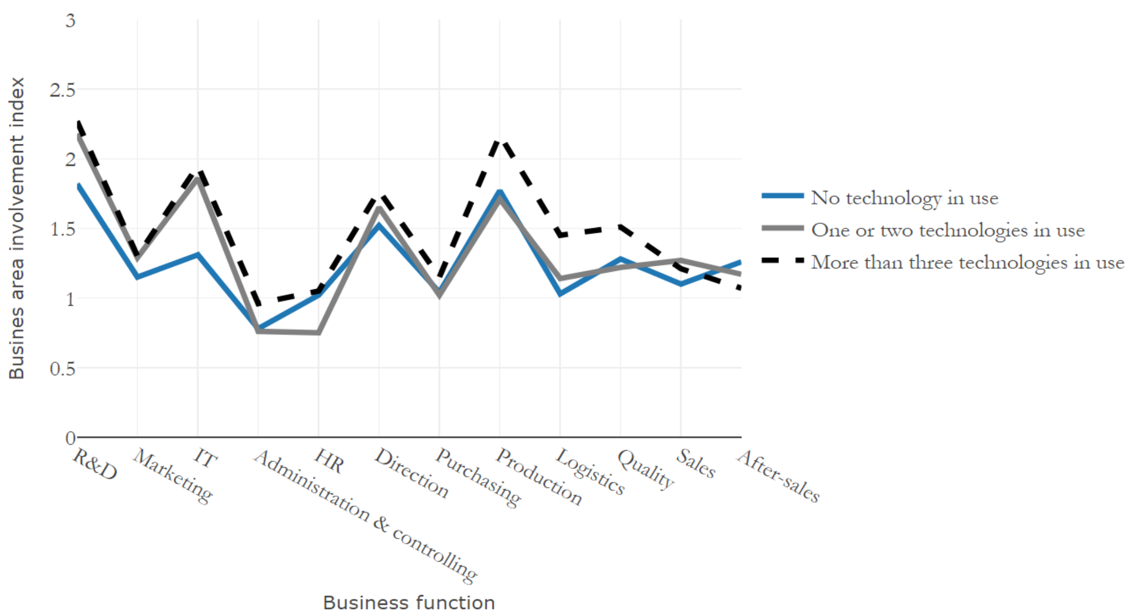

Figure 3: Relationship between I4.0 technology utilization level and business function involvement

4.2 What are the critical factors that impact the knowledge and implementation of I4.0 enabling technologies?

The first factor that impacts company's knowledge and utilization level is company size. Figure 4 and Figure 5 show the plots to demonstrate such relationships. We observed from Figure 4 that the bigger the company size, the higher the I4.0 technology knowledge level. Indeed, the proportion of companies who have at least superficial knowledge is higher in Large and Very large companies with respect to SMEs. Although there is not obvious difference between Large and Large ones, the gap between SMEs and Large companies is still found to be significant.

Figure 5 also confirms the difference between SMEs and Large companies regarding the utilization level. Although there are some cases where I4.0 implementation have been carried out in SMEs, they are still shown to have activated few I4.0 technology related projects, while for Large and Very large companies, it seems that more than half of them have adopted at one I4.0 enabling technologies. However, there is almost no difference between Large and Very large companies regarding the I4.0 implementation level.

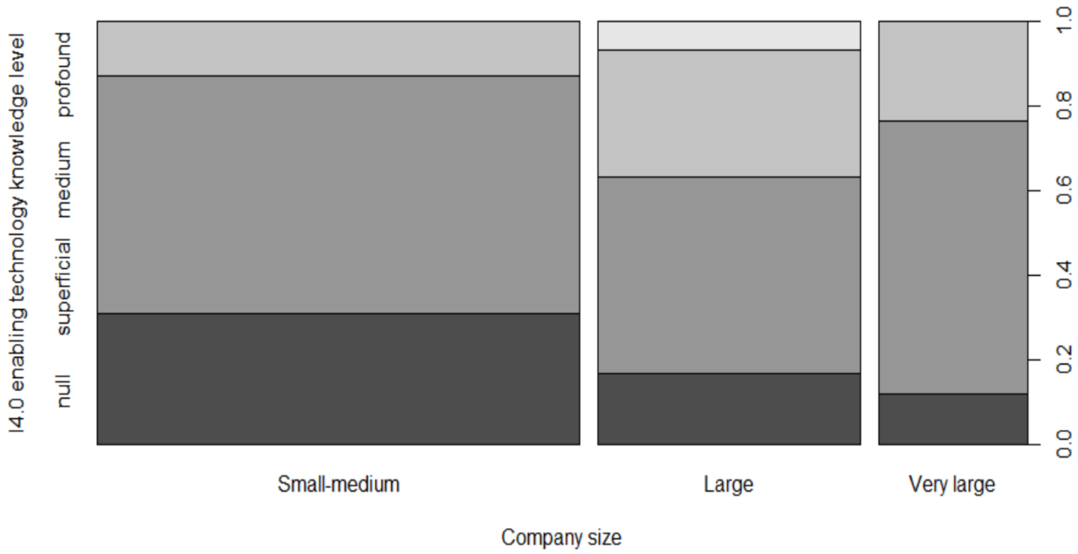

Figure 4: Relationship between Company size and I4.0 technology knowledge level

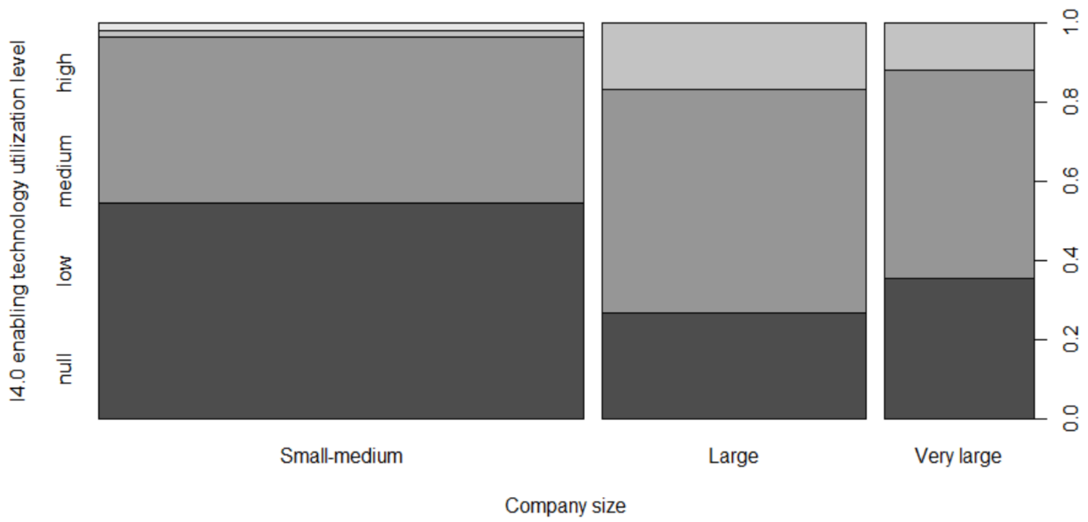

Figure 5: Relationship between Company size and I4.0 technology utilization level

The second impact factor is company's current informatization level. Figure 6 and Figure 7 show the evidences. Looking at Figure 6, a significant increase of I4.0 technology knowledge is observed between low informatization level and medium level. Meanwhile, the knowledge level seems to be equal between medium informatization level and high informatization level companies, but the percentage of above-medium knowledge level is higher for high informatization level group. In general, a positive impact of current informatization level on I4.0 enabling technology knowledge level is shown.

Figure 7 put the focus on the utilization level, it indicates that with the increase of informatization level, it tends to implement more technologies. For companies with low informatization level, no technology has been applied, for medium informatization and high informatization level companies, the average value lies the same between them, but the high informatization level companies are illustrated to implement more technologies than medium informatization level.

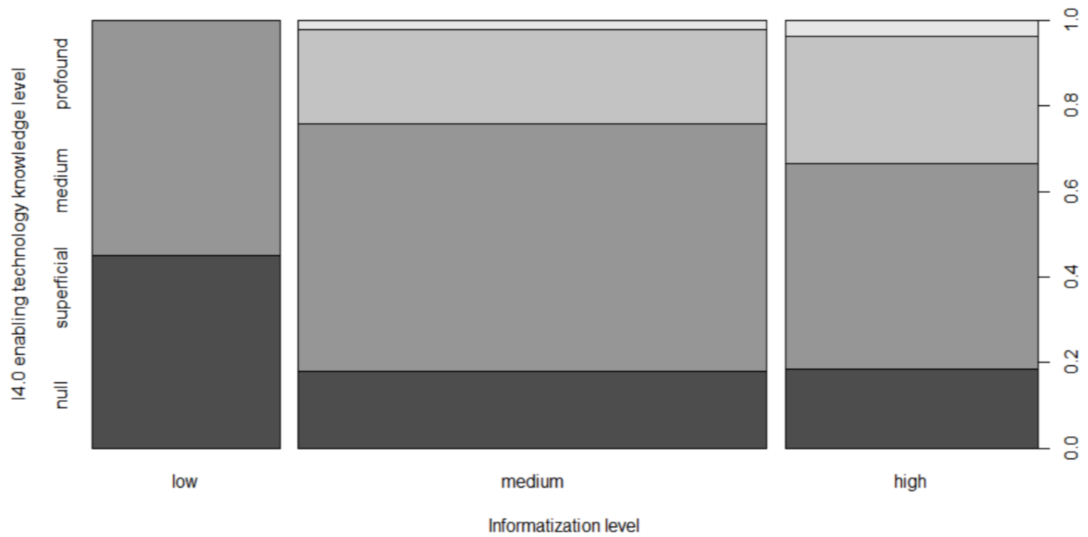

Figure 6: Relationship between Informatization level and I4.0 technology knowledge level

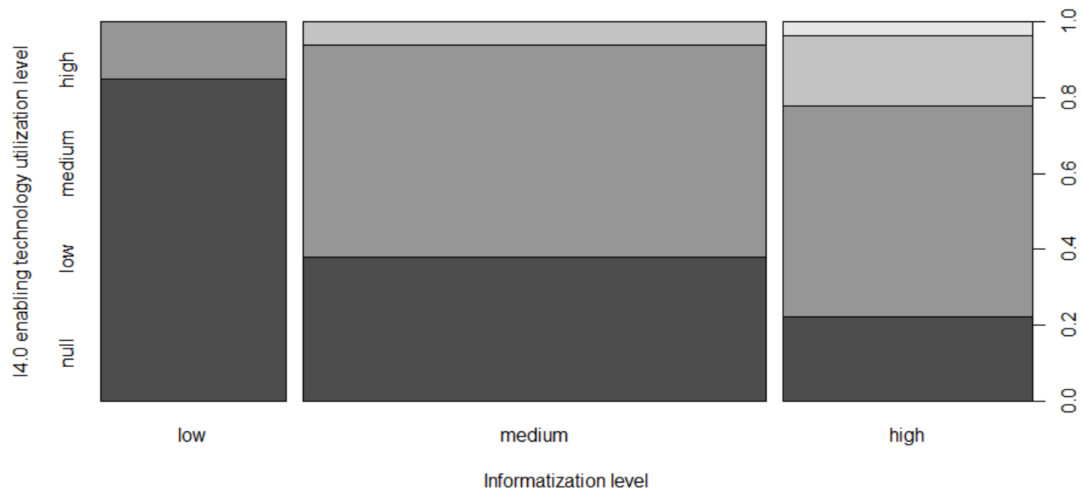

Figure 7: Relationship between Informatization level and I4.0 technology utilization level

4.3 What are the main benefits achieved by the companies that are "on the move" and what are the obstacles they are facing?

