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"IMPLICATIONS OF INDUSTRY 4.0 ON FINANCIAL PERFORMANCE: AN EMPIRICAL STUDY"

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INTRODUCTION

"The industrial environment is at the doorstep of a change so deep to be called Fourth Industrial Revolution. Products, services, and operations processes will be overwhelmed by this change. […] We are facing an industrial and cultural revolution that involves the way of thinking about industrial equipment, offices, and shopfloors." (Magone and Mazali, 2016)[1]

"Industry 4.0" is the name used to refer to the fourth industrial revolution. Industry 4.0 has been one of the most talked about topics in the last few years since its introduction in 2011. "Industrie 4.0", "Industrial Internet", "Industrie du Futur", "High Value Manufacturing", "Fabbrica Intelligente", "Industria 4.0", "Impresa 40", and "Internet plus" are all National Plans to help firms in pursuing the digitalization of their processes. In 2011, the German Government proposed for the first time the term "Industrie 4.0" to describe the new industrialization phase that it wanted to launch for its manufacturing companies. This plan is aimed at strengthening German Manufacturing Companies competitiveness worldwide. The innovative aspect of the plan is the set of concepts that have a central role in it. Cyber-Physical Systems, the Industrial Internet of Things, Smart Factories, and digital manufacturing technologies are the essence of the whole plan (Kagermann et al., 2013). There were already first examples of firms that could be considered "Smart", that aggregated their physical and digital processes to create the so called "Cyber-Physical Systems"; moreover, some enterprises had already started to adopt those superior technologies. But this plan was probably the Big Bang from which "Industry 4.0" became one of the most talked topics for institutions and businesses.

This industrial revolution is the first one to be decided *a priori* and as an upgrade of the previous one. This time, "Steam and water power" (Marr, 2016b) are replaced by a bundle of new or adapted technologies that firms can nowadays exploit to improve their performances and create more value for their customers. Mass customization, waste reduction, improved sustainability, and supply chain connection are only some of the most important benefits that smart factories can achieve (Gilchrist, 2016; Kagermann et al., 2013).

This bundle comprises several tools and concepts: industrial robots, automated guided vehicles, additive manufacturing, laser cutting, 3D scanners, big data analytics, cloud computing, the Internet of Things, sensors, cybersecurity, and machine learning. Each one of these concepts cannot be defined "new". For examples, industrial robots have been around for decades, Ashton

[1] Presentation and Note for the Reader

(2009) started talking about IoT in 1999, additive manufacturing was invented by Hull (2015) in the 1980s. But only recently these technologies have improved in many aspects:

- Their performances have been enhanced. For example, 3D printers have always been mainly known as "Rapid prototyping tools" (Gibson et al., 2015) but important global players have started to exploit them in their production function. Additionally, sensors have been enhanced in terms of both energy output and size, allowing them to be installed almost everywhere (Gilchrist, 2016; Manyika et al., .2015)
- They are more accessible than ever. For example, robots size is being drastically reduced, as well as their cost. A small collaborative robot can be purchased by even micro and small companies (as it will be demonstrated in our sample analysis). 3D Printers, 3D scanners, and laser cutters are the drivers of the "Makers" movement, which leverages on both entrepreneurial and contriver skills. Cloud service providers allow users to pay only for the computational capacity that they actually exploit, and so on.
- Each technology can be connected with other devices. The "Industrial Internet of Things" provides the possibility of connecting possibly each device one another in industrial settings. Miniaturization and energy-efficiency improvements gave access to the possibility of installing sensors everywhere, thus transforming any kind of good into a "smart device" (Gilchrist, 2016). US "Industry 4.0" champions leveraged on IIoT since the beginning, indeed (Magone and Mazali, 2016).

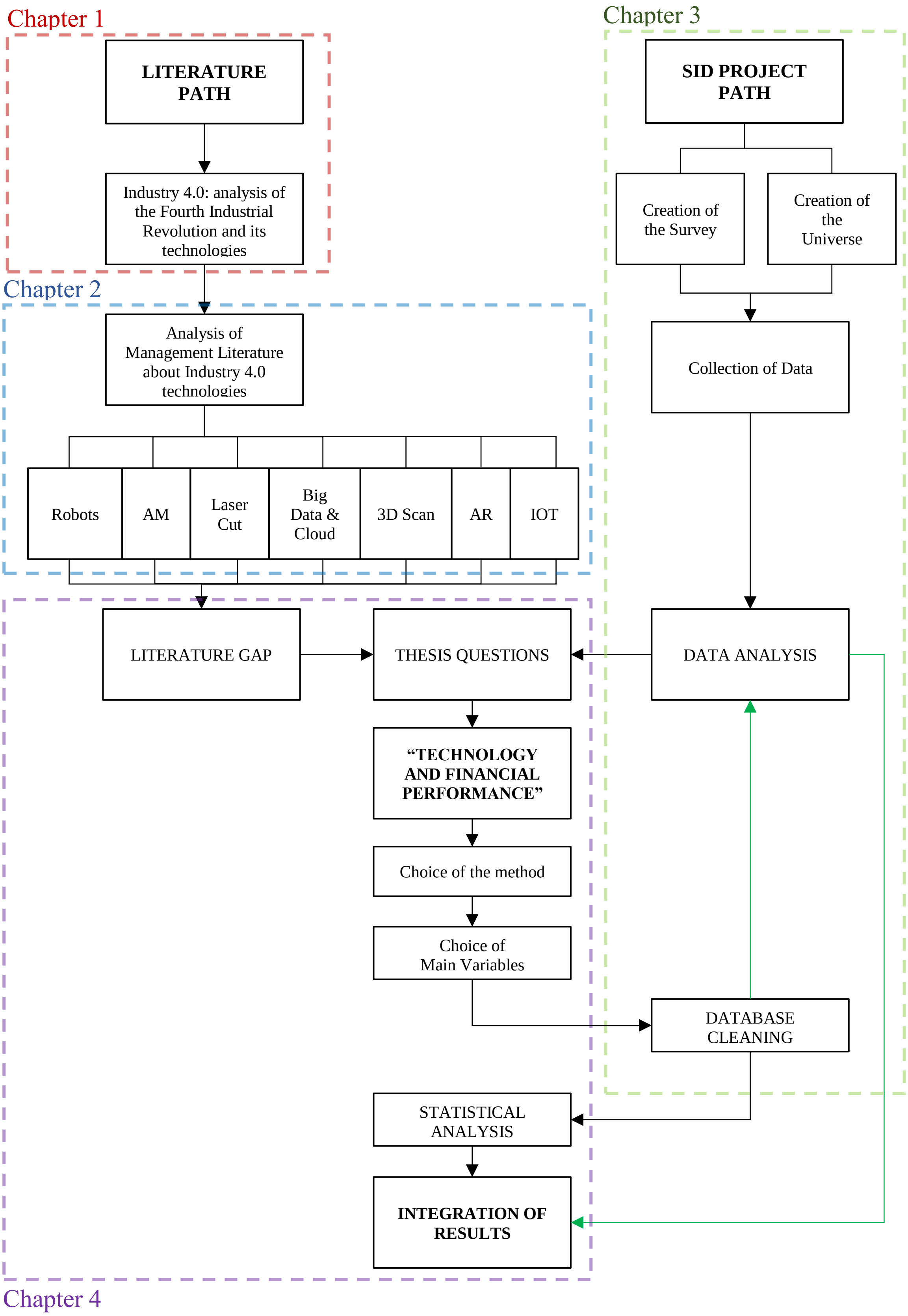
For 2017, the Italian Government has launched Italy's National Industry 4.0 plan, aimed at offering support and incentives to enterprises that aim at improving their competitiveness through the acquisition of these Industry 4.0 tools and concepts. The main aid consists in the possibility to apply super- and hyper-depreciation for investments aimed at transforming digitally and technologically enterprises[2]. Other incentives are related the most to Research & Development and training activities. First results are reassuring: both investments and R&D expenses have been increasing in the first months of 2017. "Enterprise 4.0" is the Italian National plan which will be adopted in 2018[3]. Starting from these early results, it will focus mainly on training, in both schools and companies. Technical knowledge will be essential for the digitalization of companies.

[2] http://www.sviluppoeconomico.gov.it/index.php/en/202-news-english/2036690-national-industry-4-0-plan accessed on 1 August 2017

[3] http://www.sviluppoeconomico.gov.it/index.php/it/198-notizie-stampa/2037096-piano-nazionale-impresa-4-0-i-risultati-del-2017-e-le-linee-guida-per-il-2018 accessed on 25 September 2017

The figure below summarizes the approach that has been followed in thesis, partly already explained in detail in the previous sections and conclusions.

Figure 0.1: Methodology (Author's elaboration)



This thesis was developed like this flow chart. It all started with the analysis of the literature about Industry 4.0 and technologies that characterize the studied phenomenon. In this phase, we used mainly books and articles that concerned descriptive aspects of these elements, as the focus was to improve our knowledge and understanding of all the concepts that regard Industry 4.0. Articles were mainly retrieved thanks to AIRE (Integrated Access to Electronic Resources), which is a tool provided by the University of Padova to access literature databases like EBSCO, JSTOR, Elsevier, etc. For specific journals and articles, we used also CaPerE, which allowed us to access journals databases. For Chapter 1, literature concerning presentations, definitions, details, pros and cons of the fourth industrial revolution and its representative technologies and concepts was retrieved. These themes were: industrial robots and Automated Guided Vehicles (AGV), Additive Manufacturing (AM), laser cutting, 3D scanning, Big Data analytics, the Internet of Things (IoT), cloud computing, cybersecurity, and machine learning. For each concept, we tried to include a definition, brief history, benefits, and challenges in order to deepen the understanding of their role in Industry 4.0.

Then, for Chapter 2, specific management articles were studied. This phase, performed through SCOPUS with selected keywords and analysis of article title, abstract, and tags, was aimed at understanding how Industry 4.0 and its concepts were studied by Management Literature. Moreover, Social Sciences articles were included in the research too, not to miss eventual important articles. Nevertheless, this phase revealed that Industry 4.0 literature is mainly composed of technical articles about individual technologies, or articles that consider Industry 4.0 or cyber-physical systems as a whole. It was in this phase that we noticed that a statistically significant relationship between Industry 4.0 technologies and financial performances had yet to be proven, moreover in a database composed by Italian Manufacturing firms. This analysis was integrated with the one already performed for the first chapter: even if it was not aimed at individuating only management articles, it was performed using several literature research databases like AIRE (Integrated Access to Electronic Resources), Business Source Complete (EBSCO), and CaPerE to look for articles in specific journals.

Simultaneously, we took part in a Departmental Project of the Economics and Management Department of University of Padua that is aimed at collecting data about digital manufacturing technologies and circular economy. In May 2017, the first phase of this Project took place: manufacturing firms located in Northern Italy were selected, together with a first set of sectors to be investigated, and we started to create our sample. This information was analysed as it was collected to increase knowledge about the Italian situation and shape a more specific idea about what could be analysed and which should have been the questions to be investigated. But the real analysis of the database occurred when thesis questions were defined, the most important variables were identified, and it was clear which was the correct way to clean the collected information. This is the explanation of the inclusion of database cleaning in "Chapter 3" in the map above: the initial decisions to answer the set of questions were the starting point to decide which values were "missing" and so have to be dropped. Then, the actual descriptive analysis was performed and presented in Chapter 3.

The last chapter concerns the empirical studies performed to answer our research questions. As for the decision about the method, it was chosen to adopt the t-test to compare two means of financial performances (between adopters and non-adopters) and multiple linear regressions to verify the significance of technology-adoption when other control variables are included together in the model. For statistical purposes, a significance level equal to 10% was always used in the multiple linear regression models. For the most important models, we show how statistical assumptions are respected, to increase the robustness of our models. Tables for descriptive and inferential statistics are structured as they are in the Output Sheet of SPSS by IBM, the software used for the analyses in Chapter 4.

Considering the results obtained, this thesis permits to improve the knowledge about the relationship between Industry 4.0 technologies and financial performance. Since results can be interpreted under different perspectives, this thesis can be the starting point to deepen the study concerning the role of Industry 4.0 technologies inside companies.

1 INDUSTRY 4.0

"When wireless is perfectly applied the whole earth will be converted into a huge brain, which in fact it is, all things being particles of a real and rhythmic whole. We shall be able to communicate with one another instantly, irrespective of distance […] and the instruments through which we shall be able to do this will be amazingly simple compared with our present telephone. A man will be able to carry one in his vest pocket."

With these words, more than ninety years ago Nikola Tesla (Kennedy, 1926) predicted not only mobile phones and smartphones but also a whole world in which everything is connected. This prediction reflected into the "Internet of Things" at first, when Ashton in 1999 named for the first time the phenomenon (Ashton, 2009). Nowadays, each kind of good can be connected to a network through sensors and wireless connection. Currently, these concepts are increasingly being exploited in factories, embedding the term with the "Industrial" prefix; moreover, even whole physical processes are integrated with virtual ones, giving birth to cyber-physical systems (Gilchrist, 2016). The "Industrial Internet of Things" (IIoT) and cyber-physical systems are probably the two driving concepts of "Industry 4.0", which seems to be the answer for the evolution of the manufacturing system worldwide (Magone and Mazali, 2016).

Industry 4.0 is considered by many authors as the fourth industrial revolution or, at least the fourth major trend in the industrial world, right after the introduction of lean manufacturing, outsourcing, and automation (Wagner, 2016). Since its introduction, Industry 4.0 has been keeping busy companies, organizations, and universities (Drath and Horch, 2014); academic publications, practical articles, and conferences have proliferated since the introduction of the term in 2011 (Hermann et al., 2016). Currently, the term is used to describe "smart factories" which exploit some or all the following technologies and concepts: horizontal and vertical system integration, industrial internet of things, autonomous robots, augmented reality, cloud computing, advanced analytics, big data (Rüßmann et al., 2015), laser cutters, and 3D scanners. In this chapter, the origin of the name and the fourth industrial revolution will be described and contextualized. Following, the main three terms associated with Industry 4.0 will be described: IIoT, Cyber-physical systems, and smart factories are often used as synonyms but they show some peculiarities. After this, enabling technologies and benefits that should be granted through the methods and tools promoted by Industry 4.0 will be presented. In the last part, the main technologies and analytics of the so called "Cyber-physical systems" of Industry 4.0 will be described in detail, with particular focus on the ones that will be used for the analyses of next chapters.

1.1 Industry 4.0 in the World

"Industry 4.0" is a collective term that is used to refer to a whole set of new technologies, production factors and new job organizations that are significantly changing manufacturing methods and the relationships between economic actors (including consumers). These changes are having relevant effects over the labour market and society organization (Magone and Mazali, 2016). The term "Industrie 4.0" was created by Germany in 2011: the German Government planned Industrie 4.0 as "one of the key initiative of its high-tech strategy" (Hermann et al., 2016, p.1). The German manufacturing sector is one of the most competitive ones worldwide thanks to German companies' ability to manage complex industrial processes where activities are performed by several partners in different locations. For decades, German companies have been exploiting Information and Communication technologies (Kagermann et al., 2013). The report "Securing the future of German manufacturing industry. Recommendations for implementing the strategic initiative INDUSTRIE 4.0" highlights how Industrie 4.0 aims at integrating traditional German manufacturing technologies, Information and Communication Technologies (ICT) and digital economy. Industrie 4.0 has been conceived as a double strategy: on one hand, it is aimed at strengthening the German manufacturing industry; on the other hand, it identifies the opportunity for creating and serving new markets with German superior technologies and products abroad (Kagermann et al., 2013). Moreover, the strategy aims at creating a network of small, medium, and large companies to achieve an integrated production system that involves each production stage, each product life-cycle stage and each production system life-cycle stage (Pontarollo, 2016).

Nevertheless, the idea behind Industrie 4.0 has roots in also other industrial countries, like the European Union, but also in India, China, etc. (Gilchrist, 2016). The phenomenon is called "Industrie du Futur" in France, "High Value Manufacturing" in the United Kingdom, "Fabbrica Intelligente" in Italy. China is launching a similar initiative called "Internet Plus" to integrate production with e-commerce, and "Made in China 2025", to spread the adoption of digital manufacturing technologies. The American model is completely different from the European one. The American model is leveraging on consortia and private coalitions which engage companies that work in ICT and telecommunication sectors (like Intel, Cisco Systems, IBM, General Electric, and AT&T), and in the manufacturing industry (as General Motors, General Electric, and Rockwell Automation); these coalitions are supported by also universities (Magone and Mazali, 2016). There, the Internet of Things (IoT) is the most important technology and both individuals and organizations are working to facilitate the diffusion of applications, platforms, and standards. The stress is on technologies like sensors, machine-to-machine relationships, big data, cloud computing and on the creation of platforms that permit interoperability between different suppliers. For example, “Smart Manufacturing Leadership Coalition” is an organization that is trying to build a cloud platform able to manage advanced processes like 3D modelling, virtual simulations, and analysis of data gathered through sensors (IoT). These activities are performed without aid from the Government: in fact, innovations are benefitting mainly from investments made by venture capitals like GE Ventures, Siemens Venture Capital, Cisco Investments, Qualcomm Ventures and Intel Capital. In Europe, instead, the situation is quite different. Individual countries’ activities and Horizon 2020 are at the basis of the European model. Horizon 2020 established a budget equal to 1.15 billion euros for research works based on the roadmap drawn up by European Factories of the Future Research Association (EFFRA). EFFRA is an organization which is composed of private and public actors. The most important companies in EFFRA are Siemens, Airbus, Daimler, Philips, and Bosch; moreover, Italian companies like Fiat-Chrysler, PrimaIndustrie, Comau, and Fidia joined the Future Research Association too. The association involves also public research centres, universities, and entrepreneurs’ trade associations. Horizon 2020 intends to increase European manufacturing competitivity through investments aimed at creating smart factories and strengthening supply chains. The German model is having a strong influence over the European plan because it was the first one to promote Industry 4.0 concepts. Germany deployed a budget of 400 million euros and involved government (Department of Education, Research, Economics, and Technology), public research centres and universities (Fraunhofer, National Academy of Science and Engineering, etc.), and private sectors. As for the latter, Bosch and SAP’s involvement has been significant: for example, Bosch[4] (2017) is continuously promoting talent programs to train aspiring managers in Industry 4.0 concepts (Magone and Mazali, 2016).

1.2 The Fourth Industrial Revolution

Industry 4.0 is the fourth industrial revolution. As reported by Chris Anderson (2012), the term “industrial revolution” was used for the first time in 1799 by Louis-Guillaume Otto, a French Diplomat: he used the term to describe the situation that was occurring in France in those years. The term was used also by Friedrich Engels, the famous German economist and philosopher. Nevertheless, “Industrial revolution” became a common term only in the late XIX century when Arnold Toynbee (a British economic historian) held several conferences and lectures to explain the impact of such phenomenon on the world economy. Anderson defines an industrial revolution as “a set of technologies that dramatically amplify the productivity of people,

[4] http://www.bosch.it/stampa/comunicato.asp?idCom=2602 accessed on 18 August 2017

changing everything from longevity to quality of life to where people live and how many of there are of them" (p.38). The term "revolution" means "a rapid and fundamental change": in fact, each industrial revolution is an acceleration in terms of improvements (Bloem et al., 2014, p.11).

The previous three industrial revolutions occurred over two centuries. The main technological introduction of the first industrial revolution was the mechanical loom, driven by a steam engine (Drath and Horch, 2014). It was the result of two previous innovations: first, in June 1770, Hargreaves registered the patent for a version of spinning jenny that could "spin, draw and twist sixteen threads simultaneously" (Anderson, 2012, p.35). Second, James Watt invented the steam machine in 1776. These introductions permitted to reshape the landscape and significantly improve living standards for inhabitants. For example, as clothes and soaps began to be mass-produced thanks to these introductions, almost every family could have clean clothes, thus increasing the overall hygiene level (Anderson, 2012). In fact, fabrics began to be produced only in central factories and not in private homes anymore thus increasing productivity.

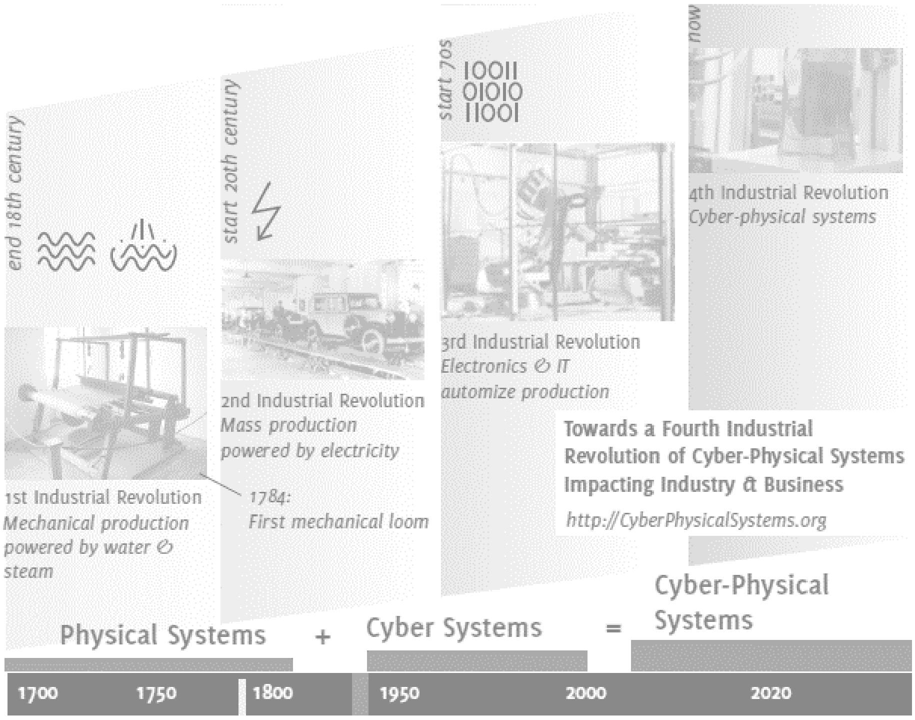
After 100 years, it was time for the second industrial revolution, which began in the slaughterhouses in Cincinnati, Ohio, when the first conveyor belt was introduced (Drath and Horch, 2014). The second industrial revolution saw the passage from "manufactory" to "factory" as new technological improvements were introduced. Improvements of steam-powered ships and railroads, the invention of the "Bessemer process for making steel in large quantities" are the other main characters of this passage (Anderson, 2012, p.38). This revolution reached its climax with the production of the famous Ford Model T (Drath and Horch, 2014). The theme that characterizes this revolution is the "introduction of electrically-powered mass production based on the division of labour" (Kagermann et al., 2013, p.13).

The third industrial revolution started after that the first programmable logic controller which enabled digital programming of automation systems was presented by Modicon in 1969 (Drath and Horch, 2014). This revolution was characterized by the adoption of electronics and IT technologies to achieve superior automation in manufacturing activities (Kagermann et al., 2013).

In 2013, Bosch's deputy chairman of the board of management Siegfried Dais predicted that, in industry, "everything will be connected to everything else"; his opinion was published by McKinsey Quarterly in the article "The Internet of Things and the Future of Manufacturing" (Löffler and Tschiesner, 2013). The same opinion is shared by Helmuth Ludwig, CEO of the

North American branch of Siemens: he predicts that "virtu-real" processes will improve companies' efficiency affecting all their functions (Bloem et al., 2014). Nowadays, thanks to miniaturization advances in computing technologies and to the limitless progress of the Internet, these predictions are becoming increasingly real. Microcomputers are being connected wirelessly and IPv6 enables the connection of almost everything. These technological improvements translate into the "Internet of Things (and services)" which, as it is being exploited in industrial settings, is the main driver of Industry 4.0 (Kagermann et al., 2013).

Figure 1.1: The Industrial Revolutions (Bloem et al., 2014)



Industry 4.0 has two characteristics that distinguish it from previous revolutions: first, it is the first industrial revolution that is predicted *a priori* and not observed only *ex-post* (Drath and Horch, 2014); on the other hand, while previous revolutions were driven by an actual leap forward, this one seems to be an updated version of the third revolution for the moment (Pontarollo, 2016). Some experts and researchers, like Frank Wagner (2016), Cornelius Baur and Dominik Wee (2015), do not consider Industry 4.0 as the fourth industrial revolution. They refer to Industry 4.0 as the "fourth major upheaval in modern manufacturing", where the previous three are: lean manufacturing in the 19070s, the outsourcing phenomenon in the 1990s and the automation boost in the 2000s. Currently, we are still at the beginning of the fourth industrial revolution, which is based on the so called "cyber-physical systems" (Bloem et al., 2014): integrations of computation, networking, and physical processes (Gilchrist, 2016). Industry 4.0 is different from the third industrial revolution, where companies' desire of improving efficiency resulted in job losses. Industry 4.0 is a transition phase towards the digital

transformation of companies, a "merging of the physical and digital world" (Gilchrist, 2016, p.198): this process holds many possibilities and does not necessarily imply that companies need to downsize their workforce. For Gilchrist (2016), Wagner (2016), Baur and Wee (2015) Industry 4.0 is currently possible because of four technological innovations:

1. In the last years, there has been a rapid improvement in terms of cloud storage, rental computing power (cloud computing performances), huge data volumes management, and ubiquitous network connectivity. These innovations are new solutions to analyse huge amounts of data as it was not possible before.
2. Analytics capabilities are being continuously improved. Analytics software permits to improve internal efficiency and effectiveness, to improve product design and development and the probability of having a successful launch. Machine learning techniques are useful for these purposes (Wuest et al., 2016).
3. The introduction of new forms of human-machine interactions was another step forward towards Industry 4.0. New robots can work as partners for employees (Magone and Mazali, 2016); additionally, improvements in displays, trackers, graphic computers and software enhanced AR technologies, which has already proved to be useful in industrial environments (Ong et al., 2008).
4. Currently, transforming digital data into physical objects is easier than ever. 3D Printers, 3D laser cutters permit to transform digital models into real products easily. 3D scanners enable the opposite process: starting from physical goods they can build a digital model of it. Both transformations "from bits to atoms" and "from atoms to bits" are simplified and accessible at lower prices than in the past (Anderson, 2012).

For Henning Kagermann, Wolfgang Wahlster, and Johannes Helbig, authors of the "final report of the Industrie 4.0 Working Group" for the German Federal Ministry of Education and Research, the three main concepts that characterize Industry 4.0 are the Internet of Things (IoT), Cyber-Physical Systems (CPS), and Smart Factories; these themes will be explained in the following sections.

1.3 The Advent of the Industrial Internet of Things

The Industrial Internet of Things (IIoT) is a concept that is relevant for the development of Industry 4.0, even if often it is confused with the fourth industrial revolution itself. The main difference is that the term "Industry 4.0" first refers mainly to the German Government plan to develop the digitalization of companies leveraging, also, on the IIoT. The term is now commonly used to refer to the fourth industrial revolution and its bundle of technologies

(Magone and Mazali, 2016). The Industrial Internet of Things, instead, consists in the application of the Internet of Things in industrial settings (De Bernardini, 2015). Nevertheless, GE adopts principles and technologies that are similar to Industry 4.0 ones, referring to them as "Industrial Internet" (Ebans and Annunziata, 2012). Gartner[5] ("the world's leading research and advisory company") defines the Internet of Things as "the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment". If such network is built in industrial settings, it is called "Industrial Internet of Things". The devices that compose this kind of network must have local intelligence, a shared API (Application Programming Interface, the set of procedures that developers can use to make a computer program perform a specific task) and push and pull status information from and to the networked world (Bradford, 2014).

The term "Industrial Internet" was coined by General Electrics (GE) in 2012 which described the technology in terms that are similar to the ones that are currently used to talk about Industry 4.0. GE has always obtained its revenues mostly through the sales of industrial equipment. Before 2011, the American company faced a new threat: IBM, SAP, and several startups tried to convince customers that they could increase their efficiency relying on more advanced analytics rather than on reliable industrial equipment. For this reason, in 2011 GE started a multi-billionaire plan to implement what it calls "Industrial Internet". In other words, the company "added digital sensors to its machines, connecting them to a common, cloud-based software platform, invested in modern software development capabilities, thus building superior analytics capabilities and embraced crowdsourced product development" (Iansiti and Lakhani, 2014, p.91). These actions contributed in changing GE's business model.

For General Electrics (Ebans and Annunziata, 2012), IIoT is the result of the combination of physical technologies developed during the Industrial Revolution and advances in computer performances, in information technologies, and communication technologies that resulted from the Internet Revolution. These improvements enabled three elements:

a. *Intelligent machines*. Through IIoT it is possible to connect a myriad of different machines. Machine-to-machine communication can now occur not only between machines inside factories but between any kind of device (Bloem et al., 2014);
b. *Advanced analytics*. Nowadays it is possible to exploit physics-based analytics, predictive algorithms, automation and "deep domain expertise in material science"

[5] https://www.gartner.com/it-glossary/internet-of-things/ accessed on 18 August 2017

(p.3), electrical engineering and other disciplines to have a better understanding of the function of systems and machines.

c. *People at work*. The Industrial Internet of Things permits people to be connected wherever they are and whenever they want, thus enhancing design activities, operations, maintenance, service quality, and safety.

These elements are like the ones described before, which enable the fourth industrial revolution. On first sight, it is possible to notice that the main differences are due to the fact that in this description of IIoT elements the emphasis on some concepts is missing. The possibility to turn virtual objects into physical ones with accessible technologies and with features that were inconceivable in the past is not included in the described definition; as well as the possibility to digitalize every real object. In fact, terms like “3D printing”, “additive manufacturing”, “laser cutting”, and “3D scanning” are not mentioned in the report “Industrial Internet: Pushing the boundaries of Minds and Machines” realized by Ebans and Annunziata (2012) and published by General Electrics to present the Industrial Internet of Things. Moreover, not even “Augmented Reality” is mentioned in that report, as well as the possibility to deploy collaborative intelligent robots throughout factories. So, “Industry 4.0” is a more comprehensive term than the Industrial Internet of Things. Nevertheless, without IIoT, it would not be possible to talk about Industry 4.0 and, probably, the fourth industrial revolution would not have been achieved. For Drath and Horch (2014) GE’s “Industrial Internet” regards further applications than the original plan “Industrie 4.0” but, currently, “Industry 4.0” seems to be an even broader concept.

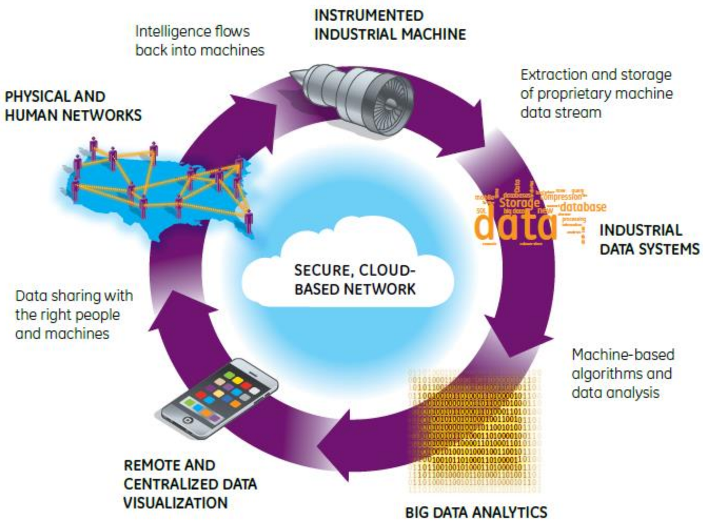
As Industry 4.0 is considered the fourth industrial revolution, IIoT is the “third wave of innovation” for GE (Ebans and Annunziata, 2012, p.9). The two previous waves were the Industrial revolution (already described before) and the Internet Revolution. The latter started in the 1950s with the introduction of big frame computers and first software. Thanks to improvements in networks, bandwidth speed and stability, costs, and computing performances the third wave began.

For General Electric, the “Industrial Internet Data Loop” consists of the following technologies:

- *Instrumented industrial machine*. Each machine inside the factory produces a large amount of data.
- *Industrial data systems*. They receive the data that is produced by machines (and by each device inside the factory).

- *Big Data analytics*. Datasets are analysed with machine-based algorithms and data analysis.
- *Remote and centralized data visualization*. Operators can access information through computers, smartphones, tablets and other devices with access permissions.
- *Physical and human network*. Information must be shared with the right persons and the right machines, forming a network that is composed by both categories. So, processed information generated by instrumented industrial machines is sent back to improve their efficiency.
- *Secure, cloud-based network*. Organizations must decide which data must be processed and stored locally and which one remotely. This is important also for cybersecurity and privacy reasons.

Figure 1.2: The Industrial Internet Data Loop (Ebans and Annunziata, 2012)



Technologies related to IIoT are not completely new. Nevertheless, the Industrial Internet of Things is becoming famous only in the last few years. There are several reasons (Gilchrist, 2016):

1. Nowadays, human operators cannot keep the pace of companies' complexity so it is becoming more and more necessary to adopt superior technologies that permit to identify new opportunities in terms of efficiency improvements from the data.
2. Thanks to cost reductions for computers, bandwidth, storage, and sensors it is now possible for IT systems to support a wider range of instrumentation, monitoring tools, and analytics tools.
3. Cloud computing is an accessible and reliable solution to manage huge amounts of data. User can pay only those computational resources that are actually exploited.
4. Solutions to manage broad networks are more stable and accessible than in the past.

In addition, improvements in sensor technology and miniaturization have been drivers in the achievement of the current level of performances of IIoT applications. Sensors are "hardware devices that produce a measurable response to a change in a physical condition, like temperature, pressure, voltage, current, etc. The analog signals produced by the sensors based on the observed phenomenon are converted to digital signals by the analog-to-digital converters and sent to processor for further processing" (Gungor and Hancke, 2009, p.4260). Sensors can nowadays be installed in any machine thanks to two major improvements:

- *Miniaturization*. Without miniaturization improvements, it would not have been possible to install sensors everywhere. Currently, sensors can have the size of a grain of sand. This process was accelerated thanks to the integration of intelligence and functions into the sensor itself, thus reducing the number of additional components required (Gilchrist, 2016).
- *Energy efficiency* (Porter and Heppelmann, 2014). Sensors are more efficient in term of energy consumption; additionally, thanks to miniaturization improvements, sensors that require no power to work (like reel switches) can be installed more easily (Gilchrist, 2016).

Current sensors are called "intelligent sensors" because they can perform more advanced tasks than in the past. They can directly transform an analog input into a digital one, they can perform analytics whenever they capture information, they can send data to another node in the network, and so on. Sometimes it could be useful to let sensors analyse data individually, other times it could be better to directly analyse information centrally.

The Industrial Internet of Things increases visibility inside a company through sensors, middleware software (software which acts as an intermediary between several applications), cloud computing, and storage systems. These introductions permit to improve both efficiency and effectiveness of companies. Gilchrist (2016) highlights how "the power of 1%" is one of the most interesting aspects of IIoT: following this rule of thumb, companies need to achieve a mere saving of 1% through the Industrial Internet of Things to improve the efficiency of operations. For instance, in the aviation industry, a saving equal to 1% of the yearly consumption of fuel equals 30 billion dollars.

1.4 Cyber-Physical Systems

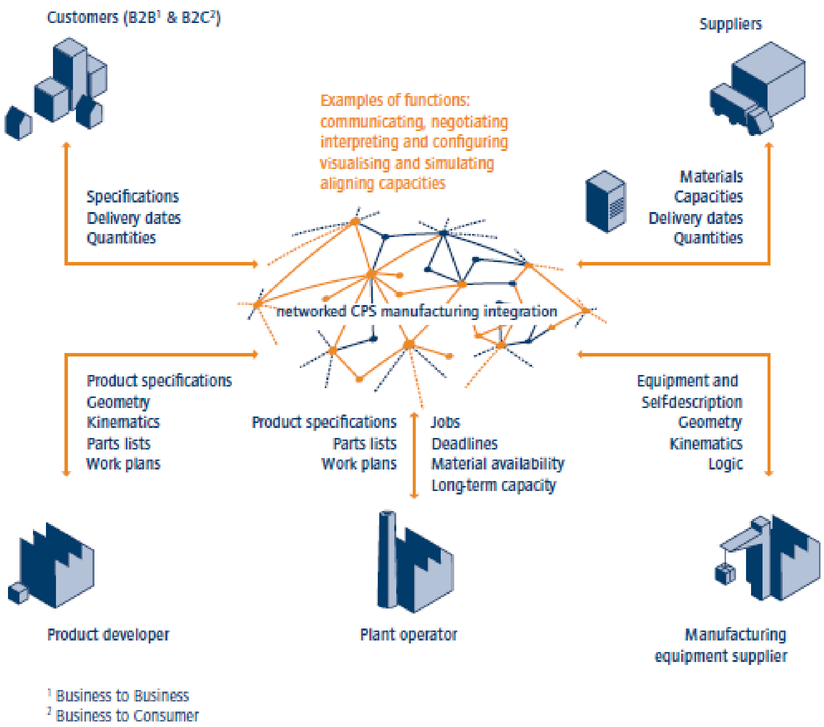
New possible relationships between humans and machines are at the basis of Industry 4.0. These interactions occur between socio-economic actors (like entrepreneurs, employees and consumers) and the whole digital world (computers, sensors, virtual world, machinery, etc.).

The marriage between these two universes is complex and solutions to ease the process are still being studied. Without any doubt, such integration would permit to obtain huge positive synergies and benefits as the potential of digital technologies is still under-exploited (Magone and Mazali, 2016).

The fourth industrial revolution is driven mainly by IoT improvements and their application in industrial settings. As seen before, the creation of global networks inside companies that incorporate their machinery, their facilities, and warehousing systems enables the creation of the so called "Cyber-Physical Systems". Cyber-Physical Systems are "integrations of computation, networking, and physical processes; embedded computers and networks monitor and control the physical processes, with feedback loops where physical processes affect computations and vice-versa" (Gilchrist, 2016, p.36). So, what distinguishes a Cyber-Physical System is the integration of ICT capabilities and technologies, physical processes, and the creation of a network. For Magone and Mazali (2016), Industry 4.0 aims at leveraging on the cyber-physical system concept to enhance operations (both production and logistics). The main advantages are two: first, it would permit to improve efficiency as costs would be reduced; therefore, firms could offer products at more competitive prices thus increasing customer demand. On the other hand, CPSs permit to widen the range of products and services, thus increasing product flexibility. The phenomenon is still at its beginning and it is impossible to identify already all the opportunities that these systems offer (Magone and Mazali, 2016). For example, in the preventive maintenance area: stress, productive time and other process parameters of a machine performing a physical process can be recorded digitally so that the actual condition of the equipment results from the object itself and its digital parameters (Lasi et al., 2014).

Cyber-physical systems leverage on sensors to collect information from physical objects, and on actuators to affect actual processes. Data is analysed and is used to affect both digital and physical processes; information is accessible independently of users' location. Connected devices form a network; connection can be either wired or wireless. Additionally, these systems can also exploit information sourced from the external environment and that is globally available. Finally, these systems are endowed with a wide range of multimodal human-machine interfaces and allow users to choose from a wide range of options to control and communicate with the nodes of the network, like voice and gestures (Geisberger and Broy, 2015). It is clear that Cyber-Physical Systems exist mainly thanks to the Industrial Internet of Things and how the concept of IIoT is connected to Industry 4.0 which, in turn, promotes the transformation of current systems into cyber-physical ones. Through this process, physical systems become themselves "Internet of Things", continuously connected with each other and with human operators (Marr, 2016a). Figure 1.3 summarizes some examples on how a CPS can integrate and manage all the actors of the supply chain.