Figure 8 and Figure 9 depict the benefits from implementing I4.0 enabling technologies and obstacles in using them respectively. Figure 8 illustrates that the higher the number of technologies implemented, the higher the perceived benefits in overall, except for Flexibility improvement, where the companies who adopted one or two technologies are shown to perceive slightly higher benefits than those who implement more than three technologies. Indeed, companies who have adopted at least one technology are shown to perceive more benefits than the ones who have not yet adopted any technology. Another finding is that Time reduction and Quality/service improvement are considered to be the biggest benefits, implying that companies are utilizing digitalized solutions as levers to reduce time-to-market and deliver high quality product/service.

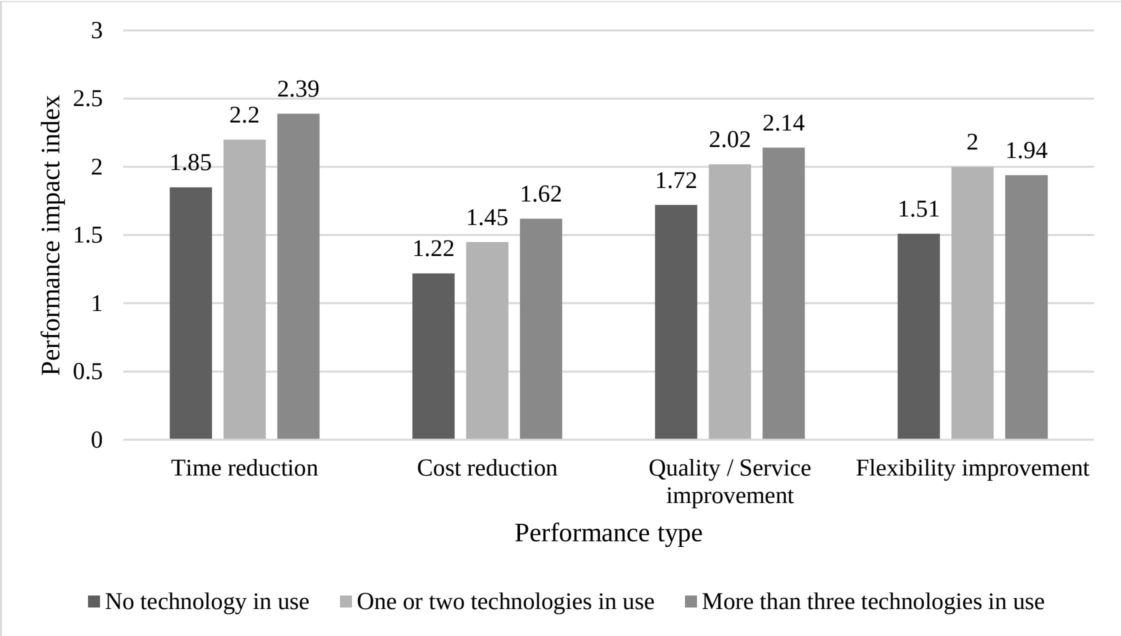

Figure 8: I4.0 enabling technologies utilization benefits

Figure 9 shows the results of obstacles faced by companies when implementing I4.0 enabling technologies. We notice that companies who adopted more than three technologies perceive less obstacles compare to those who adopted less technologies and those who adopted no technologies, the exception is High investment, where companies with higher adoption level shows to require more investment in technology implementation with respect to the ones who lower adoption level. In addition, High investment on technologies and Missing of competencies are considered as the biggest barriers for companies. Indeed, we observed that for companies who have implemented at least one technology, they perceived that there is lack of competencies for the management and utilization of technological solutions.

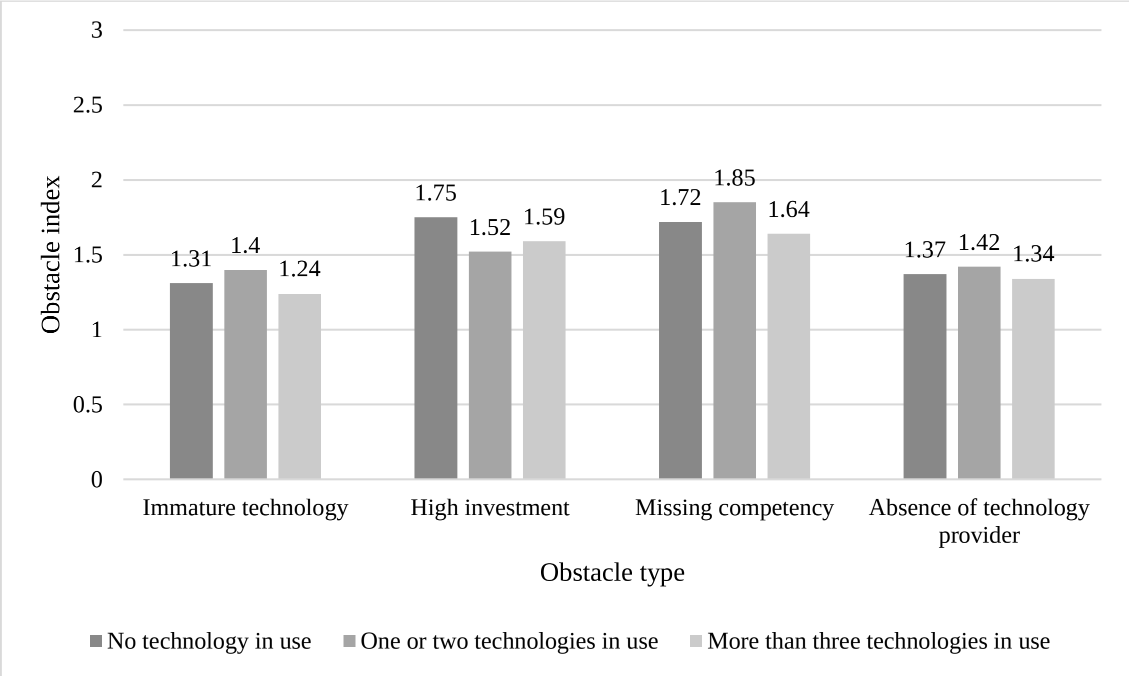

Figure 9: Obstacles in implementing I4.0 enabling technologies

4.4 What are the differences between state-of-the-art in 2019 with respect to that in 2017?

In this section, we compare the I4.0 paradigm state-of-the-art in 2019 to that of 2017 from the perspectives of I4.0 knowledge distribution, implementation distribution, performance impacts and obstacles. As shown in Figure 10, the percentage of companies which have no knowledge and superficial knowledge have been both increased with 2% and 12% separately in 2019. Meanwhile, the percentage of companies who have medium and high knowledge have decreased in 2019. Overall, the proportion of companies who have at least superficial knowledge remains almost the same in 2019 compared to in 2017.

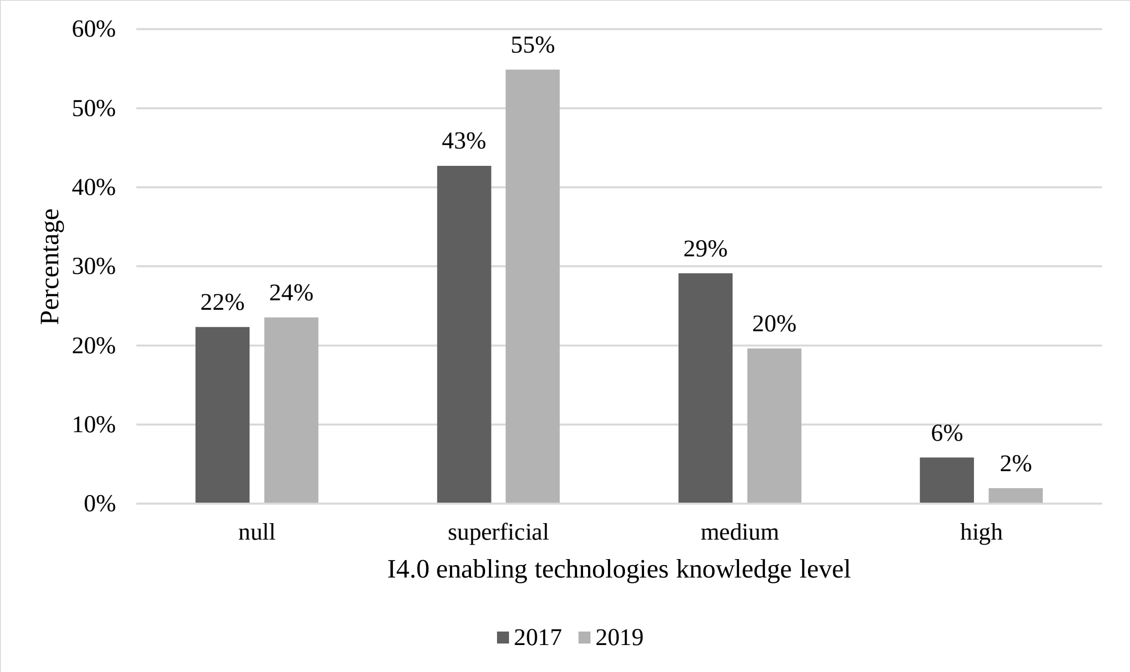

Figure 10: I4.0 enabling technologies knowledge distribution comparison

From Figure 11, we find out that there is an increase trend of technology utilization in 2019, companies who implement more than three technologies has reached almost 10% of the total sample in 2019, meantime, companies who have no technology implementation has decreased by 12%. Moreover, the proportion of companies who have adopted at least one technology has surpassed half of the sample in 2019, while in 2017 this ratio is only 45%. If we look at the utilization distribution together with knowledge distribution, we may notice that although the company's knowledge level in 2019 are smoothly lower than that in 2017, the utilization level is alternatively higher. A reasonable explanation could be that in 2017, even if the companies have higher knowledge level, they were also facing high investment on technology and immature technology as barriers for further implementation, and indeed, these two factors are perceived higher in 2017 than those in 2019 as shown in Figure 13. Therefore, companies in 2017 take more actions on economical and feasibility analysis of I4.0 solutions instead of putting into practices.