Figure 1.3: Networked CPS Manufacturing Integration (Geisberger and Broy, 2015)



1.5 Smart Factories

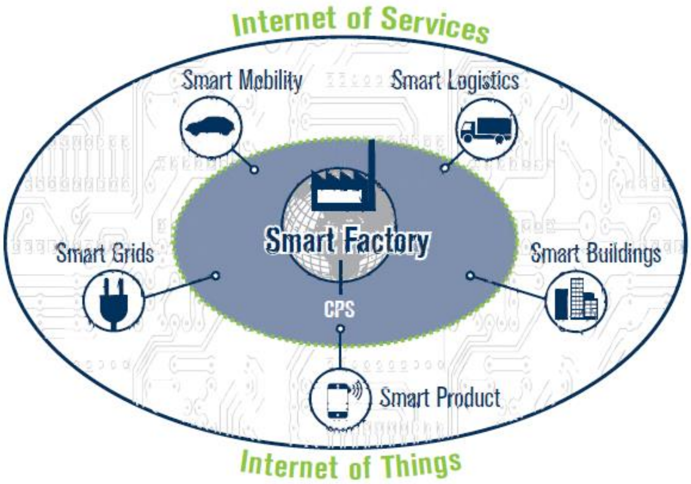
Industrie 4.0 and other plans for the adoption of digital manufacturing technologies are aimed at the proliferation of smart factories (Jazdi, 2014), factories that are characterized by:

a. *Smart Networking*. Smart factories leverage on cyber-physical systems which permit automated systems and equipment, software, and supplies to be continuously interconnected.
b. *Mobility*. Thanks to digital ubiquity, cloud computing, and smart devices information is always available to workers. Sensors constantly monitor machines and it is possible to perform preventive maintenance, thus increasing equipment efficiency.
c. *Flexibility*. Smart factories are flexible in all their parts and functions.
d. *Integration of customers*. Customers are integrated to increase value and thus their satisfaction.
e. *New innovative business models*. Thanks to Industry 4.0 technologies, it is possible to design unconventional business models. This phenomenon does not regard only the large-scale industry. For example, the "makers" movement comprehends small and medium companies that, thanks to digital manufacturing technologies (like 3D Printers,

3D Scanners and Laser cutters) and the possibilities offered by the Internet, designed business models that proved to be successful (Anderson, 2012).

As the Internet of Things will create a “smart, networked world” connecting more and more the society, the phenomenon “Industry 4.0” (and the smart factory one) will not have to be approached in isolation but considering all the key areas that affect the factory, also external ones (see Figure 1.4).

Figure 1.4: Industrie 4.0 and Smart Factory as part of the Internet of Things and Services (Kagermann et al., 2013)



1.6 Characteristics and Benefits of Industry 4.0

The original plan of Industrie 4.0 explains which are the main benefits that can be achieved adopting technologies and principles that characterize the revolution (Kagermann et al., 2013). First, through digitalization, a company can meet individual customer requirements. These requirements can be included in the design, configuration, ordering, planning, manufacture, and operation phases. The Internet of Things allows customers to increase their involvement in industrial activities (Porter and Heppelmann, 2014) and 3D printers enable the manufacturing of products with complex designs at relatively low prices. 3D printers do not require setup costs, and even a batch of one product is possible (Huang et al., 2013). The prototyping activity is simpler and cheaper, and the technology is starting to be adopted also to satisfy numerous customer requests (Ford and Despeisse, 2016).

A company moving towards Industry 4.0 should improve flexibility. The continuous feedback loop in cyber-physical systems gives access to the possibility of easily changing the setting of all business processes in terms of quality, time, risk, robustness, price, and eco-friendliness. Thanks to the connection with other parties in the supply chain, delivery and volume flexibility can be easily achieved (Gilchrist, 2016). 3D Scanners fasten reverse-engineering (Iuliano and

Vezzetti, 2013), while the proliferation of 3D printing and laser cutting permits to process any digital design (Anderson, 2012). With predictive analytics, it is possible to prepare for future inconveniences, thus obtaining a superior level of flexibility (Wuest et al., 2016). Cloud services allow users to pay for and use only the computation force that is actually needed. Information about internal changes can be easily seen by workers through their augmented reality displays, and so on (Gilchrist, 2016).

The adoption of the Industrial Internet of Things, and thus of cyber-physical systems, allows companies to optimize decision-making. On one hand, this is possible because in smart factories decision-making power is often distributed thanks to digital ubiquity (cloud computing, smart devices, etc.). Managers and workers have the possibility to access whenever they want information. On the other hand, cloud computing and big data analytics perform real-time analysis of data, presenting it in a way that is useful for and easily understandable by users (Gilchrist, 2016).

Industry 4.0 complies with the traditional objective of industrial manufacturing processes: delivering the highest value using the lowest amount of resources. For instance, additive manufacturing does not produce any waste (Huang et al., 2013); through CPSs the energy requirement throughout the company can be continuously monitored and controlled (Bloem et al., 2014). Additionally, Automated Guided Vehicles allow workers to focus on value-adding activities, etc. (Hermann et al., 2016). These are only examples of how companies can manage their resource consumption in smarter ways.

Through Industry 4.0 tools and techniques, companies may identify and seize new opportunities to satisfy customer needs. For example, through big data analytics, analysts may find new ways to enhance services (Kagermann et al., 2013). Thanks to the Industrial Internet of Things the "outcome economy" is now possible: companies can sell the use of the product rather than the product itself, in other words they can "sell light instead of the bulb" (Gilchrist, 2016, p.10). Customers' smart products can be continuously monitored and whenever a problem occurs a solution can be provided in real time (Porter and Heppelmann, 2014). In particular, the Internet of Things provides great opportunities to widen the product portfolio (Gerpott and May, 2016).

Additionally, collaborative robots and other intelligent devices allow companies to cope with ageing population, a phenomenon that concerns, for example, Italy and Japan[6]. People can be productive for much longer as they are helped by technologies and more dangerous tasks are performed by industrial robots.

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[6] https://data.worldbank.org/indicator/SP.POP.65UP.TO.ZS?name_desc=false accessed on 18 August 2017

Other advantages regard the possibility to increase competitivity of a business, its revenues, and even employment. Even if many people are scared by the coming of Industry 4.0 (Staglianò, 2016), the demand for workers with skills in the fields of engineering, data scientists, and mechanical technical work is expected to raise (Gilchrist, 2016). It is true that the adoption of digital technologies will reduce the demand for traditional assembly and production jobs, but some authors (like Sirkin, 2016) believe that the demand for new skills will more than surpass this loss. Nevertheless, for Sirkin (2016), traditional factories will continue to exist, and the fact that new technologies extend the career of old workers must not be overlooked.

Gilchrist (2016) identifies four main characteristics that characterize companies that fully embrace the concepts of Industry 4.0. These characteristics are more appropriately opportunities that can be seized by companies that start a digitalization process and can be considered as additional to Kagermann et al.'s ones (2013). These characteristics are:

1. *Vertical integration of smart production systems*. Even if smart factories are at the core of Industry 4.0, they cannot work alone. The Industrial Internet of Things (and so cyber-physical systems) enables the creation of networks that connect downstream distributors and upstream suppliers. These networks replicate the advantages of the smart factory at the supply chain level, thus further enhancing the possible benefits.
2. *Horizontal integration through the global value chain networks*. This means that a company can make its partners connect with customers to improve services.
3. *Through-engineering across the entire value chain*. Including the whole value chain in the network permits to monitor and control the product and its parts during all their lifecycle (this activity is called "through-engineering"). This is particularly important for industrial components. A company like General Electrics, which produces engines for airplanes, has legit concerns about the quality of materials and parts it uses to realize its products.
4. *Acceleration of manufacturing*. Companies can exploit many technologies to accelerate operations. Not every technology concerned with Industry 4.0 is innovative or expensive, many have been around for years. They are presented in the next sections.

Additionally, other two opportunities related to Industry 4.0 can be identified:

- *The creation of products with advanced materials*. The development of advanced lightweight materials (like composite and "fibre-reinforced polymers") will permit to produce products with lower weight while maintaining their performances and trustworthiness (Technopolis Group, 2016).

- *Sustainability improvements*. Companies can adopt more sustainable materials and clean and renewable sources of energy (wind, solar, etc.). Additionally, as Industry 4.0 concepts will expand outside firms, smart grids will proliferate. “Grids” are electricity systems that, as reported by Fang et al. (2012, p.944), “may support all or some of the following operations: electricity generation, transmission, distribution and control”. Smart grids leverage on Information Technologies to improve these operations and provide services more efficiently.

Industry 4.0 will encourage the creation of innovative business and corporate models which improve employee participation. Certainly, Industry 4.0 (and all the related government plans) will have mainly technological implications; nevertheless, the fourth industrial revolution will affect also firms’ organizational aspects (Kagermann et al., 2013).

1.7 Other Technologies and Industry 4.0 Themes

Roland Berger (Blanchet et al., 2014) described how the “fully connected way of making things” occurs in Industry 4.0 smart factories. It highlighted the role of data collected from suppliers, customers, and company itself and the increasing trend of adopting both new and old, updated technologies. For Boston Consulting Group (Rüßmann et al., 2015) the concepts that better represent an Industry 4.0 environment are nine: autonomous robots, simulation, horizontal and vertical integration systems, industrial internet of things, cloud, additive manufacturing, augmented reality, big data and analytics. To provide a list of enabling technologies to be considered for “Industry 4.0” several reports and papers were used, like Gilchrist’s one (2016), Albert’s (2015), Drath and Horch’s (2014), Bloem et al.’s (2014), and other ones.

Cyber-physical systems and the Industrial Internet of Things have already been discussed in the previous sections. The other technologies and concepts that describe Industry 4.0 are the following:

- *Robots and Automated Guided Vehicles (AGV)*. Industrial robots have been in factories for quite a while. Industry 4.0 leverages on these robots and to a new generation of robots, called “collaborative robots”. They can be considered team partners of human workers and are not isolated in cages anymore (Magone and Mazali, 2016).
- *Additive Manufacturing: 3D Printing*. Additive manufacturing permits to create products with complex designs “one layer at a time” starting from a digital 3D model (Anderson, 2012). Pontarollo (2016) includes 3D printing among the set of Industry 4.0 cornerstones.

- *Laser Cutters*. As 3D printers, laser cutters start from a digital file to cut a sheet (made of metal, wood, plastic or other materials) following the instructions on a x-y plane (Anderson, 2012). It also turns "bits into atoms", like 3D printing.
- *3D Scanners*. A 3D scanner performs the opposite operation of a 3D printer: starting from a physical object, it gathers information about the distance from its surface and creates a cloud of points, where each point corresponds to an x-y-z coordinate. It is mainly used for reverse engineering (Iuliano and Vezzetti, 2013).
- *Augmented Reality*. This term comprehends a set of technologies that allow workers to receive real-time information that enhances their physical environment. This technology can be used to improve efficiency and to train employees (Rüßmann et al., 2015)
- *Big Data Analytics*. Thanks to the diffusion of IoT devices, nowadays companies collect huge amounts of data. Improvements in terms of storage, connection and computation performances enabled the possibility to perform analytics on these big datasets (Klous and Wielaard, 2016).
- *The Internet of Things (IoT).* This term includes the whole set of components and technological devices (sensors, and GPS) that can be installed in physical objects and machinery. They assure the integration of the physical world with the virtual one and, thanks to them, devices are interconnected, can share information, receive commands, and learn (Magone and Mazali, 2016). In this section, for "IoT" we refer to the one that regards products for customers rather than to the Industrial Internet of Things.
- *Cloud Computing*. Through cloud services, companies can access additional CPUs, storage units, software, infrastructures and analytics tools and pay only what they need (Gilchrist, 2016).
- *Cybersecurity*. With the increased connectivity in Industry 4.0, it is necessary to deploy instruments and procedures to protect the whole network (Rüßmann et al., 2015). Well-trained workers are the first barrier against cyber-attacks (Disparte and Furlow, 2017).
- *Machine Learning*. It is an additional tool to analyse huge datasets; it consists in the development of algorithms to instruct computers to autonomously perform instructions for which they have not been programmed (Silva and Zhao, 2016).

Following, the main technologies that distinguish Industry 4.0 companies are presented in detail. A certain level of detail is necessary to understand benefits and challenges of each technology, as many of them will be studied in the survey analysed in the next chapters.

1.7.1 Industrial Robots and Automated Guided Vehicles

ISO 8373 (2012) defines robots as “actuated mechanisms programmable in two or more axes with a degree of autonomy, moving within their environment, to perform intended tasks”, where autonomy is the “ability to perform intended tasks based on current state and sensing, without human intervention”. The same ISO defines an industrial robot as “an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications”. “Reprogrammable” means that its functions can be changed without a physical alteration (an “alteration of its mechanical system”); “multipurpose” means that it can be used in different settings for different purposes and, finally, “axis” is used to specify the direction of movements, which can occur in a linear o rotary mode. Industrial robots can be categorized depending on the types of movements they perform. The categories are the following[7]:

- *Cartesian robots,* whose axes are the same as a Cartesian coordinate system. The arm of these robots has three prismatic joints.
- *SCAR*A (Selective Compliance Assembly Robot Arm), which is composed by four axes and can easily move on the x-y plane but it is pretty much rigid on the “z” dimension (as reported in the International Federation of Robotics).
- *Articulated robots*, whose arm has at least three rotary joints.
- *Parallel robot*s, which are characterized by concurrent prismatic or rotary joints.
- *Cylindrical robots*, which work in a cylindrical coordinate system as their name suggests.

The International Federation of Robotics[8] proposes a detailed summary of the history of robotics highlighting the major stepping stones of their development. In 1959, George Devol and Joseph Engelberger developed the first industrial robot: they exploited hydraulic actuators that were programmed in joint coordinates. After only two years, General Motors installed the first industrial robot in its production lines; it was used to produce door and window handles, gearshift knobs, light fixtures and parts for vehicle interiors. From 1966 to 1972, SRI International developed “Shakey”, the first mobile robot with the ability to “perceive and reason about its surroundings”. In Europe, robots were used for the first time only in 1967, six years after the General Motors’s adoption. In 1972 FIAT (in Europe) and Nissan (in Japan) installed robot welding lines. Then, several innovations followed: for example, in 1973 the first robot to have six electromechanically driven axes was developed, in 1974 the first industrial robot

[7] https://ifr.org/img/office/Industrial_Robots_2016_Chapter_1_2.pdf accessed on 1 August 2017
[8] https://ifr.org/robot-history accessed on 1 August 2017

controlled through mini-computer was introduced in the market, in 1978 Hiroshi Makino developed the SCARA robot, and so on. In recent years, innovations were aimed at reducing the size of industrial robots. In 2006, KUKA presented the first light weight robot which, thanks to its sensors, can perform tasks with high precision. In 2009, ABB (a Swiss company) launched the smallest multi-purpose robot ever which weighs just twenty-five kilos and can manage a load of three kilos. Nowadays, robots are proliferating thanks to several events that serve as drivers (Staglianò, 2016).

- The first driver is coming from China: Chinese workers are not cheap as they were years ago; in fact, their salaries have been increasing by 12% per year since 2001. For this reason, in 2014, a quarter of worldwide sold robots was purchased by the Chinese market; sales of robots were 54% higher than the previous year. In China, this robotics revolution is aimed at substituting workers with machines. The concept of "zero-workers factory" is increasingly taking place in the Middle Kingdom: for example, Fanuc, a manufacturer of industrial robots, has an 8000 square metres plant in which only four human employees work.
- In Germany, the concept of Industry 4.0 is being promoted. Industry 4.0, as Siemens defines it, "is aimed at gaining production benefits creating a networked manufacturing process, which is flexible and dynamically self-organized, to realize products characterized by a high degree of customization". The main term in this definition is "self-organized". Siemens's idea of Industry 4.0 is focused on machines which monitor other machines and test their output with obsessive attention (this permitted to drastically reduce the number of defective products). This does not mean that the robotization is aimed at reducing workforce like in China: since 1992, Siemens's plant has kept the number of workers unchanged. Engineers and workers have to optimize the way in which machines do what they have to do. There, the concept of "zero-errors factory" is superior to the "zero-workers factory" one.
- A few years ago, in Japan, the prime minister Shinzo Abe announced the coming of a "robotics revolution". It consists of a five-year plan (supported by companies and universities) which is aimed at enhancing the adoption of smart machines in all sectors and at quadruplicating the sales of robots. This plan has been deployed for two reasons: the national ageing population (since 1995 workforce has been shrinking), and the international competition of the robotics industry.
- In the United States, two main innovations took place. First, in 2012, Baxter was launched. Baxter is a collaborative robot which can be easily trained and costs one

quarter of similar robot of the previous generation. Its low cost makes Baxter accessible even for small and medium enterprises. Three years later, Sawyer was presented: it is even smaller than Baxter and can easily load, unload, sort and handle materials (Staglianò, 2016).

Relatively small robots, like Baxter, Sawyer, and ABB smallest multipurpose robot have an important role for Industry 4.0. These robots can work together with employees without barriers and, for this reason, they are called “collaborative robots”: they interact continuously with workers and they are more “personal assistants” than tools. This interaction is autonomous and safe for employees. This new way of using robots is renovating work organization and logistics, like in Amazon where robots perform all the inventory activities: “pick, pack and ship” (Magone and Mazali, 2016). In the past, robots needed wide clearance and fences: their movements could easily hurt or kill other employees. Nowadays, mainly thanks to improvements in sensor technology which permit robots to perceive their surroundings and to avoid collisions, these “fences” are literally going down. Other significant improvements regard actuators, optics, and advanced software. These robots are also called “adaptive robots”. Before these innovations, materials had to be positioned in precise positions to be handled by robots: now, with cameras and recognition algorithms, such precision is not needed anymore. From Shah’s research (Nikolaidis et al., 2015) four main advantages of this new generation of industrial robots emerge, as reported in the Harvard Business Review (2015):

- Robots are safer than before, and this improves employees’ mood. It was demonstrated through a survey that workers feel safer and more comfortable with these new robots.
- Non-value-added activities can be performed by these robots so that employees can complete tasks 25% faster than with fixed robots. Adaptive robots permit to reduce bottlenecks.
- Robots significantly reduce idle time. As Harvard Business Review highlights, in Shah’s work it was demonstrated that workers could perform their assigned tasks 6% faster and with 3% less idle human time and 17% less idle robot time.
- Workers want these robots as teammates. Collaborative robots are changing employee’s point of view regarding robots.

Shah, an associate professor and the director of MIT’s Interactive Robotics group, is leading a research into this new kind of smarter, smaller, safer and more flexible robots.

Automated Guided Vehicles (AGV) are a particular kind of robot and they have been improved with IoT technologies (Manyika et al., 2015). As the name suggests, they are autonomous vehicles capable of transporting, weightlifting, detecting, etc. (Wan et al., 2015). This is possible thanks to the evolution of performances and miniaturization of sensors (Manyika et al., 2015). AGV perfectly represent intelligent manufacturing. With the adoption of AGVs inside the factory, it is possible to enhance automation, increase efficiency, and increase safety (and to reduce costs related to the handling of hazardous materials). Transportation, one of the activities that do not add any value (Womack et al., 1990), can be performed without human intervention; human workers can then focus more on value-adding activities.