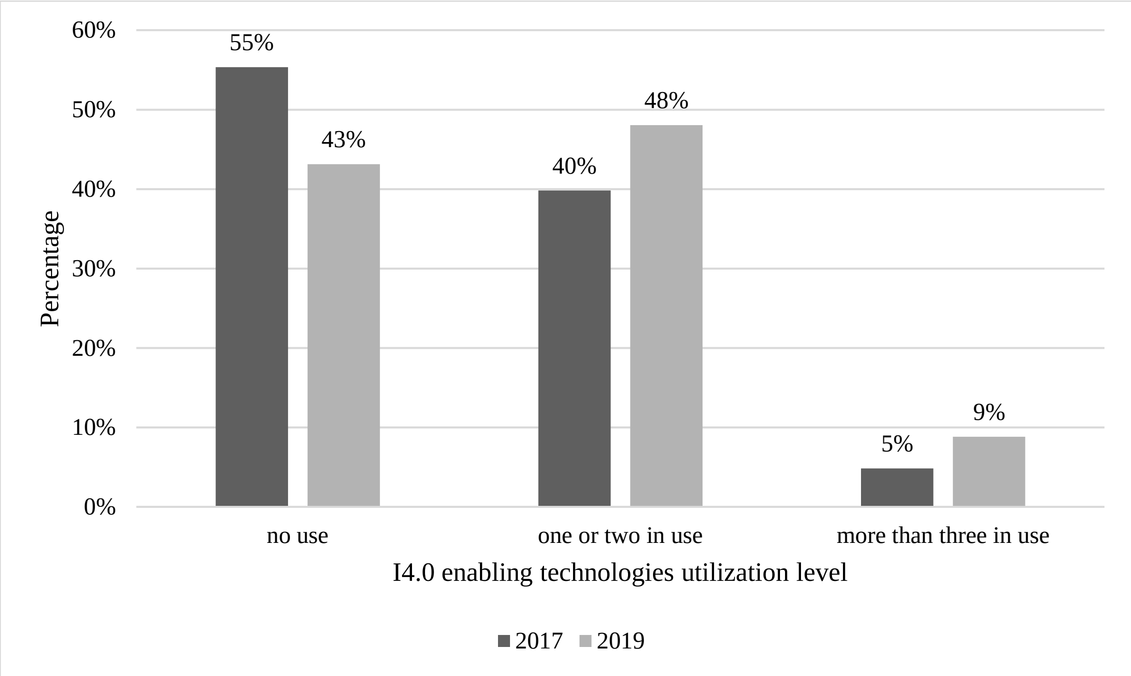

Figure 11: I4.0 enabling technologies utilization distribution comparison

The comparison of benefits and obstacles from implementing I4.0 enabling technologies are separately shown in Figure 12 and Figure 13. Several changes have been detected comparing 2017 and 2019. Regarding benefits, we observed that there is a relevant alteration for Cost reduction, where companies in 2017 perceived it as one of the biggest benefits by I4.0, instead in 2019, it falls to the last place. Flexibility improvement is also demonstrated to be lightly fall in 2019. On the contrary, Time reduction increases its position in 2019. The explanation of the above changes could be that since in 2019, the utilization level of technologies are generally increased compared to 2017, so even though the cost reduction brought by I4.0 implementation is reflected on process efficiency improvement etc, companies have still perceived the investment pressure on corresponded technologies.

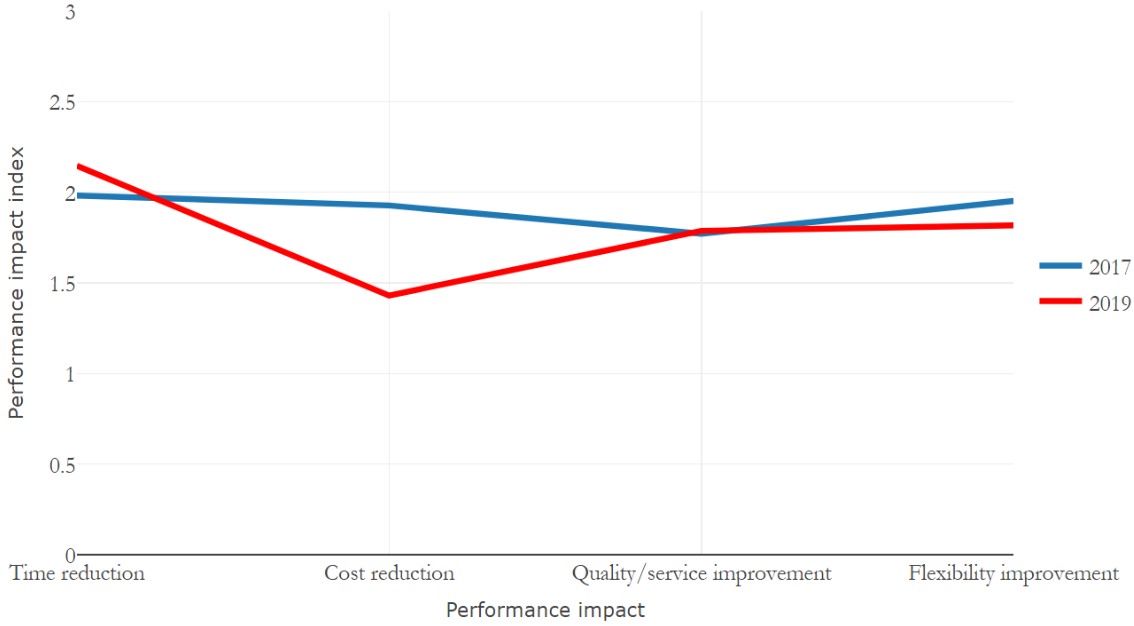

Figure 12: Comparison of I4.0 enabling technologies on performance impacts

Comparing obstacles faced by companies in 2017 and 2019. We noticed from Figure 13 that apparent reverse happens for High investment, Missing competency and Immature technology. High investment and Immature technology are considered as smaller obstacles by companies in 2019 than in 2017, while Missing competency is perceived as the biggest barrier in 2019. Such transpose is predictable, since the more companies involved in implementing I4.0 technological solutions, companies require more technical and managerial competencies to manage such transformation. Moreover, as it has passed two years, companies are more familiar with the I4.0 national initiatives launched by Italian government, and they may take the advantage of investment reimbursement, thus less investment barrier is perceived.

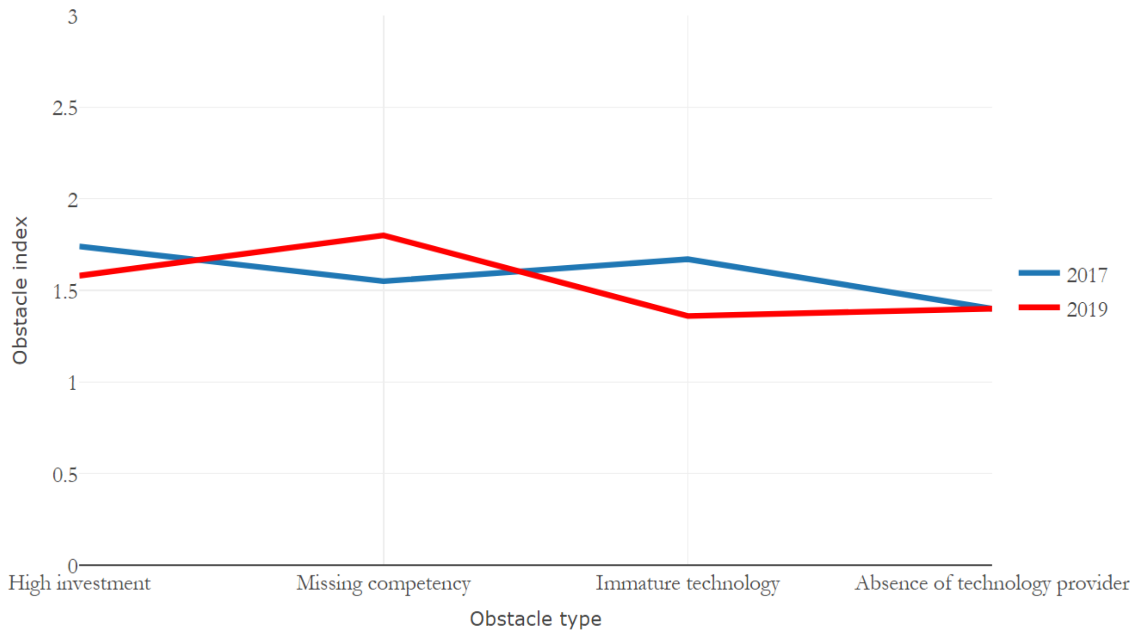

Figure 13: Comparison of I4.0 enabling technologies on obstacles

5. Discussion and conclusion

In this paper, the authors try to take the Italian manufacturing companies as research target, to map the I4.0 state-of-the-art through descriptive survey, and compare the result with that in 2017, which makes a first attempt of making longitudinal empirical study for I4.0 impact (Kamble et al., 2018; Tortorella, Giglio, et al., 2019). Our investigation shows that the Italian manufacturing companies have limited knowledge of the I4.0 enabling technologies, and they have diverse approaches when facing I4.0 paradigm transformation. Indeed, larger and more informatized companies are much more aware of the potential of I4.0 and they show a higher level of both knowledge and adoption of I4.0 enabling technologies. Such results are aligned with previous findings, for example, Gomes and Kruglianskas (2009) argue that company size might affect the access to technologies, while Chen and Fu (2001) show that company size can be an important indicator for the IT adoption pattern in manufacturing firms. Indeed, as SMEs may have not the same financial capacity as larger companies, and there is a pre-existing digitalization gap, SME may not benefit from I4.0 transformation. Thus, they require a more comprehensive assessment of their current resources and economical & technical evaluation of I4.0 solution, in order to guide their progresses in I4.0 implementation. Moreover, the comparison between 2019 and 2017 demonstrate that companies are putting more practically in I4.0 solutions adoption, meantime, they perceive more benefits regarding reduction in lead times and quality improvement, which implies that in the first stage of I4.0 practice, companies are capitalizing more on process improvement, while with the more maturity of process, they seek for creating new business model, which require for higher quality and service improvement. Finally, the survey results show that they face more difficulties in finding adequate competencies in managing digital transformation. In fact, higher skilled managerial and technological workforce are required in the novel manufacturing environment (Grzybowska and Łupicka, 2017). Companies should evaluate their workforce, plan proper qualification and update technical and managerial competencies of their workforce, in order to adapt flexibly in the changing context.

Considering that this paper presents the results of a preliminary study, there is still extensive room for improvement. In our future work, the definition of constructs and their relationships will be tested statistically, and regression analysis will also be conducted to figure out the impact patterns of each variable. Moreover, we will put more focus on SME, to understand the success roadmap for them in I4.0 transformation.

D. The impacts of Logistics 4.0 on Italian manufacturing companies: an exploratory survey

Title	The impacts of Logistics 4.0 on Italian manufacturing companies: an exploratory survey
Authors	Zheng Ting, Ardolino Marco, Bacchetti Andrea, Perona Marco
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Year	2020
Status	Published

Abstract.

This paper explores how Italian manufacturing companies are approaching towards Logistics 4.0 (Log 4.0) by adopting an exploratory survey on a sample of 91 Italian manufacturing companies. The results show that companies have very limited knowledge regarding Log 4.0 enabling technologies. The adoption of digital technologies to support logistics is also very immature. Moreover, the benefits and obstacles are analysed, among which productivity improvement is perceived as the highest benefit, while investment on technologies and missing digital competencies are considered as obstacles for Log 4.0 adoption. In addition, 'Company size' and 'Current automatization level of warehouse stocking system' are found to be the factors that affect the knowledge and adoption level of technologies.

Keywords: Logistics 4.0, digital technologies, exploratory survey

1. Introduction

The growing demand for customized products, characterised by increasing number of product variants and shortening product lifecycles is pushing companies to adapt themselves in higher competitive environment (Hermann et al., 2019). Meanwhile, Industry 4.0 (I4.0) is considered to have the huge potential to provide digital solutions to tackle the challenges, enabling fast decision making, high process efficiency and quick actions towards customer's needs (Hofmann and Rüsch, 2017). Numerous literatures have investigated technologies enabling the Industry 4.0 paradigm (Ghobakhloo, 2018; Moeuf et al., 2018). Indeed, the diffusion of the abovementioned technologies may transform not only the production process, but also the structure of supply chains and business strategies (Müller and Voigt, 2018). Indeed, new technological solutions are providing also opportunities for logistics. However, the impact of the 4.0 paradigm to support logistics in manufacturing companies is not adequately debated in the literature, especially through empirical research (Facchini et al., 2019). Therefore, this article attempts to fill this gap, trying to understand how Italian manufacturing companies are approaching towards the Logistics 4.0 (Log 4.0) paradigm, according to an exploratory survey. A sample of 91 companies has been involved, whose results have been targeted to answer the following questions: i) How the companies are aware about Log 4.0 and which actions have been taken? ii) What are the main benefits and challenges perceived by companies in adopting Log 4.0 solutions? iii) What are the factors that impact the knowledge and adoption of Log 4.0 enabling technologies?

2. Literature review

2.1 Logistics 4.0 enabling technologies and applications

The terminology of Industry 4.0 (I4.0) is well known both by academics and industrial practitioners, acknowledged as the practice of adopting digital technological solutions in industrial production (Facchini et al., 2019; Strandhagen, Alfnes, et al., 2017). On the contrary, the term Logistics 4.0 (Log 4.0) is focused on logistics process, promoting the realization of networking, automation as well as decentralized control in the supply chain through the adoption of digital technologies (Wang, 2016; Winkelhaus and Grosse, 2020). The focus of this paper is Log 4.0 in manufacturing companies, where the planning, control and configuration of logistics flow are concerned. Indeed, the common characteristics of I4.0 and Log 4.0 is the introduction of disruptive technologies. Thanks to advanced sensors and GPS devices, it is possible to achieve real-time monitoring of the goods (Strandhagen, Alfnes, et al., 2017). The implementation of BDA and AI can automize operative activities and facilitate decision-making process (Bienhaus and Haddud, 2018). Through AR technology, operators can pick and locate the order more easily

(Strandhagen, Alfnes, et al., 2017). While the use of Collaborative Robotics can support operators, providing enhanced ergonomics and safety (Chen, 2017). Furthermore, AM can improve the supply chain configuration (Ivanov et al., 2019). Additionally, the adoption of the Blockchain technology can offer companies new opportunities for tracing products and operate transactions in a safer and more controlled way (Viriyasitavat et al., 2018).

2.2 Empirical study of Logistics 4.0 across the world

The empirical studies on logistics covers a wide range of topics. Waqas et al., (2018) incorporate survey and case study to determine the critical barriers for reverse logistics implementation in Pakistani industry. Ashfaq et al., (2020) put the focus on Green Logistics (GL) effects on sustainability performance for Malaysia manufacturing companies. Lai and Wong, (2012) consider Chinese manufacturing exporters as targets to investigate the linkage between GL and company's performance. Moreover, Rahman, (2008) compare the quality management practices in logistics between manufacturing and logistics companies in Australia. Dimitrov, (2005) surveyed the Bulgarian manufacturing sector to understand the knowledge and implementation of logistics concept in the organizational structure and in the managerial practices.

The literature also presents some contributions aimed at assessing the impact of technologies supporting logistics processes. Indeed, several literatures try to link the I4.0 with manufacturing logistics. Müller and Voigt, (2018) take Engineer-to-Order industries with its supply chain partners as research target, in order to determine the potentials and challenges by I4.0. Hermann et al., (2019) seek to provide guidelines on fitting I4.0 design principles to logistics process transformation. Moreover, the applications of I4.0 technologies in manufacturing logistics are studied by Strandhagen et al., (2017), taking into account the characteristics of company's production environment. Furthermore, Facchini et al., (2019) develop a maturity model for Logistics 4.0, based on company's propensity towards Log 4.0, current technology adoption level, as well as the investment level for digital transition.

Despite the presence of the abovementioned references, we observed that the current studies on impact of I4.0 on manufacturing logistics or the Log 4.0 phenomena is mainly conducted through case studies; thus an attempt to make an exploratory investigation through survey approach is worth trying, in order to provide a more holistic insights on how manufacturing companies are proceeding in Log 4.0 journey.

3. Methodology

3.1 Survey design

Researchers often distinguish between exploratory, descriptive and theory testing survey research (Filippini, 1997). In our context, we find out that the literature shows few examples on investigation about Log 4.0 phenomena. As proof of this, the topic of Log 4.0 is at an early stage of investigation, thus our aim is to provide preliminary insights on this domain, to collect evidences of the state-of-the-art of Italian manufacturing companies regarding Log 4.0, as well as to explore some relevant impact factors. Therefore, the methodology adopted in this paper is exploratory survey.

A web survey has been administered for conducting this research, since this method has grown in popularity over the last 15 years thanks to its cost advantage and anonymity guarantee (Couper, 2000; Dillman et al., 2009).

The questionnaire was structured in 4 sections. The first section aimed to collect general information of the company. The second section asked about the supporting infrastructure and instrument for logistics activities. The third section inquired company's perception of Logistics 4.0. Then the fourth section investigated eight Log 4.0 enabling technologies, namely: Internet of Things (IoT), Big data & Analytics (BDA), Artificial Intelligence & Machine Learning (AI & ML), Augmented Reality (AR), Blockchain, Collaborative Robotics, Automated guided vehicles (AGV) and Additive Manufacturing (AM).

Concerning the survey sample, the unit of analysis in this survey refers to the Italian manufacturing companies and Italian sites of multinational corporations. Moreover, this research involves all types of companies, with no limits concerning their size and industry sector. As a result, a sample of 91 companies were surveyed for this study.

3.1 Sample description

Table 1 shows the sample information based on company size. Around 60% of the sample is represented by SMEs, and the Large size companies occupies the other 40%. Moreover, from geographical perspective, surveyed samples cover most of regions in Italy.

Table 1 – Sample description

Company size	Number	Percentage	Classification criteria
Small	18	19.8%	Persons employed < 50
Medium	36	39.6%	50 ≤ Persons employed < 250
Large	37	40.6%	Persons employed ≥ 250

3.2 Variable definition

Table 2 demonstrate an overview of the variables adopted for the analysis and their characteristics.

The variable 'Company size' follows the classification depicted in Table 1, distinguishing among 'Small', 'Medium' and 'Large' companies.

For 'Log 4.0 technology knowledge level', 'Null' means that the enterprise is not aware of the technology in question; 'Superficial' means that the company only investigated the general application field of the technology; 'Medium' indicates that the company has examined the state-of-the-art and understood the potential benefits of technology without investigating any specific application. 'High' implies that the company holds a deep knowledge of technology and has already evaluated all its benefits and costs. A percentage scale transformation has been conducted for the knowledge level variables used in the analysis, considering the cumulation of the eight investigated technologies, ranging from 0 to 100%.

Concerning 'Log 4.0 technology adoption level', since we totally investigated 8 technologies, the adoption level is simply corresponded to the number of technologies implemented by the companies.

The variable 'Current warehouse stocking system' assesses the automatization level of company's warehouse infrastructure. 'Traditional warehouse' implies that the goods are moved through forklift operated by humans and stocked on shelves. 'Semi-automated warehouse' refers to companies who have adopted partially automated warehouse, but still have areas managed in traditional way. 'Automated warehouse' indicates the full adoption of automated systems, such as vertical, horizontal warehouse.

For 'Benefits', authors investigated 13 types of benefits based on 6 diverse processes, where "Forecasting accuracy" and "Demand responsiveness" belong to Demand planning and forecasting process; "Sourcing cost reduction" belongs to Sourcing process; "Seasonal stocks optimization", "Stock level stabilization" and "Stockout reduction" belong to Inventory management; "Warehouse productivity improvement", "Warehouse process cost reduction" and "Picking error reduction" belong to Warehouse operations; "Delivery accuracy", "Delivery reliability" and "Distribution cost reduction" belong to Distribution process; Lastly, "Delivery order cycle time reduction" is investigated as a transversal benefit. For 'Obstacles', 6 types of obstacles are studied, namely: "High investment for technology", "Missing digital competencies", "Limitation of current facilities", "Limited commitment of top management", "Absence of technology provider" and "Low awareness of Log 4.0". For both benefits and obstacles, four-level scale is used ranging from null to high.

Table 2 – Variable definition and criteria

Variable	Type	Nr. of Levels	Levels
Company size	Categoric	3	Small; Medium; Large

Log 4.0 technology knowledge level	Ordinal	4	Null; Superficial; Medium; High
Log 4.0 technology adoption level	Discrete	8	Number 0 to 8
Current warehouse stocking system	Categoric	3	Traditional warehouse; Semi-automated warehouse; Automated warehouse
Benefits	Ordinal	4	Null; Low; Middle; High
Obstacles	Ordinal	4	Null; Low; Middle; High

4 Results

4.1 RQ1: How the companies are aware about Log 4.0 and which actions have been taken?

To answer the RQ1, the authors picture the distribution of company's knowledge and adoption of Log 4.0 enabling technologies, which are separately shown through Figure 1 and Figure 2.