1.7.2 Additive Manufacturing: 3D Printing

Additive Manufacturing (AM) is a method of fabricating parts which consists in "adding materials in layers" (Gibson et al., 2015, p.2). Following the definition provided by the ASTM 42 Technical Committee, which is used by several authors like Ford and Despeisse (2016, p. 1574), additive manufacturing consists in "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" and 3D printing is the "fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology"[9]. This type of processing is also known as "Automated Fabrication", to highlight the possibility to simplify or remove manual tasks from the manufacturing process; "Freeform Fabrication", to emphasise the possibility to realize products with complex designs; "Layer-Based Manufacturing", to recall the actual creation logic adopted by additive manufacturing technologies; "3D Printing" (Stereolithography) or "Rapid Prototyping", as 3D printers were initially adopted only to enhance the Prototyping Phase of Product Design (Gibson et al., 2015).

As stated by Huang et al. (2013), the additive manufacturing process starts with a digital 3D solid model which has to be converted into a file format that can be understood by the AM machine. Then, the printer must "manipulate" the file, to change for example the orientation of the product. Finally, production starts and is completed layer by layer. Additive manufacturing can be performed with either plastic or metal.

The idea behind additive manufacturing was developed during the 1950s and 1960s but only 20 years later the complementary technology was developed enough to carry on the concept. In fact, the development of 3D printers was possible only thanks to the evolution of computers, lasers, controllers, design software, inkjet printers etc. During the early 80s, several patents regarding AM were registered. Hush (2015), had the idea for the first 3D printer in 1982 and in 1986 he deposited his first patent and start to think of ways of commercializing the product.

[9] https://www.iso.org/obp/ui/#iso:std:iso-astm:52900:ed-1:v1:en accessed on 1 August 2017

The expiration of these patents was an important stepping stone in the enhancement of the technology; in fact, starting from 2010, the technology proliferated (Gibson et al., 2015). Even if since the beginning AM was exploited to perform Rapid Prototyping, nowadays several important companies are leveraging this technology to ramp up their production: General Electrics, Lockheed Martin and Boeing, Aurora Flight Sciences and Google are only a few of the most important examples (D'Aveni, 2015a). The technology is even used in the health sector as it is exploited to create prosthetics and organs (Ehrenberg, 2013).

3D Printers are certainly the main physical translation of the additive manufacturing concept. The name has not been conceived as a mere decoration. In fact, the process of 2D laser printers or inkjet printers is similar to the one of 3D printers: the latter use powder (usually) to create a product “layer-by-layer” starting from a digital image, which is realized with a 3D CAD Software (Berman, 2012).

As Steenhuis and Pretorius (2017) highlight, Additive Manufacturing is used to refer to a way to produce goods and semi-finished goods which is completely different from the traditional Subtractive Manufacturing. The authors identify four main differences between the two manufacturing systems:

1. Additive manufacturing outputs can be more complex than the ones obtained through subtractive manufacturing. 3D Printers can directly produce goods which contain parts or other smaller objects inside them.
2. The characteristic way of manufacturing used by 3D printers permits to produce in one step “hollow-products”. Since 3D printers manufacture adding one layer at a time, this kind of products is obtained in a much simpler way than through “traditional” manufacturing. With subtractive manufacturing, the same result can only be achieved producing waste.
3. As stated by Anderson (2012), the 3D printer is one of the methods to turn “bits into atoms”: in fact, since the production starts from digital designs creating one layer at a time, no mold is required.
4. Finally, thanks to the design software and the fact that production does not require molds, additive manufacturing permits to almost everyone to produce goods. This is possible also because the technology is nowadays more affordable than in the past (Ehrenberg, 2013).

Moreover, Ford and Despeisse (2016) identified other additional 3D printing advantages considering the studies of several authors like Berman (2012), Huang et. Al (2013), Petrick and Simpson (2013), and Petrovic et al. (2011):

- Final products have minimum porosity;
- 3D Printing permits to satisfy customer demand following a "Make to order" logic, reducing the risks concerning production volumes (like the risk of having unsold products, thus creating inventory) and improving the working capital management, since goods are manufactured only after their payment (Berman, 2012). Moreover, additive manufacturing does not require costly setups (Huang et al., 2013);
- Its distribution gives access to a "direct interaction" between local consumers and producer: the Digital Manufacturing Paradigm (Chen et al., 2015) focuses for instance on the role of prosumers that act as intermediaries between end-users and manufacturer.
- Additive manufacturing allows users to achieve savings in terms of material usage; waste can be reused for subsequent productions. AM has a lower environmental impact than traditional manufacturing not only because of the recycling of raw materials; in fact, it generates less pollution and it needs less landfill (Huang et al., 2013).

To summarize, additive manufacturing main advantages are flexibility and efficiency. Flexibility is enhanced because complex goods can be created in one step and setups are not costly. Efficiency instead concerns both the amount of raw materials used and the kind of resources that are needed to complete the production: with AM, many secondary machines become useless (Huang et al., 2013). Notwithstanding this, additive manufacturing is far from being the perfect production process, since it still presents many challenges to overcome. For Ford and Despeisse (2016), the main challenges are the following:

- The cost and the speed of production: even if the technology has been improved a lot since its introduction, these aspects still represent a significant drawback of the adoption of AM machines. Many companies still perceive that this technology can only be used for rapid prototyping and they do not even think about using it as the main production system. Moreover, the adoption of 3D printing solutions prevents companies from achieving economies of scale (D'Aveni, 2015a).
- Technological improvements in terms of available materials, their standardization and the development of multi-material or multi-color systems.
- Produced parts often need additional processing to correct imperfections: technology evolution should aim at correcting also this problem.

- The development of automated AM systems and process planning, because as Petrovic et al. state (2011), firms tend to develop automatic assessment tools in their production processes;
- The intellectual property issues. Designs of products protected by copyright are available online; in addition, 3D scanners are often used to perform reverse engineering on parts that may be immediately reproduced with a 3D printer (Mota, 2011).
- The relationships between collaborators may be complicated and not properly defined.
- Designers and engineers who are expert in additive manufacturing are still few.
- Competitors change continuously, e.g. because the production of customized products becomes economically attractive to a wider range of businesses.

Wohler Associates Inc. (2014) reports seven different processes of additive manufacturing. These processes are: material extrusion, material jetting, binder jetting, sheet lamination, vat photopolymerization, powder bed fusion and directed energy deposition. For Steenhuis and Pretorius (2017) the most used addictive manufacturing methods are Material Extrusion, Vat Photopolymerization and Powder bed Fusion. Even if these methods differ in terms of types materials adopted, their consistency, and physical transformation during the process, the underlying logic always consists in putting one layer at a time to create the product.

As for its future adoption, AM will need to be improved to face the challenges described before. Richard D’Aveni (2015b) highlights some ways in which the technology may evolve. For example he predicts the adoption of “Continuous Light Interface Production”, which exploits chemical reactions to enhance the control over liquids and solids and should allow the creation of items in a completely new way, different from the “Layer-by-layer” one. Another interesting development may be the so called “4D Printing” which considers time as the fourth dimension: such technology is based on “memory materials” which gain their shape when exposed to light or heat. Without any doubts, technology developments will not stop.

1.7.3 Laser Cutting

The term “Laser” stands for Light Amplification by Stimulated Emission of Radiation. A laser is a “unit that produces optical-frequency radiation in intense, controllable quantities of energy” (Oberg et al., 2012, p.1487). Lasers are used to cut, weld, drill, mark and treat surfaces. Laser cutters are tools that nowadays are even used as desktop tools. These devices cut using a powerful laser beam; they are endowed with high precision capabilities which permit them to cut every complex shape. Laser cutters input consists of sheets of metal, plastics or wood (Anderson, 2012). There are two main types of laser cutters: lasers based on gas and solid-state lasers. The former exploit gases to generate the beam (the main used ones are carbon, helium, and nitrogen) while the latter exploit solid components (Yttrium Aluminium Garnet or YAG, or glass crystals). Solid state lasers are usually more powerful than the gas ones since their energy density is higher (Thompson, 2016)

Laser cutters are used by almost any company that needs to cut metal because they offer "value-adding" qualities which are superior to the ones offered by traditional cutting techniques. Laser cutting permits to eliminate costly and less flexible equipment; to reduce waste and to create complex product design thanks to its superior precision (Caristan, 2004). Laserage[10] presents a list of advantages for laser cutting:

- Distortion on parts is minimal because heat affects a small zone;
- It permits complex part cutting;
- It permits to obtain parts with narrow kerf widths;
- The process is highly repeatable, laser cutters have high accuracy;
- Laser cutters are 30 times fasters than traditional cutting equipment.

Laser cutters are a digital manufacturing tool, in fact they belong to the CNC machines category. As for 3D printers, the initial phase consists in creating a digital model, in this case in two dimensions. If something can be drawn in 2D, laser cutters can cut it. When a laser cutter is working, a computer leads the motors which move the laser beam around the material sheet (a x-y plane). According to the level of energy output, the laser beam can cut or etch the sheet. Even if laser cutters work in two dimensions, they can be used to create 3D objects: CAD programs can transform a 3D object into several 2D parts. These parts will have to be assembled together once they have been cut (Anderson, 2012). Nevertheless, 5/6 axis lasers are adopted to achieve 3D capabilities in laser cutting (Burdel and Schawrzenbach, 2005).

The first assisted gas assisted laser cutting was accomplished in 1967. Peter Houldcroft, Deputy Scientific Director at The Welding Institute at the time, had the idea that combining a focused laser beam with an oxygen assist gas could improve thermal cutting processes in terms of both precision and speed. It was possible to confirm the feasibility of this idea thanks to the availability of an operational 300W CO_2 gas laser at the Service Electronic Research Laboratory in Harlow, near TWI. Thanks to Houldcroft's idea, many experiments took place to improve the technology. In 1969, Boeing Company demonstrated how laser cutting could be used with titanium, Hastelloy, and ceramic thus increasing production efficiency, even if the technology still needed further research and development (Hilton, 2007). Currently, laser cutting

[10] http://www.laserage.com/laser-cutting accessed on 3 August 2017

technology is often installed in robot arms to permit more sophisticated production processes and to work in three dimensions rather than in two (Defaux, 2004).

1.7.4 3D Scanners

If 3D printers start from a digital design and create the part layer-by-layer, 3D Scanners perform the opposite operation: they turn atoms into bits (Anderson, 2012). 3D Scanners carry out the so called “reality capture”: starting from a physical object, this technology permits to obtain its digital model which can then be modified and corrected on a computer. This operation is almost always necessary because 3D scanners provide only a “cloud of dots” on the x-y-z plane which is related to the surface of the scanned object (Iuliano and Vezzetti, 2013).

3D Scanners work like cameras, so they can capture and translate into bits only what is inside the cone-like field of view; what is obscured cannot be understood by the device. For this reason, often hundreds of scans are performed on the object from different directions to obtain a model that is as accurate as possible (Ciolac et al., 2011). As Ciolac et al. (2011) point out, while a camera has to capture and understand information related to colours in its field of view, a 3D scanner has to perform the same operation for the “distance information about surfaces”.

In the industrial environment, 3D scanners are mainly known as “Reverse Engineering” tools (Iuliano and Vezzetti, 2013). In fact, for companies is much easier to start from an existing part to modify its design later than to start from nothing (Anderson, 2012). But 3D scanners can be used for much more. For example Siekmann (2015) studied the adoption of 3D scanners in the insurance business: he highlighted how the technology can be used to verify damages to objects, for instance on cars or on the asphalt street.

Ebrahim (2016) summarizes the history of 3D scanners. The technology was introduced in the 1960s and exploited light, cameras and projectors but, because of the low performances of the tools, the acquisition was difficult and time-consuming. In 1985 scanners started to use laser to capture the surface of objects. At this point, capturing complex surfaces was still difficult and software had to automatically remove the duplicated points generated by the multiple scans. For a while, the adoption of 3D scanners was concentrated in the animation industry, because of the necessity to capture humans. In 1994 REPLICA, which permitted fast and accurate acquisitions, was launched by 3D Scanners (the company). Few years later (1996), the same company launched the first Reality Capture System, which was formed by a manually operated arm and a stripe 3D scanner and permitted to achieve even superior performances. Nowadays, the technology is adopted in several industries for manufacturing, utilities, archaeology, government, etc. (Ebrahim, 2016).

The available techniques used by 3D Scanners are two (Ebrahim, 2016):

- *Contact Technique*, which implies that scanners must make contact with the object. This technique is slow and may not be appropriate to scan delicate parts.
- *Non-Contact Technique*, with which contact with the surface is not necessary. This technique is extremely accurate and can be either "Active" or "Passive" depending on the radiation of energy by the scanner. Active 3D scanners radiate the object with energy, while passive 3D scanners leverage on the reflected ambient radiation to capture the surface.

The CEO of Artec 3D, a company which sells 3D scanning solutions, recently stated that "3D scanning and 3D printing are like yin and yang" (Milstein, 2017, p.18). Additive manufacturing needs a 3D digital model to start creating a part, and the output of 3D scanning fits this request. In fact, during the "pre-processing phase" of the scanning of an object, the software combines all the clouds of points collected to eliminate "noise points" to finally convert the model into a "mesh". The final output is a polygonal model which can be easily modified through 3D CAD software (Iuliano and Vezzetti, 2013). The 3D scanner was considered for the Analysis also because of its connection with 3D printing.

As for the future, Ebrahim (2016) predicts that the technology will improve in terms of data quality, software processing, and user friendliness.

1.7.5 Augmented Reality

As the "Internet of Things", "Augmented Reality" (AR) is used to refer to a family of technologies rather than to a single device (Magone and Mazali, 2016). Usually, Augmented Reality comprises all the wearable devices or, more generally, all the devices that can enhance the information that is available to the user in physical environments (rather than on digital laboratories, as it happens for virtual reality). In other words, AR is defined as "the process of overlaying animations and graphics on actual scenes in real time" (Turner et al., 2016, p.887). The applications of these technologies are still limited and experimental, like their use for the retail consumers. Nevertheless, the opportunities that these devices offer are potentially huge, in particular in settings like inventory management, logistics management, and maintenance (Magone and Mazali, 2016).

The technology was created by Ivan Sutherland (a computer graphics pioneer) and his student at Harvard University and the University of Utah. They realized the first Augmented Reality prototype in the 1960s; they used a see-through to present 3D graphics. Lately, during the 1970s and 1980s, studies were conducted at U.S. Air Force's Armstrong Laboratory, the NASA Ames

Research Center, the Massachusetts Institute of Technology, and the University of North Carolina at Chapel Hill. One of the first examples of wearable technology was Sony's Walkman in 1979; later, in the 1990s, computers were small enough to be worn. The term "Augmented Reality" was used for the first time by Caudell and Mizell (1992, p.660) to refer to a technology that was used to "augment the visual field of the user with information necessary in the performance of the current task". In the 1990s AR was considered a distinct research field, conferences on the subject were held and research on this technology accelerated (van Krevelen and Poelman, 2010). In 2009, AR was used for the first time for a commercial: a German agency developed a printed magazine advertisement which, when positioned in front of the webcam, would appear on the screen. This digital model could be rotated by simply moving the physical magazine in front of the camera. Then, several other brands started to leverage on Augmented Reality for their commercials and not only. The technology was used, for example, to permit users to digitally try jewellery. The last phases of AR proliferation are characterized by the diffusion of the technology in other industries, like tourism (Javornik, 2016). Currently, "holograms" are considered characteristic elements of smart manufacturing (Kang et al., 2016), nevertheless, AR applications in Industry 4.0 are not limited to holograms.

An Augmented Reality experience needs several technologies to work like displays, trackers, graphic computers, and software (van Krevelen and Poelman, 2010). Displays could be head-mounted, hand-held, spatial see-through or projectors. With head-mounted displays and see-through glasses (like Google Glass) users can use their hands while receiving augmented information. Vice versa, hand-held displays need at least one user's hand. Spatial displays are bigger than the other ones, but they allow users to have hands free since they are attached; given their fixed position they are not flexible and cannot be used everywhere. Projectors are used to project information on physical objects (Malý et al., 2016). Even a smartphone can be used as an AR device: AR is "only as good as the information shadow that accompanies the object the user is looking at" (Gilchrist, 2016, p. 59).

Tracking is necessary to understand where users are located with respect to their surroundings, in particular when they move their head, eyes or other parts of their body (depending on the type of AR technology that is being used). The software is important too: nowadays several open source applications are available to researchers and developers to design and create specific AR solutions (Ong et al., 2008).

The main advantage of exploiting AR in industrial settings is that it provides the possibility to fasten productivity growth. Since the Great Recession, U.S. and other developed countries have seen a significant drop in productivity growth. Moreover, new manufacturing job openings are outpacing the supply of work since 2009: this is due to a skill gap between the capabilities that companies want and the ones that the work supply can offer. To improve productivity growth, college education would be part of the solution; nevertheless, companies cannot wait for years without solving the problem. In this situation, Augmented Reality proves to be particularly useful: AR devices, like wearable technologies, deliver the right information at the right moment to workers directly in front of their eyes: traditional solutions, like stationary computers and tablet, can provide the same information, but they stop the workflow thus reducing productivity. Furthermore, AR devices, as head-mounted displays and other wearable technologies, allow workers to receive real-time information while having their hands free. With AR solutions, it is possible to reduce errors since they can be used to provide guidance to employees: each worker would have to simply follow the instructions to complete the tasks she has been assigned to (Abraham and Annunziata, 2017).

Currently, AR adoption is only “limited by the boundaries of imagination and innovation of developers and industry adopters” (Gilchrist, 2016, p.60):

- Augmented Reality has also an important role in industrial maintenance, as it can be used to reduce costs connected to this activity (Gilchrist, 2016). With AR, maintenance can be sped-up and workers might not have the need to continuously look for information about a specific tool in huge dispersive manuals (Ong et al., 2008).
- Another activity that can be enhanced by Augmented Reality is product development (Ong et al., 2008): the technology enables the possibility to perform simulations combining physical mock-ups with digital 3D graphic projects.
- Operations managers may use Augmented Reality technologies to design and manage complex production systems; in fact, AR solutions permit to test different layouts: as for product development enhancement, physical surroundings are combined with digital 3D models of objects so that managers can intuitively interact with the working environment to find the best solution (Ong et al., 2008).
- Augmented reality has the potential to improve telerobotics, an area of robotics which consists in the remote controlling of robots. With the aid of AR, a worker can use a visual image of the environment to move the robot in the actual remote workplace. The employee could even practice this operation using a virtual robot.
- Workers may have a better visualization of machining conditions using augmented CNC machining simulations: this process consists in combining virtual workpieces with physical tools and machining environments. Other than enhancing machining

conditions visualization, this activity permits to avoid tool collision with machinery and other components (Ong et al., 2008).

Ong et al. (2008) identify several challenges that need to be overcome to improve Augmented Reality. Both hardware and software must be improved. AR devices need to be more portable, smaller, cheaper, lighter, accurate and stable. As for the individual parts of AR devices, improvements need to be done for:

- *Tracking*. Enhancement of tracking technologies would give access to accuracy improvements of AR devices.
- *Registration*. Improving image (surroundings) registration is important in activities like AR-supported product design, assembly evaluation, facilities layout and mixed prototyping.
- *Sensing*. A better sensing would increase the understanding of surroundings by AR devices.
- *View Management*. This area refers to the labels and information that AR devices allow users to see on physical objects (Azuma and Furmanski, 2003). Information visualization and understanding will be easier if the positioning of these labels will be improved. Labels must not overlap so that users can understand them.
- *Manufacturing information visualization and management*. Manufacturing information should be efficiently and effectively classified so that the right information can be shown in the right place at the right moment, depending on the task that is being performed. Information has to be easily retrieved by users.
- *Displays*. Innovations should be aimed at reducing weight and discomfort, future displays must be smaller, with high-resolution, lightweight and with large fields of view.
- *User interface and interaction*. Interaction with the virtual components should be of immediate understanding and not complex.

1.7.6 Big Data

Big Data is data that "exceeds the processing capacity of conventional database systems". In other words, "Big" Data is too large and/or changes too fast and/or does not abide by the rules of traditional database management systems. Because of these factors, companies need additional expertise in data management, increasing storage capacity, and additional CPU resources (Gupta et al., 2012, p. 43).