As shown in Figure 1, companies are found to have limited knowledge on Log 4.0 enabling technologies in general. Among the eight investigated technologies, IoT is the most known one, where half of the sample demonstrate to have at least superficial knowledge about it, meantime there are around 12% of the sample is found to have high knowledge IoT. Collaborative Robotics and AGV are also relatively better known by the companies, since more than 30% of the companies are found to have at least superficial knowledge on both. Moreover, with respect to AR, AM, BDA and AI & ML, there is an increase of percentage of "Null", ranging from 76% to 80%. Moreover, the difference also lies on the group of companies who have "Medium knowledge" and "High knowledge", for example, this group in BDA is higher than that in AR, AM and AI & ML. Furthermore, we notice that Blockchain is the least aware technology, with less than 10% of sample state to have at least superficial knowledge for it.

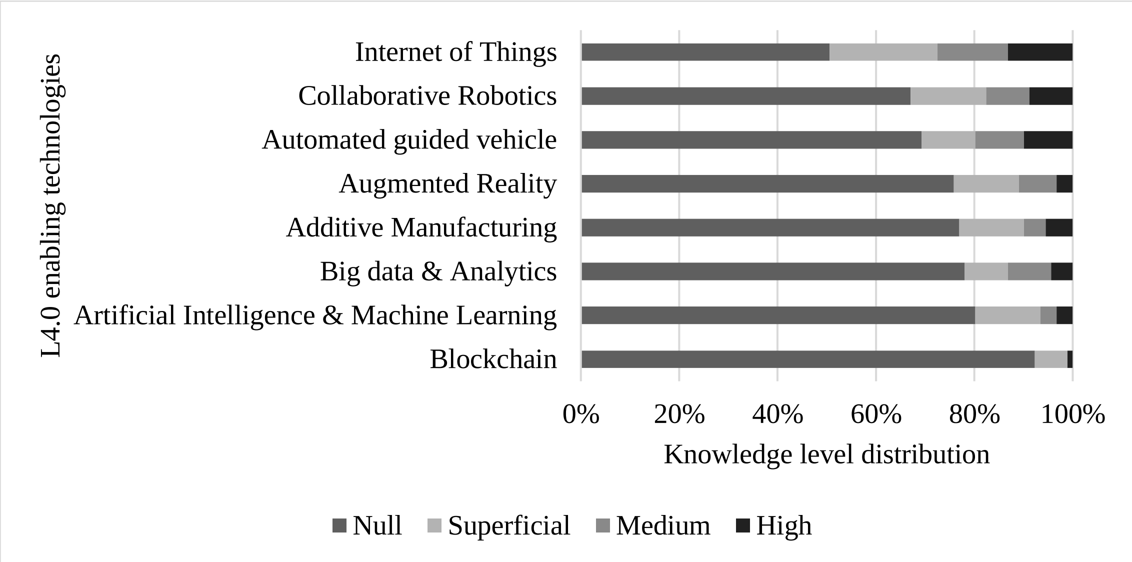

Figure 1. Knowledge distribution for Log 4.0 enabling technologies

Figure 2 shows the distribution of the adoption of Log 4.0 enabling technologies. We notice that although the companies state to have at least superficial knowledge of technologies, there is a part of them which have not activated any actions on technology adoption, shown by red colour in Figure 2, and such scale is evident for AGV, Collaborative Robotics, AM, AI & ML and AR, with more than 10%. Besides, we observed that, except for AR and Blockchain, all the other technologies have been implemented by at least one company in the sample. The first position comes to IoT, then followed by Collaborative Robotics, BDA, AGV, AM and AI & ML. Indeed, the utilization rate is generally coherent with the knowledge distribution; exceptions are AR and BDA, since no implementation is observed for AR, and the utilization proportion of BDA is about 7%, while the companies who state to have at least superficial knowledge for BDA is only around 22%.

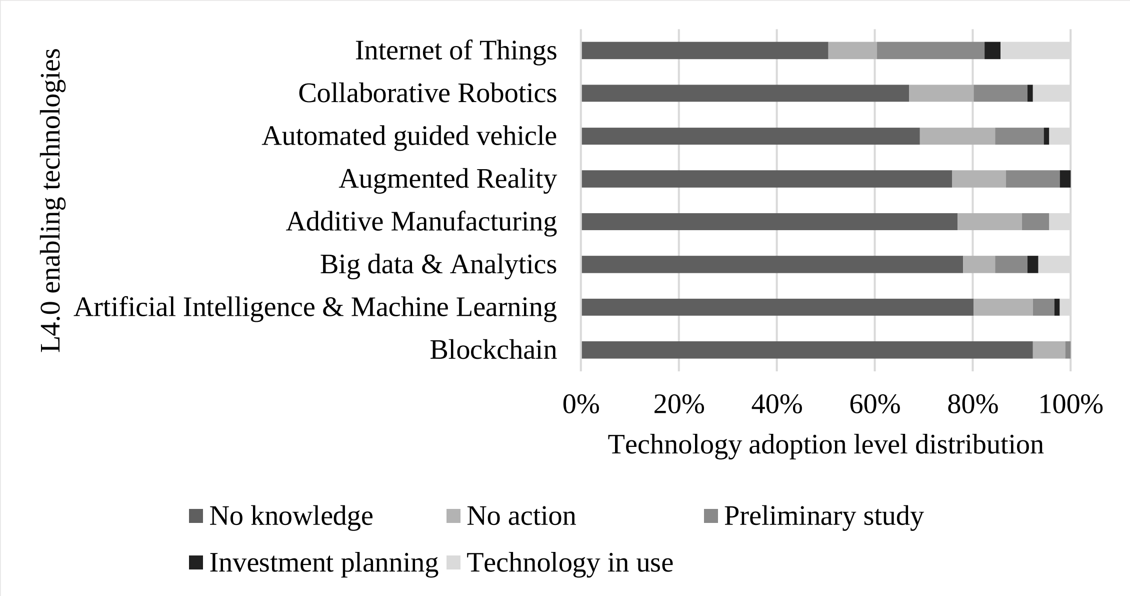

Figure 2. Distribution of Log 4.0 enabling technologies adoption

4.2 RQ2: What are the main benefits and challenges perceived by companies in adopting Log 4.0 solutions?

To answer RQ2, we draw the line plot in Figure 3 and Figure 4 to show what kind of benefits and challenges companies are perceived in adopting Log 4.0 solutions, based on the number of implemented technologies.

Figure 3 illustrates that the higher the number of technologies implemented, the higher the perceived benefits in general. The only exception is "Demand responsiveness", where the companies who adopted one or more technologies are shown to perceive lower benefits than those who implement no technologies. Overall, the benefit index is ranged between 1 and 2, indicating a relatively low-middle perceiving benefits by companies. However, among all the benefits, the top ranked benefits seem to be "Warehouse productivity improvement", "Warehouse process cost reduction" and "Picking error reduction", which are all belonging to the category of Warehouse operations. Another finding is that for Inventory management cluster, in which "Seasonal stock optimization", "Stock level optimization" and "Stockout reduction" are included, the companies who adopted one or more than one technology perceive much higher benefits than those who have not implemented any technology.

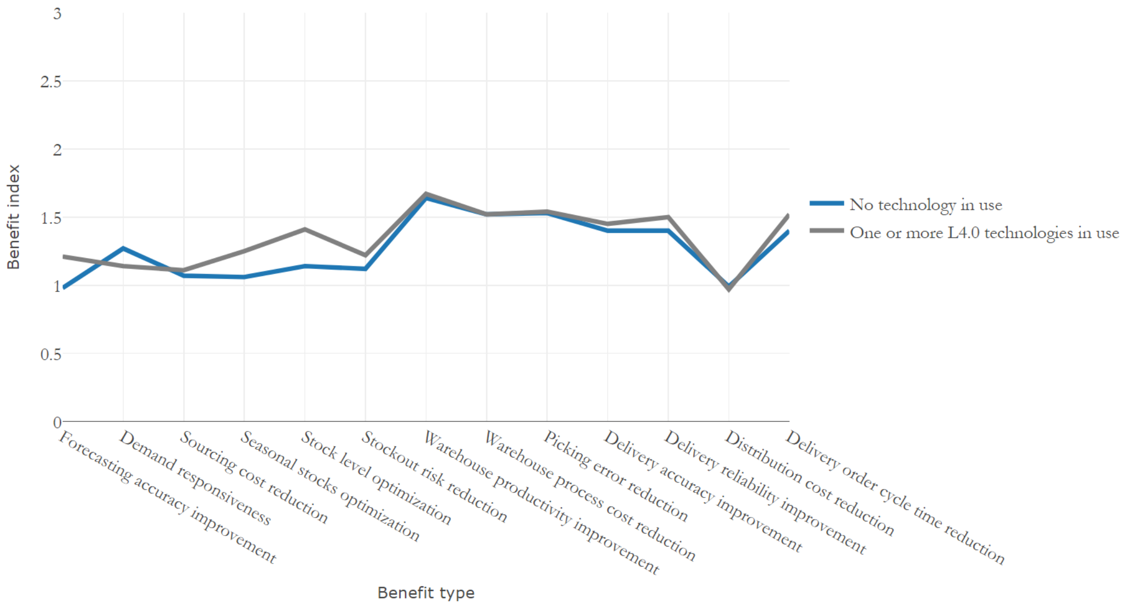

Figure 3. Benefits of implementing Log 4.0 enabling technologies

Figure 4 shows the results of challenges faced by companies when implementing Log 4.0 enabling technologies. In general, the obstacle index is between 1 and 2, which implies a low and middle obstacle, and among all the obstacles, "High investment for technology", "Missing digital competencies" and "Low awareness of Log 4.0" are ranked as the biggest obstacles. Moreover, we notice that companies who adopted at least one technology perceive less obstacles compare to those who adopted no technologies, the exception is "Limitation of current facilities". In addition, "Limited commitment of top management" is considered to be a bigger barrier for company who has not started to implement technologies. These results imply that companies still view financial issues as a barrier for adopting Log 4.0 enabling technologies, and there is also a lack of internal competencies to manage and utilize the novel technologies. Besides, the initiative by top management can reduce the barriers in moving towards 4.0 transformation.

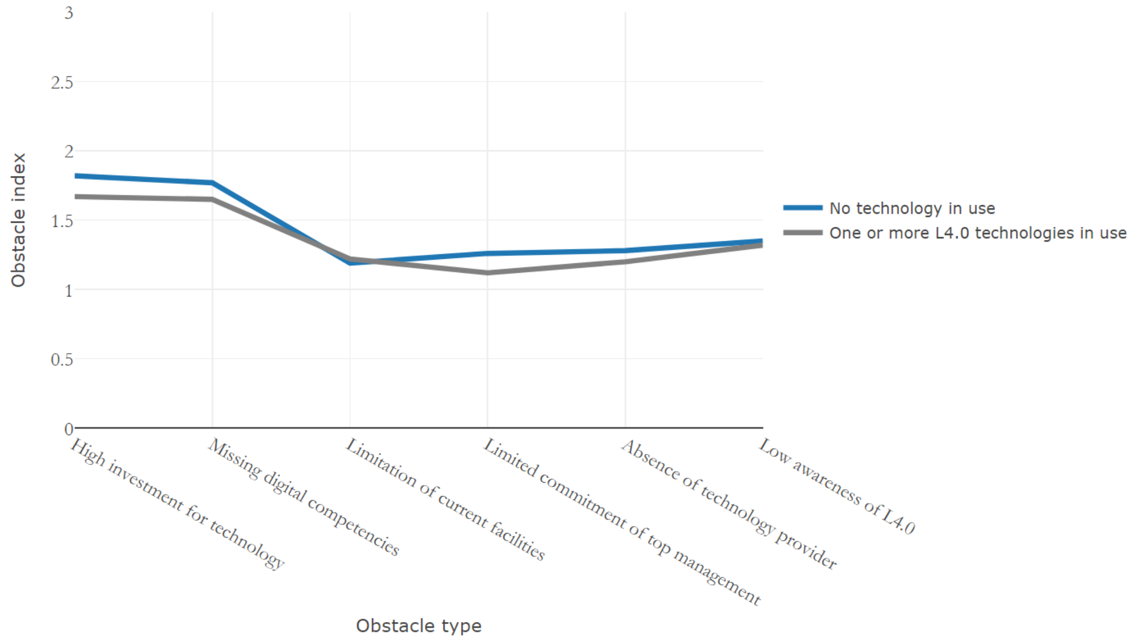

Figure 4. Obstacles in implementing Log 4.0 enabling technologies

4.3 RQ3: What are the factors that impact the knowledge and adoption of Log 4.0 enabling technologies?

To answer the RQ3, the authors analyse the variables and depict the relationships among these variables, boxplots are shown separately in Figure 5, Figure 6 and Figure 7.

The first factor that impacts company's knowledge and adoption level of Log 4.0 enabling technologies is company size. Two boxplots are shown in Figure 5 and Figure 6 to demonstrate such relationship. From Figure 5, we notice that with the increase of company size, there is also the increase of company's knowledge level. Indeed, the mean of knowledge level for small companies lies only 0, which corresponds to "No knowledge", where the mean of knowledge level for medium and large sized companies situate separately around 0.1 and 0.15. Moreover, we observe that for Large sized companies, they tend to have higher upper 25 quartile with knowledge level index ranging from around 0.3 to 0.7, while for small sized companies, similar index is ranged from around 0.15 to 0.25, which indicates that a proportion of large companies are shown to have deeper knowledge, meantime the small companies are not. In addition, the outliers in the plot can be explained by companies who have higher knowledge level, this phenomenon is noticed for each group.

Figure 6 confirms the difference between small companies and medium, large ones, but there is almost no difference between medium and large group. It is also observed that the mean of technology adoption level is very low, which is applied to all sizes of companies. However, for medium- and large-sized companies, the upper 25 quartile lies between 1 and 2, implying that at least one technology is adopted.

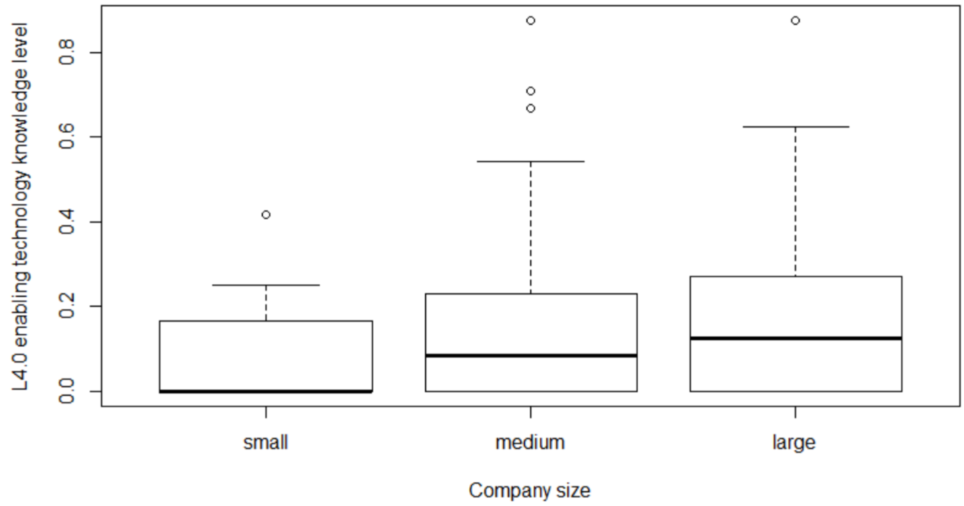

Figure 5. Relationship between Company size and Log 4.0 technology knowledge level

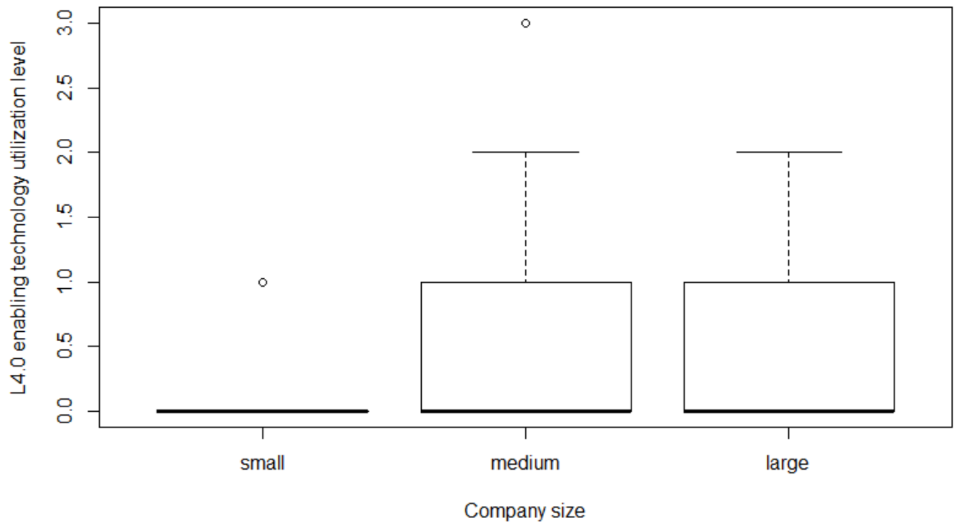

Figure 6. Relationship between Company size and Log 4.0 technology adoption level

The second factor analysed in this study is the automatization level of company's current warehouse stocking systems, which affects the adoption level of Log 4.0 technologies. Figure 7 indicates such relationship. It shows that for all types of warehouse stocking systems, the mean equals to 0, which is aligned with the result shown by Figure 2, where it illustrated that the adoption level of Log 4.0 technologies is pretty low, and 70% of the companies have not implemented any technologies. However, we still notice that for companies who have semi-automated warehouse stocking systems, it is higher the upper 50 quartile, and such increase is much more obvious for companies who have automated warehouse stocking systems. The possible explanation is that due to the experience of managing and utilizing automated systems, when facing with novel digital technologies, companies are more ready to integrate them with their existed system for further improvement.

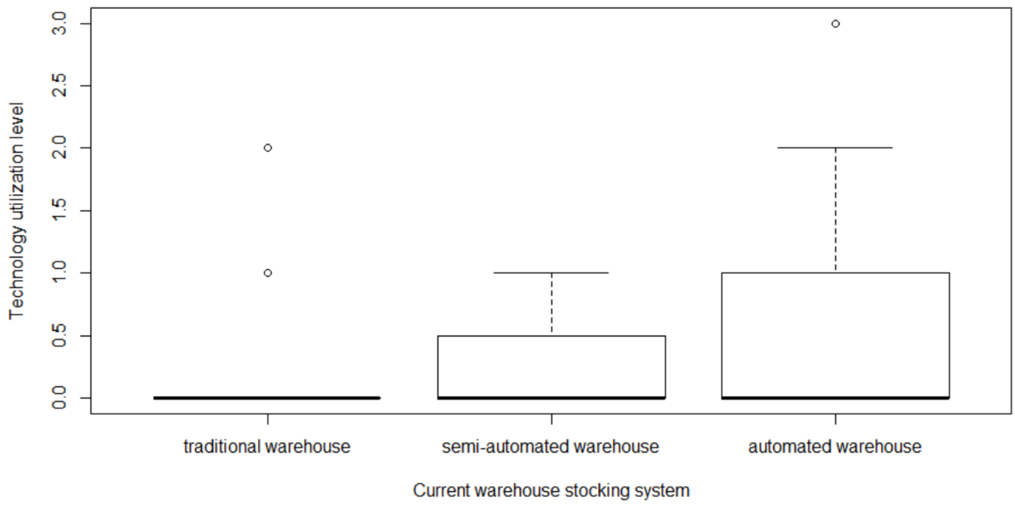

Figure 7. Relationship between Company's current automatization level of warehouse stocking system and Log 4.0 technology adoption level

5 Discussion and Conclusion

In this paper, the authors attempt to map the Log 4.0 state-of-the-art in the Italian manufacturing companies through an exploratory survey, particularly from the perspectives of the awareness and adoption level of Log 4.0 enabling technologies by companies, benefits and obstacles the companies are facing up with, as well as the critical factors that impact the knowledge and adoption level.

Overall, our study shows that the Italian manufacturing companies have narrow knowledge of the Log 4.0 enabling technologies, and the adoption of technologies is limited. However, IoT is demonstrated to be better known and applied by companies, which is the pillar technology of I4.0. Moreover, companies are found to have higher awareness and implementation level for Operation Technology (OT), such as the Collaborative Robotics and AGV, and less for Information Technology (IT). The explanation can be twofold: from one side, since there are a portion of companies who have adopted automation systems for logistics operations, they tend to be more familiar with the management and utilization of automated robots; from the other side, as the IT cluster adoption usually requires profound business and infrastructure transformation, it may require companies to put more time and investment for implementation. Indeed, this result is aligned with the findings from benefits and obstacles analysis, where companies state that they consider “High investment for technology” and “Missing digital competencies” as the biggest barriers for Log 4.0 technology adoption. Besides, companies perceive “Warehouse productivity improvement”, “Warehouse process cost reduction” and “Picking error reduction” as the biggest benefits brought by Log 4.0 enabling technology, which also confirms the fact that companies adopt more Log 4.0 solutions for Warehouse operations, and these solutions are mainly OT related. Another finding is that companies are shown to have diverse approaches towards Log 4.0 transformation. Indeed, larger and more automated companies are much more aware of the potential of Log 4.0 and they show a higher level of both knowledge and adoption of Log 4.0 enabling technologies. Small size companies may have not the same financial capacity as larger ones, and since a complex computer solution management is required for Log 4.0 transformation, small companies are therefore shown to be behind the larger ones. However, a comprehensive assessment of their current resources and evaluation of economical & technical feasibility for Log 4.0 solution can be carried out, to find out the appropriate Log 4.0 implementation.