Big Data is not a new phenomenon. Organizations have been collecting and analysing large amounts of data for years. But, thanks to the proliferation of the Internet, both collection and analysis have been drastically improved. The Internet and social media diffusion is certainly one important driver of Big Data (Mourtzis and Vlachou, 2016). Moreover, the proliferation of sensors and Internet of Things devices has furtherly enhanced these activities (Klous and Wielaard, 2016). The digitization of almost everything (documents, images, videos, music, maps and sensor signals) is being another important contribution to the creation of Big Data (Brynjolfsson and McAfee, 2014). As for businesses, collecting information during the production process is not an innovation that became famous only with the sprouting of Industry 4.0 and IIoT. Installing sensors in manufacturing tools to receive feedback during production is nothing new. The evolution of both sensors and radio technology has driven the diffusion of these technologies. In fact, currently, sensors can be installed everywhere thanks to miniaturization improvements. This proliferation of sensors applications boosted data flows increasing the need to have adequate tools to deal with these huge datasets (Gilchrist, 2016). Klous and Wielaard (2016) consider the improvement of storage capacity and computational performances as key factors of the "Big Data revolution", but the increasing capacity of networks is the main driving force. Industry 4.0 is leveraging on what is called "Big Data 3.0". Big Data 1.0 (1994-2004) started with e-commerce, Big Data 2.0 (2005-2014) with Web 2.0 and social media proliferation; Big Data 3.0 comprehends all the improvement made in the previous two phases and exploits IoT applications, thus sensors (I. Lee, 2017).

Big Data can be described considering its "V's", a set of attributes whose number has continuously been changing in the last years. Describing a dataset using these factors permits to identify the type of Big Data that must be managed. Depending on the type of Big Data, a company could adopt a specific technology instead of another (Gilchrist, 2016). Because of the rising trend regarding e-commerce in the early 2000s, Laney (2001) predicted the increasing importance of data and considered three first attributes that must be considered to deal with it. These attributes are Volume, Velocity, and Variety.

- *Volume*. As Gilchrist (2016, p.53) pointed out, "the ability to analyse large volumes of data is the whole purpose of Big Data" since larger samples always provide more trustworthy results. Laney highlighted how companies could reach more customers through e-commerce and, at the same time, how the information regarding an individual transaction increased tenfold. This Big Data dimension refers to the amount of data that is either created or collected by an organization or an individual; currently, the minimum volume to qualify a dataset as Big Data is 1 Terabyte, but this threshold will continuously rise as both hardware and software will improve (I. Lee, 2017). One terabyte can currently store as much as 1500 CDs or 220 DVDs; in terms of Facebook

Pictures, one terabyte corresponds to 16 million photographs (Gandomi and Haider, 2015). Data is collected not only through e-commerce but also through social networks and sensors. Moreover, big data comprises videos, audio files, and images, thus increasing the amount of stored information (I. Lee, 2017). As the Internet of Things and smart devices will become even more widespread, collected data will continue to increase (Rowe, 2016). Taleb (2013) points out how large data-sets risk to provide wrong information: given the fact that "large deviations are vastly more attributable to variance (or noise) than to information (or signal)", large data-sets could lead to bad decisions.

- *Velocity*. Velocity regards both data collection and speed of analysis. This aspect is particularly relevant; for instance, financial institutions and banks installed a submarine cable between New York and London to improve real time information by a millisecond (Gilchrist, 2016). The need for real-time analytics is growing as smart devices (smartphones, tablets, and smartwatches) and sensors are proliferating. Each installed application gathers huge volumes of information about the user, this information regards demographics, geographic location, behavioural patterns, etc. For example, collected information can be used to send customized offers to clients (Gandomi and Haider, 2015). Initially, organizations analysed data following a batch process because the process was slow and costly, but nowadays real-time analysis is a norm (I. Lee, 2017). Gartner (2017) forecasted 8.4 billion connected devices at the end of 2017 and that this number will grow up to 20 billion by 2020. As reported in Gartner's data, in 2018 each day 7.72 million new devices will be connected. These IoT units will contribute for collecting, analysing and sharing data, thus further increasing velocity (Gandomi and Haider, 2015).
- *Variety*. This attribute refers to the types of data that nowadays can be collected and analysed. Currently, it is possible to identify three different kinds of data: structured data, semi-structured data and unstructured data (I. Lee, 2017). Structured data is organized, usually in tables and relations; such regular way of organization is applied to all data in a dataset (Losee, 2006). An unstructured dataset consists for example of text, pictures, videos, audio (I. Lee, 2017) which contain information, but "contain no explicit structuring information" (Losee, 2006, p.441). Typically, Big Data processing is carried out to extract meaning from unstructured data so that it can be used for further analyses. This "cleaning" process permits to input data as structured data (Gilchrist, 2016). Semi-structured data does not abide by the characteristic regulations of structured data, but is "interpreted with structural information supplied as tags" (Losee, 2006, p.441). One of

the most typical examples of semi-structured data is the Extensible Markup Language (XML) which is a textual language that is used to share information on the Web. Documents written adopting this language contain tags which allow computers to read them (Gandomi and Haider, 2015). Laney (2001) considered XML as one of the available solutions to resolve issues related to data variety. New formats of data will proliferate, in particular because of the various sensors that are spreading among organizations and individuals. Integrating these new formats will require a makeup language (Zhong et al., 2016). Nevertheless, companies have to analyse data from all sources and formats to benefit from the Industrial Internet of Things (Gilchrist, 2016).

These were the main three attributes considered to describe Big Data. Some authors, like Lugmayr et al. (2017), consider four aspects in total. Several authors consider instead other additional three attributes, like I. Lee (2017), Gilchrist (2016), Gandomi and Haider (2015); nevertheless, the set of attributes considered by these authors is not equal. In fact, in total the additional attributes are four and not three. These attributes are:

- *Veracity*. Veracity is related to the uncertainty and the consequent unreliability which are embedded in data sources. Such issues are due to "incompleteness, inaccuracy, latency, inconsistency, subjectivity and deception in data" (I. Lee, 2017). Customer sentiments in social media are used as a clear example of veracity by Gandomi and Haider (2015); this kind of information is typically uncertain since it involves human judgement. As Rowe (2016) states, determining veracity is significantly important for third-party datasets. Rowe reported Dale Renner's words concerning third party data: Renner, the CEO and founder of RedPoint Global (a data management and marketing technology company) considers these datasets as the worst ones while first party data is "the cleanest data in any organization" (p.31) because of the edits and validation rules it needs to pass through. Other than uncertain and unreliable, data can be even false. For example, it may occur that an organization collects information from unreliable sensors. In this case, results would be useless too, considering the "garbage in, garbage out" logic (Gilchrist, 2016).
- *Variability*. SAS[11] added two concepts to Laney's definition of Big Data: variability and complexity. Variability regards data flow and its fluctuations. For example, a peak may be caused by a trending subject on social media. Data flows are unpredictable, and peaks imply difficult decisions regarding computational capacity. Similarly to manufacturing capacity, investing too much leads to underutilization of assets (I. Lee, 2017).

[11] https://www.sas.com/en_us/insights/big-data/what-is-big-data.html accessed on 9 August 2017

Complexity is related to the fact that organizations have to collect data that is generated by several resources. All these flows have to be connected, matched, cleaned, transformed and analysed (Gandomi and Haider, 2015).

- *Value*. Not all data has the same value. Resources are often limited, and it is necessary to decide what data to gather and to compute. The whole Big Data idea consists in collecting huge data sets that must be analysed, even useless data. But if a company's data analysts are not able to retrieve the value from such datasets, the whole activity is being carried out for nothing. Trends and correlations can be revealed only if analysts are able to program algorithms to do so (Gilchrist, 2016). This opinion is shared by Gandomi and Haider (2015), who agree with Oracle's definition of value: Big Data has often "low value density", in particular in their original form. This means that originally collected data has low value with respect to its volume. Extracting value from datasets is complex because of the other previous Big Data "V" factors (Zhong et al., 2016). IT professionals should determine benefits and costs that are generated by Big Data, identify the most value-adding sources and compute the right algorithms to obtain useful information for managers. I. Lee (2017) considers also "decay" as an additional attribute for Big Data, referring to how data loses value over time.
- *Visibility*. This factor is concerned with data visualization. Data doesn't have to be only collected and analysed; visualization of both raw data and results is important as well. Visualization software permits to present datasets and results in understandable and immediate ways through the creation of graphical reports and spreadsheets (Gilchrist, 2016). Nowadays spreadsheet and charts may not even be sufficient to have a clear understanding of a dataset. For this reason, the so called "data artists" are exploiting new technologies, like touchscreens, to make Big Data even more understandable (CACM Staff, 2014).

Bean (2017) has been interviewing executives of Fortune 1000 companies since 2012 to understand how they interpret Big Data value. His research reveals that 80.7% of executives consider their investments in Big Data as "successful". Firms are seeing Big Data value for obtaining cost savings, finding new innovation avenues and launch new products and services. Furthermore, technology does not represent anymore an obstacle for companies. Instead, the main challenges are organizational alignment, resistance or lack of understanding and change management (Bean, 2017).

Several functions of a company can benefit from Big Data. For example, Rolls Royce uses Big Data mainly for three activities: design, manufacture, and after-sales support. Each design of engines for airplanes or ships is virtually tested, generating tens of terabytes of information. This information is then analysed and visualized to understand if the specific design is good or bad (Marr, 2015).

Big Data becomes useful for any organization when it drives decision making. To do so, large datasets must be processed to obtain useful insights (Gandomi and Haider, 2015). Labrinidis and Jagadish (2012) broke down this process into four main stages. The starting step is data acquisition from all the various organization's sources. Then, an information extraction process must take place: this permits to arrange data in a structured form to simplify analysis. Additionally, erroneous data must be dealt with. In fact, the subsequent step is data analysis; given data volumes, this operation should occur in an automated manner. Finally, results have to be interpreted. The first two steps compose the data management process, while the last two compose the analytics process. The main analytics tools available to analyse big data are text analytics, audio analytics, video analytics, social media analytics and predictive analytics (Gandomi and Haider, 2015).

Analysing Big Data requires a certain level of computation performances. Nowadays, companies can easily exploit cloud analytics to manage this kind of processing. Cloud services providers offer resources to compute, store and share datasets and results (Gilchrist, 2016). In fact, cloud services consist of distributed processors and storage units (Gupta et al., 2012).

For I. Lee (2017), the main advantages resulting from an investment in Big Data analytics are:

- The possibility to customize marketing activities for customers;
- The possibility to improve pricing. Using Big Data to set prices at a granular product level permits to increase margins; moreover, analytics lead to the identification of price drivers (Baker et al., 2014).
- The possibility to obtain cost savings. For example, Big Data analytics permits to make more accurate forecasts, to mitigate shipping accidents and manage warehouses more efficiently (House, 2014).
- The improvement of customer services. Big Data permits both to increase value for customers and to control transaction activities in real time.

Jachimowicz (2017) proposes a 5-step process that should be followed to use the organization's data more efficiently which can be applied to Big Data. First, data quality should be improved: structured information is easier to be managed than unstructured one. After this, analysts should link different data and then analyse it. Then, it is necessary to infuse data with theory: this means looking for similar past researches that have been performed on the same topic to understand even more the analysis results. Finally, the first four steps have to be applied, and new outcomes should be monitored.

The main challenges that Big Data must overcome are:

- *Data quality*. Keeping “right” data is more important than having “big” data (Wessel, 2015).
- *Cybersecurity*. This issue is one of the main elements that characterize Industry 4.0 because Smart Factories exploit the Industrial Internet of Things and make high use of networks. Additionally, given the concerns regarding privacy, it is important to keep the collected data protected from threats and cyberattacks (Blanchet et al., 2014).
- *Privacy*. As datasets are becoming bigger, privacy is becoming increasingly important for individuals, organizations, and governments. Individuals are often reluctant to give information even if it could provide benefits for both parties (I. Lee, 2017).
- *Investment Justification*. Often it is difficult to justify investment if intangible benefits are large but tangible benefits are lower than costs (I. Lee, 2017).
- *Data Management*. Huge volumes of data are still difficult to manage (I. Lee, 2017).
- *Shortage of qualified data scientists*. This professional role is becoming increasingly important in industry 4.0 (Blanchet et al., 2014).

Cloud analytics and Cybersecurity are two of the main elements which characterize Industry 4.0, as well as Big Data. They will be analysed in the next paragraphs.

1.7.7 The Internet of Things: Smart Products

Impacts of the Internet of Things on the whole manufacturing process are at the foundation of Industry 4.0. The application of IoT inside the “Smart Factory” is called “Industrial Internet of Things” (Gilchrist, 2016). In this paragraph, the “traditional” Internet of Things will be described: the one that is in contact with customers, the one that characterizes “smart” products.

Gartner, the world leading information technology research and advisory company defines the Internet of Things as “the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment”[12]. The Internet of Things (IoT) leverages on the Internet to connect the so called “smart devices”: consumer items, automobiles, city infrastructure, enterprise assets (see the Industrial Internet of Things), and a myriad of other physical objects are linked one another in order to be controlled and/or to share information. The network of these connected “things” is an extension

[12] https://www.gartner.com/it-glossary/internet-of-things/ accessed on 18 August 2017

of the enterprise computing environment (Steenstrup, 2013). Smart connected products consist of three core components that enhance one another in a "virtuous cycle of value improvement" (Porter and Heppelmann, 2014):

- *Physical components*. These are the mechanical and electrical part of the products. For a car, physical components would be for example the engine block, tires and batteries.
- *Smart components,* as sensors, microchips, CPUs, software and controls that are embedded in the product. Smart components improve physical components capabilities, thus increasing their value.
- *Connectivity components*. This category comprises all the antennae, ports and protocol which permit the product to connect to a network, wirelessly or not. Connectivity components improve smart components capabilities and value and permits their existence outside their physical boundaries. Connectivity can occur in three ways: one-to-one, through which a product connects to its user, the manufacturer or another single product; one-to-many, through which a central system is connected to several devices at the same time (e.g. to control their performances); and many-to-many, through which several products are connected one another at the same time (Porter and Heppelmann, 2014).

The proliferation of smart devices is one of the drivers of Big Data. Consumer's everyday life has already been marked by the Internet of Things diffusion. One of the main examples is the smartphone: it is endowed with multiple sensors (like accelerometer, gyro, video, proximity, compass, and GPS) and several connectivity options (Roaming, Wi-Fi, Bluetooth and Near Field Communication). Smartphones are Internet of Things devices without any doubts. They can collect information regarding the user's position, health, and behaviour in real-time continuously. Another less common example is Echelon, a smart light system which provides a certain level of lighting on the streets depending on weather, time of day, and season. This permits to enable a more efficient use of electricity to light up streets (see Postscapes)[13]. Smart products enable the monitoring of their condition, external environment, and usage. Through installed sensors, they can be controlled through remote commands or algorithms that have been filed in the product's software. These first two capabilities (monitoring and control) of smart products allow companies to optimize performances of their products: smart products may be endowed with algorithms that, considering historical data and in-use data improve "output, utilization and efficiency" (Porter and Heppelmann, 2014). Smart devices are achieving a significant level of autonomy thanks to their monitoring, control and optimization capabilities.

[13] https://www.postscapes.com/internet-of-things-examples/ accessed on 2 August 2017

These devices can work in coordination with other products and systems and can even function in complete autonomy. In this last case, individuals would just have to monitor their performances (Porter and Heppelmann, 2014).

IoT is related to several technologies and concepts:

- *Ubiquitous computing*. The Internet of Things is often referred to as an "ubiquitous infrastructure", "ubiquitous computing", "ambient intelligence" and "distributed electronics" (Bi et al., 2014); this concept has been discussed for decades, and it refers to the possibility of keeping individuals connected everywhere and whenever they want (Weiser, 1993). Thanks to smart devices, individuals are empowered since they are able to solve more complex problems (Bi et al., 2014).
- *RFIDs*. Radio-frequency Identification is a wireless technology that is used for retail, commercial and industrial IoT (Gilchrist, 2016). This technology exploits tags to store electronic information; RFID tags can be identified by RFID readers from distance and a line of sight is not necessary (Want, 2006).
- *Wireless sensor networks*. As explained before, the Internet of Things is an Internet-based network in which each "Thing" (the devices) has its own ID (Bi et al., 2014).
- *Cloud Computing*, which consists in the "delivery of on-demand computing resources - everything from applications to data centres - over the internet on a pay-for-use basis", as explained by IBM[14].

IoT is continuously expanding. McKinsey Global Institute (Manyika et al., 2015) predicts that in 2025 the Internet of Things will have a global potential impact equal to 3.9-11.1 trillion dollars per year. Such impact will derive from all the nine IoT applications that have been considered:

- *Human*. Devices can be attached to or inside individuals' bodies. These devices are applied for two main applications: health and productivity. Tools to check, monitor and improve fitness performances and human health are included in the first category. The second category comprises technologies and applications that permit to enhance productivity and redesign jobs in a more efficient way.
- *Home*. Smart devices are increasingly being installed in houses. Sensors connected with thermostats and other domestic appliances allow users to control in real-time the so called "Smart home".

[14] https://www.ibm.com/cloud-computing/learn-more/what-is-cloud-computing/ accessed on 12 August 2017

- *Retail environments*. In these settings, IoT can be applied everywhere. The Internet of Things provides tools that permit retailers to compete and coexist with the online retailing. "Coexist" because, for example, in physical places IoT could guide shoppers towards the items they looked online, thus enhancing their experience.
- *Offices*. IoT is used in these environments mainly because of its benefits in term of security and energy management. In these settings, IoT can be used to improve employees' performances: companies may provide them with fitness monitors and badges to continuously check their health, and design jobs according to this information.
- *Factories*. For McKinsey Global Institute, this will be one of the largest sources of value, according to their predictions. IoT in industrial settings permits companies to improve operations as it provides manufacturers a complete view of what is going on in the production site whenever they want. Moreover, IoT technologies allow companies to perform predictive and improved maintenance, to optimize inventory management, to improve workers safety, to gather data for "usage-based design", and so on.
- *Worksites*. In its research, McKinsey defines oil and gas exploration and production, mining, and construction as "worksites". These environments are dangerous and unpredictable: IoT can improve these workplaces in both these two aspects. IoT could even be applied through the deployment of self-driving trucks.
- *Vehicles*. Sensors and other devices can be installed on vehicles to monitor, control and optimize their performance. As reported in the Worksites example, "smart" vehicles gain a certain level of autonomy. Sensors may help manufacturers in discovering other ways to serve customers. The Industrial Internet of Things permits companies to satisfy consumers following the "outcome economy" idea, where manufacturers sell the use of the product and not the product itself (Gilchrist, 2016). One of the easiest examples of the application of sensors for this purpose regards vehicles: a logistic company may prefer to pay only for the mileage and wear it uses on the tires of its trucks rather than actually buying those tires.
- *Citie*s. Cities are important settings to experiment IoT applications. Cities can benefit in four areas: transportation, public safety and health, resource management, and service delivery. Currently, transportation is the area in which the Internet of Things is applied the most.
- *Outside*. This category refers to IoT applications in settings that are different from the previous one. For example, IoT technologies can be used to "improve routing of ships, airplanes and other vehicles" (p.9). This category comprises also the adoption of self-driving vehicles outside cities.

Whitmore, Agarwal, and Xu (2015) predict the "Web of things" as a possible future vision for the Internet of Things. This concept proposes to use web standards to reach full integration of smart devices in the World Wide Web. This would ease the creation of applications for developers and enabling interoperability and communication of different devices would be simpler. Whitmore et al. (2015) report that some researchers that support the "Web of Things" idea think that this future vision will be achieved by introducing again the Web 2.0 concept of "mashup", but applying it to physical objects rather than on applications. A mashup is an application which dynamically includes contents that come from several sources. The Internet of Things proposes a myriad of opportunities, but it poses also several challenges that need to be overcome. The main concerns are security, privacy, and problems in data movement and storage; as for Big Data (E. T. Chen, 2017).