Considering that this paper presents the results of an exploratory study, we only present the results of our survey without a reference framework guiding the assumptions derived from the survey responses, and there is still extensive room for improvement. In our future work, the definition of constructs and their relationships will be tested. Then the investigation for staff training activities, competencies as well as comparison with retailer companies can be further developed.

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APPENDIX

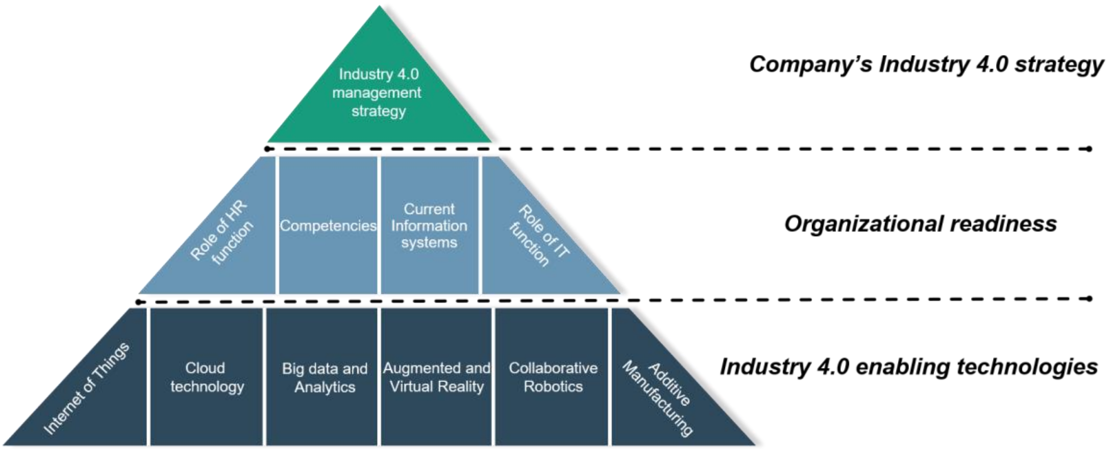
Appendix A. Survey protocol: The impact of Industry 4.0 in the Italian manufacturing context

A. Introduction to the questionnaire

INDUSTRIE 4.0

"Industry 4.0 is one of the most frequently discussed topics in practice and science today. This trend is usually seen as a disruptive development, aiming at the digitalization and networking of products, business models, and value chains through information technology (IT) and operating technology (OT)".

QUESTIONNAIRE SCHEME



QUESTIONNAIRE TARGET

The questionnaire is aimed at manufacturing companies in Italy, regardless of their size and sector.

The processing of the questionnaire can be carried out by different respondents from the same company, depending on the skills required to answer the questions. The potentially suitable respondents will be suggested:

- Founders or managers of the company (CEO, managing director, general manager, etc.)
- Management
- Chief Information Officer (CIO)
- Chief Digital Officer (CDO)
- Chief Technology Officer (CTO)
- Operations Manager/Supply Chain Manager
- Head of production/manufacturing
- Head of Research & Development
- Technical support manager
- Human Resources Manager

BENEFITS OF RESPONDENTS

Self-assessment tool & benchmark building

Executive summary of the research result

Free participation in the presentation event

COMPILATION TIME

You will need only 5 to 10 minutes to answer the complete questionnaires.

DATA TREATMENT

You can find our data protection information about our survey here.

IN COLLABORATION WITH

AHK Deutsch-Italienische Handelskammer
Camera di Commercio Italo-Germanica

B. General information of the company

1. How many employees did your company have in 2019?

< 10	10-49	50-249	250-1000	> 1000

2. Which of the following industries does your company belong to (according to NACE)?

10 - Manufacture of food products	
11 - Manufacture of beverages	
12 - Manufacture of tobacco products	
13 - Manufacture of textiles	
14 - Manufacture of wearing apparel	
15 - Manufacture of leather and related products	
16 - Manufacture of wood and of products of wood and cork, except furniture	
17 - Manufacture of paper and paper products	
18 - Printing and reproduction of recorded media	
19 - Manufacture of coke and refined petroleum products	
20 - Manufacture of chemicals and chemical products	
21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	
22 - Manufacture of rubber and plastic products	
23 - Manufacture of other non-metallic mineral products	
24 - Manufacture of basic metals	
25 - Manufacture of fabricated metal products, except machinery and equipment	
26 - Manufacture of computer, electronic and optical products	
27 - Manufacture of electrical equipment	
28 - Manufacture of machinery and equipment n.e.c.	
29 - Manufacture of motor vehicles, trailers, and semi-trailers	
30 - Manufacture of other transport equipment	
31 - Manufacture of furniture	
32 - Other manufacturing	
33 - Repair and installation of machinery and equipment	
Other (please specify):	

3. Where is your company located?

4. Please identify the competitive priorities of your company:

	Irrelevant	Low relevant	Neutral	Relevant	High relevant
Cost					
Quality					
Delivery time					
Flexibility					

5. Please give your opinion on the following statements regarding the innovation approach of your company:

	Fully disagree	Rather disagree than agree	Neutral	Rather agree than disagree	Fully agree
Innovation is mainly driven by the **R&D** department, then innovative technology is applied to products/processes.					
Innovation is mainly driven by **marketing**, which best understands the requirements of the market					
Innovation in our company is driven by **design**. New technologies support the aesthetic and symbolic quality of the products.					

6. Please rate your companies in terms of operational performance compared to competitors in your industry:

	Bottom end of the industry	Below average	Average or equivalent to the competitors	Better than average	Superior or much better than average
Cost					
Quality					
Delivery time					
Flexibility					

C. Industry 4.0 enabling technologies

This section examines the relevance and potential deployment of the technology and analyses the knowledge of the potential benefits and diffusion barriers.

7. Indicate which statement best describes your knowledge of the following technologies:

	Knowledge				
	I don't know it very well	The general field of application of the technologies is known	The state of the art and the potential benefits have been examined.	The technical specifications and operating principles of the technology are known	Others
Internet of Things					
Big data and Analytics					
Cloud technology					
Augmented and Virtual Reality					
Collaborative Robotics					
Additive Manufacturing					

8. Please state your opinion on the relevance and implementation of the following technologies in your company:

	Relevance				
	Not relevant	Low relevant	Neutral	Relevant	High relevant
Internet of Things					
Big data and Analytics					
Cloud technology					
Augmented and Virtual Reality					
Collaborative Robotics					
Additive Manufacturing					

	Implementation						
	No action is taken	Preliminary study	Technical-economic feasibility analysis	Investment planning	Implementation in progress	Technology in use	Technology was used and then abandoned
Internet of Things							

Big data and Analytics							
Cloud technology							
Augmented and Virtual Reality							
Collaborative Robotics							
Additive Manufacturing							

9. In your opinion, how strongly can the following performances/goals be influenced by Industry 4.0 enabling technologies?

	Low	Medium	High	Not relevant
Increase in turnover				
Increase in turnover (new market)				
Creation of a new business model				
Processes automation				
Increase of flexibility				
Improve the quality of products/services				
Reduce cost				
Increase of customer satisfaction				

10. In your opinion, how strongly can the following performances/goals be influenced by Industry 4.0 enabling technologies?

	Not an obstacle	Small obstacle	Medium obstacle	Big obstacle
Investment required for the acquisition of enabling technologies				
Investments necessary for the acquisition and development of skills				
Lack of commitment on the part of the market leader in the supply chain and business partners to introduce new technological solutions				
lack of digital culture				
Missing and/or difficult to find suitable technology providers				
Difficulties in estimating the benefits of industry 4.0				

D. Industry 4.0 strategy of the company

This section asks about the company's strategy and positioning with regard to the Industry 4.0 paradigm.

11. How do you evaluate the importance of Industry 4.0 in the business strategy of your company?

Not relevant	Low relevant	Neutral	Relevant	High relevant

12. How do you compare your company to your competitors in terms of Industry 4.0 implementation?

We are very far behind	We're a little behind	We're on the same level	We're a little ahead	We are very far ahead	I do not know

13. To what extent do you agree with the following statements regarding the participation of Top management in I4.0 projects?

	Fully disagree	Rather disagree than agree	Neutral	Rather agree than disagree	Fully agree
Top management is personally involved in Industry 4.0 projects.					
All important business function heads are informed about the strategy for Industry 4.0.					

14. Estimate the extent to which business functions are affected by Industry 4.0 projects in your company:

	Null	Low	Medium	High
Marketing & Sales				
Information system (IT)				
Administration & Controlling				
Research & Development				
Purchasing				
Production				
Logistics & Distribution				
Quality				
Service & Customer care				
Other (please specify):				

E. Role of Human Resources (HR) department:

The following section is intended for HR managers. If you do not have an HR function, you can simply skip to the next section by clicking "No".

15. Do you have a formal HR function in your company which deals with planning training for employees, selecting new employees, etc.?

Yes	No

16. Do you think the HR function plays a strategic role in the transformation to Industry 4.0?

Fully disagree	Rather disagree than agree	Neutral	Rather agree than disagree	Fully agree

17. How would you characterize the role of the HR department with regard to the introduction of Industry 4.0 solutions in your company?

It is guided by the other business functions in assessing the skills and professionalism required to implement I4.0 enabling technologies	
It leads the other business functions in identifying and mapping the 4.0 competencies of their employees	
It focuses on the topics of employment and occupational safety in the connection with the new I4.0 enabling technologies	
It is seldom involved in decisions on the introduction of I4.0 enabling technologies	
It is only involved at the end of the I4.0 project introduction by assessing the skills needed to fully exploit the potential made possible by the project	
Other (please specify):	

F. Company's competencies

This section asks about the competences of the company.