1.7.8 Cloud Computing

Cloud computing is defined by the National Institute of Standards and Technology (Mell and Grance, 2011) as "a model for enabling ubiquitous, convenient, on-demand networks access to a shared pool of configurable computer resources (like networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or server provider interaction". Cloud computing came to the fore in the 2000s, when Amazon launched Amazon Web Services: Amazon built massive data centers in order to comply with its web scale requirements and decided to rent its spare capacity in the form of "leasing compute" and its storage resources on an "as-used basis". Nowadays, cloud services providers are still using the "pay-as-you-use" formula like Amazon: this feature makes cloud computing solutions attractive to even SMEs (Gilchrist, 2016). Mell and Grance (2011) identify five main characteristics that compose a cloud model:

- *On-demand self-service*. Consumers can easily ask for and access computing resources, without human interaction with each service provider.
- *Broad network access*. Computing capabilities are available over the network.
- *Resource pooling*. The service provider pools its resources to serve a myriad of consumers. Some of these resources are: storage, processing, memory and network bandwidth.
- *Rapid elas*ticity. Capabilities provided are flexible and scalable depending to comply with the demand. Consumers do not perceive any limit of the offered capabilities.
- *Measured servi*ce. Providers automatically optimize their resources.

Cloud computing is a valuable option for companies that need resources like storage, additional CPUs and processing capabilities, etc. The value of this solution comes mainly from the possibility of packaging and obtaining resources in an economical, scalable and flexible way that is both affordable and attractive to users (Motahari-Nezhad et al., 2009). With cloud services, individuals and organizations gain the illusion of infinite computing resource and do not have to plan the investment they need to make in terms of computing capacity. Moreover, the commitment in hardware and software is not necessary anymore. Users can use and pay only the resources needed and release them when they are excessive (Armbrust et al., 2009).

Cloud providers offer four different kinds of services (Hassan, 2011):

- *Infrastructure-as-a-Service (IaaS).* This service is similar to what Amazon offered in 2005: it had excess infrastructure, so it leased the excess resources to companies (Gilchrist, 2016). Through this option, a company can rent the hardware it needs like memory, storage, CPUs, networks, etc. (Hassan, 2011).
- *Platform-as-a-Service (PaaS).* With this service, users obtain access to a platform which permits to ease and accelerate the development of applications. Microsoft and other providers noticed that developers need access to software development languages, libraries, and other services other than infrastructure to create Windows based applications; for this reason, this type of service was launched (Gilchrist, 2016). Currently, applications are often realized through Internet browsers.
- *Data-as-a-Service (DaaS).* If companies rent this service they can save the money that would be spent in costly Database Management Systems (DBMS) and storage (Hassan, 2011).
- *Software-as-a-Service (SaaS).* Through SaaS, companies can access applications through the Internet instead of purchasing or building them on their own (Hassan, 2011). Through the browser, users can access web server-based shared applications (Gilchrist, 2016).

Depending on the type of owner, a cloud may be private, public, or hybrid (Gilchrist, 2016). Private clouds are accessible by a single organization, even if it can have several “customers”, like its business units (Mell and Grance, 2011). In a public cloud, a community shares all the resources (following a per-usage model) and each customer has an ID to prevent other customers’ access. Hybrid clouds consist of a combination of the previous two types of cloud: for example, a company may rely on a private cloud for sensitive data and exploit applications in another cloud. A firm may also exploit multi-cloud services (Gilchrist, 2016).

Cloud solutions offer many benefits for companies and individuals. The pay-per-use policy and the fact that no commitment is required is attractive for those who do not have many economic resources. Nevertheless, cloud computing presents some challenges that should be considered before subscribing to these services. Hassan (2011) summarizes the main problems that companies have to face when they rely on cloud services.

- *Standards*. Each provider offers its own technologies and standards, thus porting between providers is impossible for users.
- *Dependability*. Organizations are worried about the possible departure of the provider they have chosen. They do not want to invest in a solution that is going to disappear soon.
- *Transparency*. Providers may change hardware and software resources without notifying their customers.
- *Security*. Organizations are reluctant about entrusting critical data to a third party. They fear possible security breaches (hackers' attacks) and monitoring by their competitors.
- *Internet Connections*. To access cloud services, a good Internet connection is necessary. Dependable Internet connection is not available worldwide and for some organizations the costs of installing a sufficient connection could exceed the savings achieved relying on cloud services.
- *Availability*. Cloud providers' resources could become inaccessible for several reasons: server crashes, interrupted Internet connection, human error, etc.
- *Legislation*. The relationship between provider and user is based on trust. A complete legislation to regulate cloud computing would facilitate trust building between parties.

1.7.9 Cybersecurity

In the last two decades, Cybersecurity has been defined in many ways. A comprehensive definition is the one proposed by Craigen et al. (2014, p.17): "cybersecurity is the organization and collection of resources, processes, and structures used to protect cyberspace-enabled systems from occurrences that misalign de jure from the facto property rights". The International Telecommunications Union[15] provides another broad definition: "Cybersecurity is the collection of tools, policies, security concepts, security safeguards, guidelines, risk management approaches, actions, training, best practices, assurance and technologies that can be used to protect the cyber environment and organization and user's assets. Organization and user's assets include connected computing devices, personnel, infrastructure, applications, services, telecommunications systems, and the totality of transmitted and/or stored information in the cyber environment. Cybersecurity strives to ensure the attainment and maintenance of

[15] http://www.itu.int/en/ITU-T/studygroups/com17/Pages/cybersecurity.aspx accessed on 17 August 2017

the security properties of the organization and user's assets against relevant security risks in the cyber environment. The general security objectives comprise the following: availability; integrity, which may include authenticity and non-repudiation; and confidentiality".

Cybersecurity must not be confused with information security: while information security is the protection of information from possible threats and vulnerabilities, cybersecurity refers to both protection of information and of "those that function in cyberspace and any of their assets that can be reached via cyberspace" (von Solms and van Niekerk, 2013, p.101).

Cybersecurity is an issue that is becoming increasingly important for companies as Industry 4.0 advances: the huge amount of data and the digitalization process of companies requires a high level of protection from cyber-attacks (Blanchet et al., 2014). In 2013, more than fifty governments had already planned some sort of cybersecurity strategy to face cyberattacks (Klimburg, 2012). Recently, Yahoo admitted that it suffered two of the biggest cyberattacks ever: in 2013, hackers stole one billion accounts, while in 2014 they stole another five-hundred millions. The disclosure of this theft of sensitive information occurred only while Yahoo was in the middle of the acquisition by Verizon. But a myriad of companies suffered attacks by hackers in the last years: besides Yahoo, also Target, JPMorgan Chase, Home Depot, Sony Pictures, and Ashley Madison are victims of cyberattacks (Ramalho et al., 2017). For Cesar Cerrudo (2017) cybersecurity should be the biggest concern of 2017 for companies; he thinks that cybersecurity represents a serious problem because often it is underestimated, industrial settings are characterized by a mix of new and old technologies and a single weak point is sufficient to make the whole system collapse, and finally because often cybersecurity solutions are released in too much time. With Industry 4.0, companies' concerns multiply, as the environment to control is expanding and the number of connected objects is exponentially increasing. For Waslo et al. (2017), the challenge of implementing a secure, vigilant and resilient cyber risk strategy is more complex in Industry 4.0, as supply chains, smart factories, and customers are connected; thus, increasing the risk of a breach in the system. These authors, experts in cybersecurity practices in Deloitte & Touche LLP, consider three main areas that have to be protected with cybersecurity tools: connected digital supply networks (DSN), smart factories and connected devices.

1. *Connected digital supply network*. With Industry 4.0 digital integration of the supply chain is promoted and new cyber weaknesses arise. These weaknesses regard data sharing between stakeholders in the supply chain and vendor processing. As for the former, parties should consider which information to share and how to protect it. Using network segmentation (introducing figures that act as "intermediaries" in the

information sharing) and implementing procedures like cryptologic support, hardware authentication and attestation, and robust access controls are critical activities to protect at best shared data. Cyber-risk strategies should be continuously updated after having performed risk assessments. As for vendor processing, broadening the network would cause the detachment of the vendor acceptance process in use. To avoid the acceptance of fraudulent vendors, the adoption of governance, risk and compliance software, and the introduction of new shared policies are critical factors.

2. *The smart factory*. The basics of cyberattacks in Industry 4.0 companies are the same as in Industry 3.0 (third industrial revolution), but the methods to deliver the attacks are currently more complex: in Industry 4.0, connectivity proliferates not only in the virtual sphere but also in the physical one. For this reason, attacks are potentially more dangerous than before. Digital processes and machinery must be considered continuously together; this means uniting Information Technologies (IT) with Operational Technology (OT). Manufacturers "cyber imperatives" (themes towards which cybersecurity efforts should be aimed at) should be: health and safety, production and process resilience and efficiency, instrumentation and proactive problem resolution (as problems in the factory affect brand reputation), systems operability, reliability, and integrity, efficiency and cost avoidance, and regulatory and due diligence.
3. *Connected objects*. As IoT smart devices proliferate, the risk of cyber-attacks increases. Moreover, nowadays IoT devices are used to perform important tasks like controlling water purification, energy output, chemical production, and so on. To safeguard connected objects new approaches are needed. Planning, designing, and incorporating cybersecurity practices in both hardware and software from the beginning and during the whole development life cycle is a good starting point. The same attention should be maintained in protecting the data generated by these devices, not only because it may include intellectual property but also for privacy reasons. In the recent future, adopting an AI to manage cybersecurity could be the solution. Finally, since no company is completely safe from cyberattacks, it is necessary to be able to recover really fast from an attack: "a resilient organization should minimize the effects of an incident" (Waslo et al., 2017).

When dealing with possible cyberthreats, managers must consider three "uncomfortable truths" (Disparte and Furlow, 2017):

- Cyber-risks grow following Moore's Law, technological solutions alone are not able of keeping up with this growth.

- Defending is always more difficult than offending, like in all threat management.
- Unlike managers and companies, hackers are patient and have latency on their side.

Companies cannot protect completely themselves against cyber-attacks. Nevertheless, they should focus on two things. First, they should choose which areas to protect: a cybersecurity framework should initially focus on the business factors that drive growth and profitability and, subsequently, on the whole technology infrastructure. On the other hand, after having identified which business aspects are the most important and the risks related, companies should understand which risks have to be prevented and which ones have to be continuously monitored (Bell, 2016). Even though companies are continuously looking for the "perfect software" to assure cybersecurity, the best cybersecurity investment a company can make is a training improvement (Disparte and Furlow, 2017). Security technology is certainly useful and makes managers feel "safe", but cyber threats are often provoked by workers. All workers must be risk-agile and trained to face cyber-threats. Nevertheless, every executive should be concerned with cybersecurity tasks (Sweeney, 2016).

1.7.10 Machine Learning

Machine learning is related to "the study, design, and development of algorithms that give computers the capability to learn without being explicitly programmed" (Silva and Zhao, 2016, p.71). Nowadays, machine learning is seeing an increasing interest by companies. For example, a computer may learn how a tool is supposed to operate, even the "behavioral patterns that constitute degradation and failure", without the need for humans to specifically program it to do so. From sensor data, a computer may predict when a breakdown could occur, permitting managers to plan preventive maintenance activities (Brooks, 2016). Louis Columbus (2016) lists the main advantages of adopting machine learning. For example, machine learning permits a more efficient use of materials and equipment, and to identify which are the factors that impact quality the most, etc. Machine learning intelligence can even be installed at the sensor/machine level to predict machine failures (Wessels, 2017).

Machine learning is becoming particularly important because of the huge amount of data that companies collect. Machine learning techniques are data-driven approaches that allow to find "highly-complex and non-linear patterns" in datasets (of different types and sources) and they are able to transform raw data into a model which can be applied for prediction, detection, classification, regression, and forecasting. As computing power and data availability will improve, Machine learning will be used more and more by companies. Even if large datasets can distract firms, a support to handle huge amounts of data is certainly needed (Wuest et al., 2016). Machine learning satisfies several manufacturing requirements. Machine Learning techniques can deal with high-dimensional problems and datasets, they can find out information that was hidden inside datasets and they are able to translate results in terms that are useful for decision makers.

Traditionally, the fundamental types of machine learning are:

- *Unsupervised machine learning*, where the learning process is guided solely by data.
- *Supervised machine learning*, where the learning occurs with the help of training data, a set of information that has to "instruct" the computer.
- *Semi-supervised learn*ing, which combines aspects of the previous two methods (Silva and Zhao, 2016).

2 MANAGEMENT ARTICLES OF INDUSTRY 4.0 TECHNOLOGIES

In this chapter, management articles regarding the main technologies of Industry 4.0 are analysed. The research was conducted using Scopus, which was founded by Elsevier, the most important publishing company for medical and scientific publications. Scopus is “the largest abstract and citation database of peer-reviewed literature”[16], as reported by Elsevier on their Internet Web site. Scopus allows users to analyse interdisciplinary scientific information as it comprehends all research fields like science, mathematics, engineering, technology, health and medicine, social sciences, and arts and humanities. The analysis was performed for the following Industry 4.0 themes:

- Robots and Automated Guided Vehicles (AGV);
- Additive Manufacturing;
- 3D Scanner;
- Laser Cutting;
- Big Data;
- The Internet of Things;
- Cloud Computing;
- Cybersecurity;
- Machine Learning.

The research was conducted considering the following terms and their synonyms and alternative wordings that are used to refer to the same technology. Using Boolean search operators, like “AND”, “OR”, and other Scopus’s operators, the results were filtered each time in order to obtain the results desired. In fact, this literature analysis was not aimed at obtaining a broad view of all the publications that have been produced for the considered technologies. The main objective was the analysis of their literature in journals in relation to Industry 4.0. Many technologies have been around for decades; for example, the first industrial robot was introduced in 1959[17]: a simple research with the technology term alone would produce thousands of results that may not be related to the fourth industrial revolution. The search input regarded each time not only the technology but also “*Industry 4.0*”. Additionally, other terms that are related or may be used to refer to Industry 4.0 were added as input, like:

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[16] https://www.elsevier.com/solutions/scopus accessed on 17 August 2017
[17] https://ifr.org/robot-history accessed on 1 August 2017

- "*Industrie 4.0*", the name of the German plan which started the whole "fourth industrial revolution" concept;
- "*Industrie du future*", the term that is used in France when referring to Industry 4.0 (Magone and Mazali, 2016);
- "*High quality manufacturing*", that is the name of the English plan that has been deployed by the Government to promote companies' digitalization.
- "*Fabbrica Intelligente*". It stands for "smart factory" in Italian and it is the name of the Italian organization that promotes Industry 4.0 inside the country (Magone and Mazali, 2016). We included also the term "*Industria 4.0*", which is the literal translation.
- "*Fourth Industrial Revolution*", as this is the first definition of Industry 4.0. The term was input also as "4^{th} industrial revolution", to take into account for different wordings of the phenomenon.
- "*Cyber-physical system*", as this is one of the major aspects that characterize Industry 4.0 factories (Bloem et al., 2014). "*Cyberphysical system*" was also input to consider different wordings of the term.
- "*Industrial Internet*", that is at the basis of the American idea of Industry 4.0 (Magone and Mazali, 2016). The term was created by General Electrics in the same period as Industrie 4.0 (Ebans and Annunziata, 2012). Searching for "Industrial Internet" (with the inverted commas) permits to find results that include these words in this exact order. For this reason, it also finds results that include the term "industrial internet of things", a term whose connection to Industry 4.0 has already been confirmed and explained (Gilchrist, 2016). Often, "Industrial Internet of Things" and "Internet of Things" are used alternatively without considering the differences between them. Nevertheless, the research included only the former to identify those articles that are strictly related to the fourth industrial revolution.
- "*Smart factory*" or "*smart manufacturing*". Smart factories are at the core of Industry 4.0 (Gilchrist, 2016).

The technology name and these terms related to Industry 4.0 had to be included in the title, abstract or among the keywords to allow a publication to be found: these elements were considered good representatives of the content of a paper. The obtained results were furtherly filtered. Only articles and reviews were kept, as this analysis is aimed at observing trends in management journals. Additionally, only two research fields were kept on Scopus query editor: "Business, Management and Accounting" ("BUSI") and "Social Sciences" ("SOCI"). The latter field was input to keep articles that may be related to management, but they have not been included under the correct field of research. Nevertheless, we mainly focused on “Business, Management and Accounting” ones.

Summarizing, we looked for articles and reviews that contained both the technology name and one of the terms related to Industry 4.0 in their title, abstract or among their keywords. The output regarded only two fields of research: “Business, Management and Accounting” and/or “Social Sciences”. Only articles published up to 31 August 2017 were considered. An example of an input string is provided for Industrial Robots and Automated Guided Vehicles research. The others can be observed in Appendix A.

2.1 Industrial Robots and Automated Guided Vehicles – Articles and Reviews

For this first research, the following string was adopted:

> *(TITLE-ABS-KEY ("robot*" OR "automated guided vehicle" OR "agv") AND TITLE-ABS-KEY ("industria 4.0" OR "Industry 4.0" OR "Industrie 4.0" OR "Cyber-physical system" OR "Cyberphysical system" OR "Industrial internet" OR "Digital Manufacturing" OR "fourth industrial revolution" OR "4th industrial revolution" OR "smart factory" OR "smart manufacturing" OR "Industrie du futur" OR "High value manufacturing" OR "Fabbrica intelligente")) AND DOCTYPE (ar OR re) AND (LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , " BUSI "))*

It is possible to observe all the parameters that were discussed before: Industry 4.0 terms, different wordings, research fields, type of document, and where the filtering had to be carried out (title, abstract, and keywords). The output consisted of 10 articles, 6 for the “Business, administration and accounting” field and 4 for “Social Sciences”. The other queries will be included in Appendix A.

As for Social Sciences articles, two of them regard ways of improving education and training for robotics and cyber-physical systems. Vona and NH (2013) promote the use of an Open Hardware Mobile Manipulator (OHMM) whose project can be easily downloaded from the Internet to build its main parts through a 3D printer. It is designed to facilitate learning mainly for students, as the robot is endowed with low-level and high-level processors, an arm and gripper, a mast-mounted camera, a Kinect (a particular type of camera) to understand its surroundings, and other particular features. Its “open hardware” design should boost the number of its adoption. Its usage certainly has the potential to shorten the skills gap between labour demand and offer that characterize Industry 4.0 companies. For a similar purpose, Crenshaw (2013) presents UPBOT, “a robotic testbed hosted at the University of Portland, Portland, OR”. This testbed has been conceived to accelerate graduate students’ learning of cyber-physical systems: the engineers that introduced these networks that mesh ICT and physical processes in companies are retiring at a faster pace than the one at which universities are graduating engineering majors. The testbed includes a desktop machine equipped with Linux Operating System and a wireless card, and a robot.

Continuing with Social Sciences articles, Lee and Thuraisingham (2012) present a secure cyber-physical system for communications between surgeon controllers and telesurgical robots, robots that can be used to perform surgical operations without the physical presence of the doctor neat the patient. In her article, Donna Ellen Frederick (2016) proposes a brief presentation of the main factors that characterize Industry 4.0 and focuses on the consequences that the fourth industrial revolution may have on libraries. She describes a scenario in which robots have to carry out tiring tasks in place of humans in libraries: for example, RFID-endowed-robots could be “pulled” by online users’ requests and retrieve books for them. Muñoz (2016) thinks that robotics proliferation and their increasing intelligence open opportunities for programs of unconventional cognitive enhancement in order to shorten the gap between technological development and transformation of educational systems. Finally, Romanova (2017) includes robotization in the set of processes that must occur during the industrialization phase, which precedes the revolutionary one.