18. Indicate the level of competence in your company regarding the following areas and technologies related to Industry 4.0:

	Not available	Low	Medium	High
Business process digitalization				
Data analysis				
Cybersecurity				
Programming				
Soft Skill - Problem solving, creativity, logical thinking				
Soft Skill - Business communication				
Soft Skill - Teamwork				
Soft Skill - Leadership				
Soft Skill - Result orientation, time and stress management				

19. In your opinion, how relevant are the following levers for filling the competence gaps in your company?

	Not relevant	Low relevant	Moderately relevant	Relevant	Highly relevant
Search and recruitment of new competent employees					
Planning of I4.0-related training for employees					
Increase cooperation with external bodies					
Other (please specify):					

20. Concerning the implementation of the following I4.0 enabling technologies, please indicate which profiles are (if any) present in your company and how relevant they are to reach the full potentialities of the technology:

	Presence				Relevance	
Internet of Things	Yes, internal profile	Yes, external consultant	No, but in search	No	Yes	No
IoT Strategist						
IoT Solutions Architect						
Software Development Engineer						
Additive Manufacturing						
3D Digital Designer/Modeler						
Material Engineer						
3D Machine Supervisor						

Big data and Analytics						
Data Scientist/Architect						
Data Analyst						
Data Security Manager						
Collaborative robotics						
Computer Vision/Perception Robotics Engineer						
Machine System Engineer						
Mathematical and Data Analyst						
Augmented and virtual reality						
AR/VR Software Engineer						
Augmented Reality Application Developer						
3D Graphics Designer and Animator						
Cloud technology						
System/Infrastructure Architect						
Machine Supervisor						
Network Security Manager/Analyst						
Managerial roles required for each I4.0 enabling technology						
Digital Project Manager						
Strategy and Innovation Manager						
Chief Digital Officer						

G. Role of the IT department

The following section is intended for IT managers/leaders. If you do not have a formal IT role, you can simply skip to the next section by clicking "No".

21. Do you have a formal IT department in your company?

Yes	No

22. Do you think that the IT department plays a strategic role in the transformation to Industry 4.0?

Fully disagree	Rather disagree than agree	Neutral	Rather agree than disagree	Fully agree

23. How would you characterize the role of the IT department with regard to the introduction of Industry 4.0 solutions in your company?

The IT function is constantly informed about new technological developments and proactively offers these to the business units of the company.	
The IT function is led by the other business functions in evaluating new emerging technologies	
The IT function focuses only on the issues of security and the integration of new digital technologies into the existing information infrastructure	
The IT function is seldom involved in the choice of technologies, but only in their operational implementation	
Other (please specify):	

H. Current information systems

This section asks about the coverage of information systems in the company.

24. Please give your opinion on the following statements:

	Fully disagree	Rather disagree than agree	Neutral	Rather agree than disagree	Fully agree
We mainly use paper for document management, formulation and dissemination of procedures, etc.					
A management information system is a major investment for us.					
Information systems can improve our work efficiency.					

25. Specify which types of information systems are available in the company:

	System in use	System to be used	System in the planning stage	System not planned
ERP (Enterprise Resource Planning)				
CRM (Customer Relationship Management)				
MES (Manufacturing Execution System)				
APS (Advanced Production Scheduling)				
S&OP (Sales & Operation Planning)				
PLM/PDM (Product Lifecycle Management/Product Data Management)				
WMS (Warehouse Management System)				
BI (Business Intelligence & Analytics)				
CAD/CAM (Computer-Aided Design/Manufacturing)				
Other (please specify):				

Thank you very much for your participation in our survey!

26. Would you like to give additional feedback or participate in an interview? If so, please enter your e-mail address:

Appendix B. Survey protocol: The impacts of Logistics 4.0 on Italian manufacturing companies: an exploratory survey

A. Questionnaire presentation

INTRODUCTION

The main objective is to analyze the level of adoption of the 4.0 paradigm, in the Italian manufacturing context, with a focus on logistics and supply chain processes.

QUESTIONNAIRE TARGET

The questionnaire is targeted to manufacturing companies of any size & sector, with headquarters or at least one manufacturing plant in Italy. The completion of the questionnaire is recommended to the company's logistics, supply chain, and operations manager.

BENEFITS OF RESPONDENTS

The completion of the questionnaire will ensure that the respondent can:

- Get a free copy of the final research report
- Participate free of charge in the results dissemination events
- Position yourself within a representative sample of respondent companies

INSTRUCTION FOR COMPILATION

- The compilation can be interrupted and resumed later, even after the PC has been turned off. The user, accessing from the same PC, can resume the compilation from the last updated section

ESTIMATED AVERAGE TIME FOR COMPILATION

15-20 minutes

DATA TREATMENT

The data entered will be treated confidentially within the research laboratory and will not be disclosed outside, except in aggregate form.

For further information on data processing please refer to the following information note: LINK.

B. General information of the company

1. Company name:

2. Name of respondent:

3. E-mail:

4. Respondent's business role (in detail):

5. Phone number:

6. Company's turnover in 2018 [€ million]:

7. Please indicate the proportion (%) of turnover generated by sales in Italy in 2018:

0% - 20%	21% - 40%	41% - 60%	61% - 80%	81% - 100%

8. Please indicate the number of employees in the company:

9. Where is your company located?

C. Systems and tools to support logistics processes

This section of the questionnaire aims to collect information about the systems, infrastructure, means, and instrumentation under the direct control of the company (regardless of whether they are owned or rented). Please evaluate all the logistic-productive nodes of the company (not only the single production plant).

10. Please indicate which of the following informative systems are present in the company:

	System already in operation	System in implementation	System not available	Not applicable to our context
Demand planning software				
CPFR (collaborative planning, forecasting, and replenishment)				
RSP (resource and Supply planning)				
DRP (distribution requirement planning)				
IBP (integrated Business Planning)				
FMS (fleet management system)				
RTLS (real-time location system)				
TMS (transportation management system)				
WMS (warehouse management system)				
Information system to support radiofrequency systems				
Auto-identification systems				
Other (please specify):				

11. Device and equipment:

Bar-code reader	Tag RFID	Tablet	Wearable device (e.g. smart glasses …)	None	Other (please specify)

12. Storage infrastructure:

Vertical automatic warehouses	
Horizontal automatic warehouses	
Warehouse with a shuttle system	
Automated storage with trasloelevator	
None	
Other (please specify):	

13. Stocking and picking infrastructure:

Miniload	
Dispenser system	
Pick-to-box system	
None	
Other (please specify):	

D. Logistics 4.0

This section of the questionnaire aims to investigate the positioning of the company concerning the adoption of the 4.0 paradigm to support logistics processes (Logistics 4.0).

14. What is the perception of the adoption of the Logistics 4.0?

It represents a bubble that will soon deflate	
It represents an objective to strive towards for the company, but which will not have an impact on logistic processes	
It is the model to be pursued to optimize logistics processes, but it is concretely achievable only by medium-large companies	
It is the model to be pursued for all companies that want to remain competitive and survive in a globalized environment	
Other (please specify):	

15. How would you define the positioning of your company regarding the adoption of the Logistics 4.0?

No action is taken	
Technical-economic assessment of enabling technology(s)	
Implementation of individual technology without full integration among them	
Adoption of different technological solutions with integration among them	
Other (please specify):	

16. How would you define the positioning of the company regarding the adoption of the Logistics 4.0 compared to your competitors?

There are no particular differences with respect to the positioning of our competitors	
Competitors have already taken initiatives in the 4.0 area and we are trying to make up this gap	
Competitors have already taken initiatives in the 4.0 area, but we do not think it is useful to try to recover this gap	
We are leaders in the application of concepts and technologies related to the 4.0 model in logistics processes	
The behavior of competitors is not known	
Other (please specify):	

17. Which measures of the National Enterprise 4.0 Initiatives did the company have access to (concerning logistics processes)?

Superamortisation	
Iperamortisation	
Research & Development tax credit	
Training 4.0 tax credit	
New Sabatini	
No measures	
Other (please specify):	

18. Initiatives have been carried out (or are in progress) to align and/or reconfigure workers' skills given the Logistics 4.0:

Yes, they've already been done	
Yes, they are in progress	
No, but they've already been planned for the future	
No, and they are not currently scheduled	
Other (please specify):	

19. To what extent do you think that the Logistics 4.0 impacts/possibly impacts the following performance and objectives?

	Not relevant	Low relevant	Relevant	High relevant
Improvement of warehouse productivity				
Reduction of internal warehouse process costs				
Reduction of procurement costs				
Reduction of transport distribution costs				
Reduction of errors in picking activities				
Reduction in stock level				
Reduction of the cycle time perceived by the customer				
Increase delivery punctuality				
Improve delivery accuracy				
Increase delivery reliability				
Reduction of stock breakages				
Increase accuracy in demand forecasting				
Optimization of the seasonal stock planning process				
Increase responsiveness to changes in demand				
Improve working conditions for operators				
Other (please specify):				

20. What do you think are the most inhibiting obstacles to the application of Logistics 4.0 in your company?

	Not an obstacle	Small obstacle	Medium obstacle	Big obstacle
Investment required for the purchase of enabling technologies				
Investment required to acquire and develop the appropriate skills				

Limitation of endogenous enabling infrastructures (absence of IT systems, ...) and/or exogenous (limited internet connection bandwidth, ...)				
Limited commitment of top management and/or limited digital corporate culture				
Absence and/or difficulty in finding suitable technology providers				
Limited awareness of the 4.0 paradigm and difficulty in estimating its benefits in the logistics processes				
Other (please specify):				

E. Knowledge and utilization of digital technologies

This section examines the relevance and potential deployment of the technologies.

21. Indicate which statement best describes your knowledge of the following technologies:

	Knowledge				
	I don't know it very well	The general field of application of the technologies is known	The state of the art and the potential benefits have been examined.	The technical specifications and operating principles of the technology are known	Others
Internet of Things					
Additive Manufacturing					
Augmented Reality					
Collaborative Robotics					
Artificial Intelligence					
Big data and Analytics					
Automated Guided Vehicles					
Blockchain					

22. Please state your opinion on the relevance and implementation of the following technologies in your company:

	Relevance				
	Not relevant	Low relevant	Neutral	Relevant	High relevant
Internet of Things					
Additive Manufacturing					
Augmented Reality					
Collaborative Robotics					
Artificial Intelligence					
Big data and Analytics					
Automated Guided Vehicles					
Blockchain					

	Implementation

	No action is taken	Preliminary study	Technical-economic feasibility analysis	Investment planning	Implementation in progress	Technology in use	Technology was used and then abandoned
Internet of Things							
Additive Manufacturing							
Augmented Reality							
Collaborative Robotics							
Artificial Intelligence							
Big data and Analytics							
Automated Guided Vehicles							
Blockchain							

23. Please indicate any other enabling technologies that have been involved when adopting the following listed technologies:

	Internet of Things	Additive Manufacturing	Augmented Reality	Collaborative Robotics	Artificial Intelligence	Big data and Analytics	Automated Guided Vehicles	Blockchain
Internet of Things								
Additive Manufacturing								
Augmented Reality								
Collaborative Robotics								
Artificial Intelligence								
Big data and Analytics								
Automated Guided Vehicles								
Blockchain								
Other (please specify):								

Thank you very much for your participation in our survey!