As for “Business, Administration and Accounting” articles, three of them are from Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb (ZWF), a German journal that “provides expert articles on recent developments in production engineering as well as on industrial service processes”, as reported on their website[18]. The first article retrieved presents a way to exploit the cloud to outsource robot management tools (Vick and Krüger, 2016). The second, instead, is a brief presentation of the international exhibition for metal working in Stuttgart. The exhibition was aimed at presenting current trends to work metal and it consisted of six clusters: Industry 4.0, energy-efficient production, robot machining, reliable and complete machining process, lean machining and additive manufacturing (Abele et al., 2016). Finally, Heß and Wagner (2015) studied the collaboration between robots and humans. The article written by Müller et al. (2016)

[18] http://www.hanser-elibrary.com/loi/zwf accessed on 22 August 2017

is in German too: they describe how Industry 4.0 solutions enable improvements in operations efficiency by reducing throughput losses caused by robot failures.

Probably, one the most interesting articles retrieved is probably Khalid et al.'s one (2016): "A methodology to develop collaborative robotic cyber physical systems for production environments". This paper was driven by the need for human-robot collaboration in future manufacturing environments. The analysis presented in the article considers humans as completely integrated in cyber-physical systems. First, it is important to understand the level of cooperation between robot and humans to classify their relationship. This classification is based on four Key Performance Indicators (KPI): performance level (taken as "mean time to dangerous failure"), safety distance (computed considering man speed, time the robot needs to stop, and the additional distance which depends on sensor performances), risk (the percentage of unsafe components), and reaction time (which depends on sensor transmission rates). Depending on the cooperation classification, the authors suggest a set of sensors that are necessary to sustain such relationship. In some cases, applying authors' advices, even old big robots could work together with humans, creating a "Collaborative Robotic Cyber-Physical System" (CRCPS).

Baban (2016) and Pontarollo (2016) include robots as one of the main technological characteristics of Industry 4.0. In particular, Pontarollo's article is a brief presentation of the fourth industrial revolution: he includes robots in the set of Industry 4.0 pillars together with horizontal and vertical integration, simulation, big data and analytics, augmented reality, additive manufacturing, cloud, and cybersecurity. This is the only article that marginally mentioned automated guided vehicles, as the author considers autonomous robots as one of the main Industry 4.0 pillars. No article explicitly regarded automatic guided vehicles. In the following table, a summary of the research output is shown. Finally, Teresko's paper (2004) must be recalled as it tried to predict the future of manufacturing way before the arrival of Industry 4.0. He stated the importance of simulation software, flexible machine tooling and flexible machines. All Industry 4.0 machines are characterized by a certain degree of flexibility: for example, as robots are exiting from their cages (Magone and Mazali, 2016), they can be used in more flexible ways.

Table 2.1: Industrial Robots and AGV – Articles and Reviews (Author's elaboration)

Authors	**Title**	**Year**	**Source title**		**Business, management, accounting**	**Social Sciences**
Romanova, O.A.	The innovation paradigm of new industrialization in the conditions of the integrated world economic way	2017	Economy of Region			1

Authors	Title	Year	Source title		Business, management, accounting	Social Sciences
Khalid, A., Kirisci, P., Ghrairi, Z., Thoben, K.-D., Pannek, J.	A methodology to develop collaborative robotic cyber physical systems for production environments	2016	Logistics Research		1	
Vick, A., Krüger, J.	Cloud and service-based production platforms [Cloud- und dienstebasierte Produktionsplattformen]	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb		1	
Abele, E., Baier, C., Schaede, C.	The PTW presents the innovation tour „future trends" at the international exhibition for metal working (AMB) in Stuttgart [Innovationstour Metallbearbeitung auf der AMB 2016: Die „Trends von morgen" gebündelt auf einem Messestand – Die Themen der Sonderschau des PTW]	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb		1	
Ellen Frederick, D.	Libraries, data and the fourth industrial revolution (Data Deluge Column)	2016	Library Hi Tech News			1
Pontarollo, E.	«Industry 4.0»: A new approach to industrial policy [Industria 4.0: Un nuovo approccio alla politica industriale]	2016	Industria		1	
Muñoz, M.M.	Unconventional cognitive enhancement options addressing structural unemployment in the technological context of the fourth industrial revolution [Opciones de mejora cognitiva no convencional como respuesta al desempleo estructural en el contexto tecnológico de la cuarta revolución industrial]	2016	Gazeta de Antropologia			1
Baban, A.	Industry 4.0: The entrepreneurial perspective [Testimonianza. Industria 4.0, il punto di vista dell'imprenditoria]	2016	Industria		1	
Müller, C., Grunewald, M., Spieckermann, S., Spengler, T.S.	Contribution of smart industry to the robust design of automated flow lines [Potenziale für die robuste Konfiguration automatisierter Fließproduktionssysteme]	2016	Productivity Management		1	
Heß, P., Wagner, M.	Human-robot-collaboration as a part of the production of the future [Mensch-roboter-kollaboration in der fertigung der zukunft]	2015	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb		1	

Authors	Title	Year	Source title		Business, management, accounting	Social Sciences
Crenshaw, T.L.A.	Using robots and contract learning to teach cyber-physical systems to undergraduates	2013	IEEE Transactions on Education			1
Vona, M., Nh, S.	Teaching robotics software with the open hardware mobile manipulator	2013	IEEE Transactions on Education			1
Lee, G.S., Thuraisingham, B.	Cyberphysical systems security applied to telesurgical robotics	2012	Computer Standards and Interfaces			1
Neil, S.	MES success is in the value added[19]	2009	Managing Automation		1	
Teresko, J.	Lean, green & smart	2004	Industry Week		1	

2.2 Additive Manufacturing – Articles and Reviews

For this research, several synonyms of additive manufacturing and related terms were included. The picked synonyms were: “3D Print*” (and both “3D-Print* and “3-D Print” to include different wordings with the same prefix), “Rapid prototyping” (Iuliano and Vezzetti, 2013), “Automated fabrication”, “Freeform fabrication”, “Layer-based manufacturing”, and “Stereolithography” (Gibson et al., 2015). The research provided 20 results, 14 “Business, administration and accounting” articles, 5 for “Social Sciences”, and one for both fields of research. A paper was not considered since it used the term “Rapid prototyping” in a context that did not concern 3D Printing, another because it was not related to Industry 4.0.

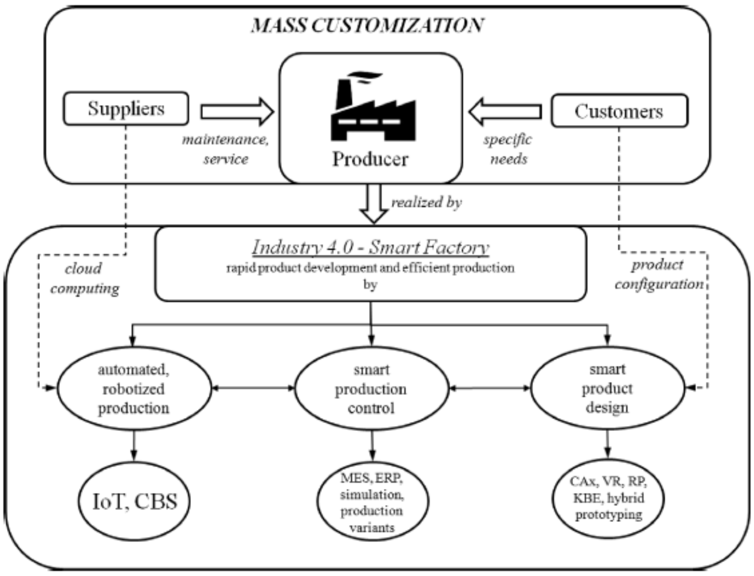
As for Social Sciences, two of the most recent articles regard the adoption of 3D printers in education to develop a pre-engineering curriculum (Chien, 2017) and the adoption of technical support centers and the role of Fablabs to improve knowledge concerning this innovative manufacturing method (Egorov et al., 2016). 3D Printing permits to develop and share open-source hardware; as a matter of fact, several digital designs are published online and among research centres: in this way, they can be easily replicated by whoever has the technology with relatively low costs. Starting from such feature, Vona and NH (2013) promote the Open Hardware Mobile Manipulator, that can be easily created through 3D printing and 3D laser cutting by users. This subject was analyzed also in another article: for example, Pearce (2016) show how funding on open-source hardware permits to achieve a huge return on investment and fastens innovation. Prause (2015) cites 3D Printing as one of the technologies that characterize Industry 4.0. He lists a series of alternative and sustainable business models that

[19] This article was found only because it recalls robotics simulation in its abstract

companies build thanks to the new available tools, like open innovation models (similar to the ones described by Anderson, 2012) and service design models.

As for Business, Administration and Accounting literature, Chang and Chen (2017) develop a graphical approach to integrate 3D printing and Knowledge-Based design System (design KBS) through a cyber-physical system. The authors describe design KBS as a "computer-based technique where the design procedures are captured as a set of algorithms and design rules" (p.649). This design technique is becoming increasingly important for firms but the output of KBS cannot be read by computer-aided design software; so, it is not currently possible to create a model that can then be printed "layer-by-layer". Through their research they want "to establish seamless connections between design and manufacturing so as to realize the free information transmission, integrated data processing, and efficient prototyping and production" (p.649). In the end, they succeed in building such connection, thus improving both design and manufacturing techniques and helping firms that strive to integrate the two tools.

Figure 2.1: Mass Customization in Industry 4.0 (Zawadski and Żywicki, 2017)



Zawadzki and Żywicki (2016) present various techniques and technologies that companies that want to build a business model based on mass customization have to follow. In particular, they highlight how mass customization is still a challenge for companies, even if Industry 4.0 has already demonstrated the benefits of its technologies in terms of increased flexibility and efficiency. The main elements identified by the authors are: smart product design, hybrid prototyping, and smart production control. As for smart product design, for Zawadzki and Żywicki a design must be easy, quick, and right at the first iteraction. They highlight the benefits of knowledge-based design systems as Chang and Chen (2017). 3D Printing is part of the "hybrid prototyping" concept, which integrates virtual reality and rapid prototyping to enhance this phase. Finally, they discuss the possibility to achieve smart production control exploiting, for example, the Internet of Things.

Holmström et al. (2016) show instead how direct digital manufacturing technologies like 3D printing are still lagging behind traditional tool-based manufacturing techniques. In their paper, they propose a research agenda for Operations Management to study direct digital manufacturing at the factory, supply chain, and operations strategy level. In the short and medium term, 3D printing probably will not have performances comparable to batch- or line-based manufacturing; nevertheless, in case of low-volume operations, direct digital manufacturing changes traditional operations like job-shop scheduling, inventory management, and so on. The authors predict that 3D digital models will become more important than inventory in Operations and Supply Chain Management. Sasson and Johnson (2016) propose a way to integrate both traditional mass manufacturing technologies and direct digital manufacturing technologies. As 3D printing fits low-volume spare parts requirements, they suggest the set-up of multi-product producer supercenters that exploit the technology to satisfy local manufacturers' demand for such parts. Additive manufacturing business model innovations are discussed also by Rayna and Striukova (2016). Yablochnikov et al. (2015) exploit 3D printing to perform rapid prototyping during their experimental process to create polymer optical products in a cyber-physical system.

Chen et al. (2015) present the sustainability benefits provided the adoption of direct digital manufacturing (DDM) technologies, in particular of 3D printing, which they consider a very promising technology. The paper lists 3D printing advantages in the environmental dimension and in the social dimension. DDM requires less raw materials, produces less waste and needs lower amounts of energy. Additionally, it introduces democratized production systems. In 2013, the Economist noticed the upward trend in 3D printing improvements and proliferation and described the situation of RedEye, a company located in Minnesota that gambled on digital manufacturing technologies to realize its products. A year before, also Berman (2012) noticed the 3D printing potentials and he nominated additive manufacturing as the new industrial revolution. Industry 4.0 does not leverage only on 3D printing, but it is certainly one of its most important pillars. Both benefits and challenges that Berman identifies are in line with the other authors' ones: cost and speed are only two of the several aspects that will need to be improved. The remaining business literature for additive manufacturing consists of Abele et al's article (2016) and Pontarollo's one (2016), already cited to describe research trends for robots and automated guided vehicles. In the same journal cited before (Zeitschrift fuer Wirtschaftlichen

Fabrikbetrieb), Abrahams (2016) includes 3D printing among the main innovating trends at the 19th METAV.

The research gave as output also the article "The birth of 3D printing", in which the inventor of 3D printers himself explains how he developed the first device and how the idea turned into a commercial product as it is known today (Hull, 2015).

Table 2.2: 3D Printing – Articles and Reviews (Author's elaboration)

Authors	**Title**	**Year**	**Source title**	**Business, management, accounting**	**Social Sciences**
Chien, Y.-H.	Developing a pre-engineering curriculum for 3D printing skills for high school technology education	2017	Eurasia Journal of Mathematics, Science and Technology Education		1
Chang, D., Chen, C.-H.	Digital design and manufacturing of wood head golf club in a cyber physical environment	2017	Industrial Management and Data Systems	1	
Zawadzki, P., Zywicki, K.	Smart product design and production control for effective mass customization in the industry 4.0 concept	2016	Management and Production Engineering Review	1	
Abele, E., Baier, C., Schaede, C.	The PTW presents the innovation tour „future trends" at the international exhibition for metal working (AMB) in Stuttgart [Innovationstour Metallbearbeitung auf der AMB 2016: Die „Trends von morgen" gebündelt auf einem Messestand – Die Themen der Sonderschau des PTW]	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Pontarollo, E.	«Industry 4.0»: A new approach to industrial policy [Industria 4.0: Un nuovo approccio alla politica industriale]	2016	Industria	1	
Holmström, J., Holweg, M., Khajavi, S.H., Partanen, J.	The direct digital manufacturing (r)evolution: definition of a research agenda	2016	Operations Management Research	1	
Pearce, J.M.	Return on investment for open source scientific hardware development	2016	Science and Public Policy		1
Abrahams, H.	Zukunftsweisende fertigungstechnologien klar im fokus: Technischer abschlussbericht zur METAV 2016	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Sasson, A., Johnson, J.C.	The 3D printing order: variability, supercenters and supply chain reconfigurations	2016	International Journal of Physical Distribution and	1	1

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
			Logistics Management		
Rayna, T., Striukova, L.	From rapid prototyping to home fabrication: How 3D printing is changing business model innovation	2016	Technological Forecasting and Social Change	1	
Egorov, S.B., Kapitanov, A.V., Mitrofanov, V.G., Shvartsburg, L.E., Ivanova, N.A., Ryabov, S.A.	Modern digital manufacturing technical support centers	2016	Mathematics Education		1
Yablochnikov, E.I., Vasilkov, S.D., Andreev, Y.S., Pirogov, A.V., Tretyakov, S.D.	An integrated approach to development and simulation manufacturing processes of optical products	2015	Management and Production Engineering Review	1	
Hull, C.W.	The birth of 3D printing	2015	Research Technology Management	1	
Chen, D., Heyer, S., Ibbotson, S., Salonitis, K., Steingrímsson, J.G., Thiede, S.	Direct digital manufacturing: Definition, evolution, and sustainability implications	2015	Journal of Cleaner Production	1	
Prause, G.	Sustainable business models and structures for industry 4.0	2015	Journal of Security and Sustainability Issues		1
Akanmu, A., Anumba, C.J.	Cyber-physical systems integration of building information models and the physical construction	2015	Engineering, Construction and Architectural Management	1	
[No author name available]	3D printing scales up: Digital manufacturing: There is a lot of hype around 3D printing. But it is fast becoming integrated with mainstream manufacturing	2013	Economist (United Kingdom)	1	
Vona, M., Nh, S.	Teaching robotics software with the open hardware mobile manipulator	2013	IEEE Transactions on Education		1
Berman, B.	3-D printing: The new industrial revolution	2012	Business Horizons	1	
[No author name available]	Graduates' new bureaus of investigation	2009	Crafts	1	

2.3 3D Scanner – Articles and Reviews

The research was conducted considering the following terms: “3D Scan”, “3D-Scan”, “3D Scanner”, “3D-Scanner”, “3D Scanning”, “3D-Scanning”, “3D Model acquisition”, “3D Imaging”, “Laser Scanning”, “Laser Digitizing”, “Digital Shape Sampling and Processing”, "DSSP", and "Digital Shape Sampling & Processing"[20]. The output consisted of only one article that does not really concern Industry 4.0. Nevertheless, it was an article to promote the adoption of digital manufacturing technologies in universities to let graduate designers practice with such tools.

Table 2.3: 3D Scanner – Articles and Reviews (Author's elaboration)

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
[No author name available]	Graduates' new bureaus of investigation	2009	Crafts	1	

2.4 Laser Cutter – Articles and Reviews

This research was conducted using as input the term "laser cut*". This input allowed us to find articles that contain either "laser cutting" or "laser cutter" in their title, abstract or keywords. The only output was the article "Teaching robotics software with the Open Hardware Mobile Manipulator" already described before for the section regarding industrial robots and automated guided vehicles. This "training robot" is accessible to firms not only thanks to the diffusion of 3D printing, but also thanks to the proliferation of laser cutting. As for "Business, Administration, and Accounting" field of research, there was no output.

Table 2.4: Laser Cutter – Articles and Reviews (Author's elaboration)

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
Vona, M., Nh, S.	Teaching robotics software with the open hardware mobile manipulator	2013	IEEE Transactions on Education		1

2.5 Augmented Reality – Articles and Reviews

In this case, the input to find articles was "augmented reality". Four articles were found, whereof three were of the field of research "Business, Administration and Accounting".

Even in this case, German literature provides studies that concern simultaneously the technology considered and Industry 4.0. Wolfartsberger et al. (2017) define Augmented Reality (AR) as "the computer-based integration of digital, context-sensitive information with the user's environment in real time". They propose an AR-application for self-assembly because

[20] http://www.absolutegeometries.com/3D-Scanning.html accessed on 23 August 2017

the technology is currently mainly used for assembly and maintenance only on an experimental level in most cases; for the authors, AR will surpass classic hardcopy construction manuals. In any case, AR is becoming workers' smart assistant and its adoptions improve both flexibility and cooperation with automated machines (Aehnelt et al., 2016).

To define Augmented Reality, Turner et al. (2016) start from Nieleblock et al.'s definition of mixed simulation (Nielebock et al., 2012), which is a combination of discrete event simulation and virtual reality. Mixed reality is a combination of computer graphics and physical environments and augmented reality is a concept that follows this continuum. The authors define it as "the process of overlaying animations and graphics on actual scenes in real time" (p.887). As for the previous technologies, Pontarollo (2016) includes augmented reality among Industry 4.0 pillars.

Table 2.5: Augmented Reality – Articles and Reviews (Author's elaboration)

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
Wolfartsberger, J., Obermair, F., Egger, S., Höller, M.	Assembly instruction 4.0: Augmented reality as compensation for the paper based construction manual [Augmented Reality als Ersatz für die Aufbauanleitung in Papierform: Möglichkeiten von augmented reality in der (selbst-)montage]	2017	Productivity Management	1	
Turner, C.J., Hutabarat, W., Oyekan, J., Tiwari, A.	Discrete Event Simulation and Virtual Reality Use in Industry: New Opportunities and Future Trends	2016	IEEE Transactions on Human-Machine Systems		1
Pontarollo, E.	«Industry 4.0»: A new approach to industrial policy [Industria 4.0: Un nuovo approccio alla politica industriale]	2016	Industria	1	
Aehnelt, M., Müller, A., Hauck, S.	Assembly assistance with smart and visual judgement [Montageassistenz mit Augenmaß: Intelligent und visuell!]	2016	Productivity Management	1	

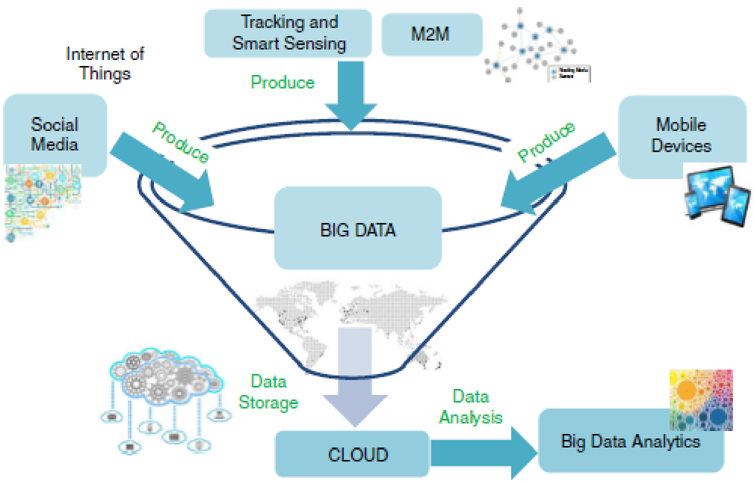
2.6 Big Data – Articles and Reviews

The literature on this topic was searched considering only the term "Big Data". Output consisted of 14 articles: 11 articles concerned the "Business, Administration and Accounting" field of research, the remaining 3 were social sciences articles.

Several authors write about Big Data when describing the fourth industrial revolution. Pontarollo (2016) deems Big Data as one of the main pillars on which Industry 4.0 is based. Moreover, Big Data is one of the common aspects of the European plans concerning Industry

4.0. He highlights how sensor proliferation is boosting the generation of data, which needs increasingly powerful computing capabilities and storage volumes to be dealt with. Nevertheless, Big Data has a large potential to improve efficiency and effectiveness. Also Frederick (2016) presents Big Data as one of the main elements of Industry 4.0. Kang et al. (2016) describe past, present and future trends of the "Smart manufacturing" concept. First, they point out too as Big Data, together with many other technologies, is one of the pillars of Industry 4.0 government plans in Germany, the United States and South Korea. Subsequently, they analyse the literature concerning smart manufacturing technologies from 2005-2009 to 2015. As for smart manufacturing, Big Data literature growth boosted starting from 2011. Big Data literature concerned processes and machines in more than 60% of the cases and the factory itself in almost 40% of the articles. Additionally, the authors point out that Big Data existed before the Industry 4.0 boom; for this reason, studies are related the most to the application of this concept on technologies of the past. So, Big Data was studied more with past technologies than in smart manufacturing contexts. Kumar et al. (2016) even broaden the idea behind smart manufacturing at the city level. In fact, thanks to Big Data analytics and distributed manufacturing in the supply chain, it is possible to apply the smart manufacturing concept to a whole city. The smart city idea is linked to other current phenomena, like digital manufacturing technologies, the pressure for sustainable sources of energy and processes, and the urbanization of people. Additionally, each transaction generates huge amounts of data (big data) that can be used also in this context to improve efficiency.

Figure 2.2: Combination of key enabling techniques – Cloud manufacturing environment (Mourtzis and Vlachou, 2016)



Several other articles discuss the exploitation of Big Data for various industrial settings. Mourtzis and Vlachou (2016) explore cloud computing evolution, advances, and future improvements. In their paper, they talk about the fact that cloud computing is becoming more and more important as mobile computing is advancing and sensors are proliferating, thus increasing the amount of data generated. They identify the enabling elements and challenges of a cloud manufacturing environment (in other words, of a cloud-based cyber physical system): big data support, real-time operations, configurability and agility, security, cyber-physical systems, social interactions and quality of service. Figure 2.2 summarizes the relationship between data sources, Big Data and cloud computing.

Cloud must be able to deal with huge datasets. Virtual limitless capabilities of cloud computing are one of characteristics that make cloud solutions attractive for any kind of company (Gilchrist, 2016). Park et al. (2017), instead, explore new approaches to perform quality management based on Big Data, Internet of Things, and Artificial Intelligence

A framework to exploit Big Data analytics for Internet-based intelligent manufacturing shop floors is proposed by Zhong et al. (2017). An intelligent manufacturing shop floor is a working environment which leverages on the Internet of Things and wireless network. It is usually characterized by a strong adoption of RFID sensors to endow the premises with intelligence. In other words, it is the working environment that is promoted by the Industrial Internet of Things, cyber-physical systems, smart factories, and so on. Following its description, an intelligent manufacturing shop floor seems to be one of the necessary (not sufficient) conditions for a company that aims at completely embracing the principles of Industry 4.0. In the proposed framework, the first step consists in defining a RFID data structure, since logistics in the shop floor are quite complex, because of the number of involved devices and logistic flows. In the described settings, RFID tags are applied to workers, machines, and objects; thus, the first phase is essential. Following, the transfer, visualization, and interpretation methods and protocols must be defined. In the third phase, since this huge amount of data has to be centrally managed, a Big Data warehouse is established. In the fourth phase, Big Data analytics comes into play as data needs to be cleaned, classified, compressed and algorithms for pattern excavation, standardization and expressions have to be performed. Finally, the results should help management in improving operations performances in terms of logistic plans and schedules. Some of these authors deal with Big Data analytics in RFID-enabled shop floors also in other papers, for example leveraging on RFID-cuboids (Zhong et al., 2015); a cuboid is a method to carry out data flow analysis that consists of three tables that store information about the product, about items that are together at a location and path information (Kwon et al., 2009).

Zheng and Wu (2017) exploit Big Data analytics to improve inventory management of consumable spare parts in a semiconductor fabrication plant, which has always been a challenge. Traditionally, this activity is characterized by “low hit rate, high on-hand inventory and intensive manpower requirement” (p.755). Furthermore, while time-based demand for spare parts is usually regular and not difficult to forecast, usage-based demand is more complex to forecast. The authors propose a method to produce spare parts "for the right machine, at the right time with the right quantity" (p.756) and they highlight the importance of the smart use of information. Improvements in both data collection and predictive analysis allow the exploitation of better information from machines, factories, and suppliers. The authors' method considers health condition, historical data of breakdowns, opportunity costs and part holding costs to compute the order priority of parts. With this framework, semiconductor fabs do not have to produce randomly spare parts and suppliers can be informed *ex-ante* so that they can plan their production.

Three articles obtained from the research are from "Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb", that was the source of many articles for the previous technologies. All these articles deal with big data as one of the main pillars of Industry 4.0 (Uhlmann et al., 2016; Berger et al., 2016; Eigner et al., 2015).

The last two articles concern social sciences. Lee et al. (2017) focus on data brokers' role, which is becoming increasingly important with the rise of Industry 4.0. Data brokers' activity consists in collecting and selling information that users may need for different purposes (like fraud prevention, credit risk assessment, and marketing activities). Given the growing interest towards data, the authors propose a data broker model that is based on data analysis which will be needed more by firms in the future. Turner et al. (2016) describe instead new opportunities and future trends of virtual reality and discrete events simulations (DES) in industrial settings. For these authors, virtual reality is becoming more important for firms, as stated before for augmented reality. In particular, for the authors "the need for decision making and support services" (p.882) that characterize the smart factory concept provides a role for both virtual reality and discrete event simulation. Virtual reality is different from augmented reality. The former "seeks to imbue users with a sense of presence in a synthetic environment generated by a computer system" (p.882), the latter enhances physical objects embedding them with additional information (Magone and Mazali, 2016). DES can be linked to real-time big data, and through virtual reality new graphical representations of datasets are possible.

Table 2.6: Big Data – Articles and Reviews (Author's elaboration)

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
Hyun Park, S., Seon Shin, W., Hyun Park, Y., Lee, Y.	Building a new culture for quality management in the era of the Fourth Industrial Revolution	2017	Total Quality Management and Business Excellence	1	

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
Zhong, R.Y., Xu, C., Chen, C., Huang, G.Q.	Big Data Analytics for Physical Internet-based intelligent manufacturing shop floors	2017	International Journal of Production Research	1	
Zheng, M., Wu, K.	Smart spare parts management systems in semiconductor manufacturing	2017	Industrial Management and Data Systems	1	
Lee, W., Jang, E., Lee, J.	Data-driven modeling and service based on big data analytics and perception process	2017	Journal of Cognitive Science		1
Berger, C., Huber, J., Klöber-Koch, J., Schreiber, M., Braunreuther, S., Richter, C., Reinhart, G.	OpenServ4P: Offene, intelligente Services für die Produktion	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Turner, C.J., Hutabarat, W., Oyekan, J., Tiwari, A.	Discrete Event Simulation and Virtual Reality Use in Industry: New Opportunities and Future Trends	2016	IEEE Transactions on Human-Machine Systems		1
Kumar, M., Graham, G., Hennelly, P., Srai, J.	How will smart city production systems transform supply chain design: a product-level investigation	2016	International Journal of Production Research	1	
Uhlmann, E., Laghmouchi, A., Ehrenpfordt, R., Hohwieler, E., Geisert, C.	Intelligentes Elektroniksystem für Condition Monitoring in Industrie 4.0: Mikro-elektromechanisches Elektroniksystem zur Zustands-, Verschleiß-,Prozess- und Anlagenüberwachung	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Mourtzis, D., Vlachou, E.	Cloud-based cyber-physical systems and quality of services	2016	TQM Journal	1	
Ellen Frederick, D.	Libraries, data and the fourth industrial revolution (Data Deluge Column)	2016	Library Hi Tech News		1
Pontarollo, E.	«Industry 4.0»: A new approach to industrial policy [Industria 4.0: Un nuovo approccio alla politica industriale]	2016	Industria	1	
Kang, H.S., Lee, J.Y., Choi, S., Kim, H., Park, J.H., Son, J.Y., Kim, B.H., Noh, S.D.	Smart manufacturing: Past research, present findings, and future directions	2016	International Journal of Precision Engineering and Manufacturing - Green Technology	1	
Eigner, M., Faißt, K.-G., Apostolov, H., Schäfer, P.	Short description and benefits of system lifecycle management in context of industrial internet including industry 4.0 and internet of thinks and services [Kurzer Begriff und Nutzen des System Lifecycle Management: Industrial Internet mit	2015	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
	Industrie 4.0 und Internet der Dinge und Dienste]				
Zhong, R.Y., Huang, G.Q., Lan, S., Dai, Q.Y., Chen, X., Zhang, T.	A big data approach for logistics trajectory discovery from RFID-enabled production data	2015	International Journal of Production Economics	1	

2.7 The Internet of Things – Articles and Reviews

The research was performed considering only the "Internet of Things" to include the technology in the query. Unlike previous queries, this one provided a significant number of articles and reviews. In total, 55 papers were found, of which 38 regarded business fields of research. As imagined, most of the articles concerned Internet of Things as Industry 4.0 driving factor, using it as synonym of industrial IoT to describe how the fourth industrial revolution is possible thanks to the application of smart devices on manufacturing shop floors. Nevertheless, including "Internet of Things" instead of "Industrial Internet" (to include articles concerning either IoT or IIoT at the same time) in the previous queries would have brought more dispersive results, as the Internet of Things is a concept that exists outside Industry 4.0 and has been talked about for years before the recent industrial revolution. The following analysis focuses mainly on business articles and reviews.

Many authors recognize the importance of the Internet of Things for Industry 4.0. Mülder (2016) uses the term "Internet of Things" as a synonym of Industry 4.0 even in the title of his paper ("The discussion about industry 4.0 - or internet of things - is focused on technological innovations"), as well as Sauer (2017). Lörz (2017) considers "Internet of Things", "Industry 4.0", and "digitalization" as different related terms. What is certain is that this new industrial revolution is possible only because IoT and all the related technologies (like sensors, actuators, RFID, etc.) are entering factories (Peßl et al., 2014). Moreover, IoT is always included among the range of technologies used to describe Industry 4.0 (Sommer, 2015) and is usually recognized as the first and most important pillar of the phenomenon, like for Pontarollo (2016) and Sailer et al. (2015). Its impact is often one of the starting points to understand Industry 4.0 benefits and develop innovative business models, as in Gronau's (2016) and Jondral's (2016) papers.

It can be immediately noticed that German articles regarding Internet of Things application in Industry 4.0 settings have been proliferating. Besides the already cited authors, Eigner et al.

(2015) recall the Internet of Things to discuss challenges that engineering needs to overcome considering Industry 4.0-driven changes; Eigner et al. (2016) study these trends and the opportunities they bring, as well as Axmann (2016). Internet of things is cited also by Rübenach (2016), who studies Industry 4.0 challenges. Roy, Mittag, and Baumeister (2015) cite IoT to study how the five principles of lean manufacturing are influenced by the fourth industrial revolution. Moreover, Müller et al. (2016) include Internet of Things improvements to describe innovations that enable the reduction of throughput losses due to robotics in automated flow lines. Noennig et al.'s (2016) paper concerns the Internet of Things from the point of view of smart devices, as described before: they propose an algorithm that permits to infuse objects with "smartness" and to connect them to a cyber-physical system.

Most of the retrieved articles concern IoT applications in manufacturing shop floors and industrial contexts. In fact, for some authors Internet of Things is defined as "embedding sensors and communication equipment in manufacturing machineries and lines" (Kang et al., 2016, p.3). IoT, cyber-physical systems, and cloud manufacturing are all driven by smart sensors at the hardware level. The actual Industrial Internet of Things started with the adoption of Ethernet connection and Internet protocol on manufacturing shop floors to connect Information and Operational Technologies (Neubert, 2016). IIoT should permit companies to excel in asset-performance management, augmented operators and smart enterprise control. As stated in The Economist (2016), the Industrial Internet is not GE's exclusive anymore for a few years now; its proliferation its continuously being studied by experts (Basl, 2017). IIoT advantages in operations are currently being explored by researchers, in particular when combined with Big Data analytics (Zhong et al., 2017). IIoT has the potential to significantly improve logistics management; for example, Qu et al. (2017) design an IoT cost-effective solution to manage logistics which leverages on real-time information collection and analysis. Bogataj et al. (2017) propose the exploitation of IIoT technologies to reduce post-harvest losses in a supply chain of fresh fruit and vegetables: in their paper they suggest, for example, to adopt sensors to gather data concerning decay acceleration factors in order to improve decision-making and, maybe, save as much of the cargo as possible. Zheng and Wu (2017) propose a solution based on the Internet of Things and Big Data analytics to improve spare parts management in the supply chain. Kumar et al. (2016) suggest an IoT-based framework to exploit synergies between digital manufacturing technologies in a smart city production system. IoT (and RFID) can be used to improve efficiency significantly and to automate transactions in an ERP System (Majeed and Rupasinghe, 2017). The technology, together with Big Data analytics and cyber-physical systems, can be exploited to develop cloud-based cyber-physical systems; such framework should permit to overcome new challenges and trends (Mourtzis and

Vlachou, 2016). As for RFID sensors, Gładysz (2015) designed a framework for decisions concerning their installation in manufacturing plants. These articles show how the IoT adoption in manufacturing settings can occur in different ways to enhance several aspects of a firms' performances.

The remaining several articles in this research area concerned other applications of the IoT technologies in Industrial Settings (Park et al., 2017; Hwang et al., 2017; Beier et al., 2017; Venables, 2016a and 2016b; Wuest and Nana, 2016; Sanders et al., 2016).

The Internet of Things that will be studied through the interviews of the next chapter is mostly the one that concerns smart-connected products (Neubert, 2016). Lee and Lee's (2015) paper contains a detailed description of the Internet of Things, without focusing only on its industrial applications. As a matter of fact, the authors discuss the opportunities and challenges that smart devices and products bring to companies. Two important examples of IoT applications are Disney's MagicBand and Kroger's new IoT-based system. The former consists in a wristband that visitors of Disney's entertainment parks wear to simplify and accelerate access to attractions, the latter is instead a retail platform that enhances customer experience by leading clients toward the products they desire to buy. First, the authors identify the IoT enabling technologies, already listed before as this article was found when looking for cloud computing literature. Then, they also identify IoT main applications:

- *Monitoring and control*, as smart devices collect information regarding equipment performance, energy usage.
- *Big Data and analytics*. With IoT, data collected increases exponentially; this fact is one of the main reasons of its exploitation in industrial settings. Nevertheless, having huge amount of data is not sufficient, it must be converted into strategic and tactical intelligence. As a matter of fact, querying methods are still being studied to overcome this issue (Polyvyanyy et al., 2017).
- *Information sharing and collaboration*, "between people, people and things, and between things" (I. Lee and Lee, 2015, p.434).

The diffusion of the IoT will strongly depend on the development of 5G networks, which allow devices to communicate at an even higher speed (J. Chang, 2015).

As for Social Sciences articles, they are concerned with different aspects of the Internet of Things. One article concerns smart and connected product. This paper suggests that to successfully implement IoT components in a firm's portfolio it is important to understand the role of these parts. Gerpott and May (2016) identify three different roles for IoT components in a product portfolio. These roles are:

- *Smoothing*, when IoT components are added to reduce transaction costs.
- *Adaption*, when IoT components increase value and add functionalities to the good in which they are installed but they are not the core value driver.
- *Innovation*. In this case, IoT components are the main value drivers and firms can launch products with features that were not available in the past.

For Gerpott and May (2016), achieving business objectives through the installation of IoT components in the product portfolio partly depends on the fit between role and targets.

Lin, Sun, and Qu (2015) and Alcaide et al. (2013) focus on privacy. Starting from the fact that currently more and more devices are being connected to the Internet and sensors are installed in an increasingly larger variety of goods (like houses), they recognize the need for anonymous authentication protocols in order to preserve privacy while using these devices. Other researchers, like de Brjiin and Jansen (2017), Ashibani and Mahmoud (2017) and Ransbotham et al. (2016) focus instead on cybersecurity, that is as important as privacy for huge datasets. Kukka et al. (2015), and Salim and Haque (2015) propose in-depth analyses of urban computing, that is ubiquitous computing applied to urban areas. Urban computing, a concept related to "smart cities", is possible thanks to the Internet of Things. Cyber-physical systems are not limited to domestic and industrial applications but can connect whole cities and, idealistically, whole countries. Other studies regard IoT applications to enhance occupational safety and health (Podgórski et al., 2017), to improve luggage tracking (Wong and Wong, 2017) and to create scheduling function mechanism in 6TiSCH networks (Duy et al., 2017). Other social sciences papers concern different aspects of Industry 4.0. While Belov (2016), Roblek et al. (2016) provide a general view of Industry 4.0, others analyse other matters related to Industry 4.0 like product design (Gerlitz, 2015), innovation policy (K. C. Lin et al., 2017) and e-learning (Wanyama, 2017; Cho and Kim, 2016).

Table 2.7: Internet of Things – Articles and Reviews (Author's elaboration)

Authors	**Title**	**Year**	**Source title**	**Business, management, accounting**	**Social Sciences**
Bogataj, D., Bogataj, M., Hudoklin, D.	Mitigating risks of perishable products in the cyber-physical systems based on the extended MRP model	2017	International Journal of Production Economics	1	
Duy, T.P., Dinh, T., Kim, Y.	Distributed cell selection for scheduling function in 6TiSCH networks	2017	Computer Standards and Interfaces		1

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
Polyvyanyy, A., Ouyang, C., Barros, A., van der Aalst, W.M.P.	Process querying: Enabling business intelligence through query-based process analytics	2017	Decision Support Systems	1	
Hyun Park, S., Seon Shin, W., Hyun Park, Y., Lee, Y.	Building a new culture for quality management in the era of the Fourth Industrial Revolution	2017	Total Quality Management and Business Excellence	1	
Ashibani, Y., Mahmoud, Q.H.	Cyber physical systems security: Analysis, challenges and solutions	2017	Computers and Security		1
Basl, J.	Pilot Study of Readiness of Czech Companies to Implement the Principles of Industry 4.0	2017	Management and Production Engineering Review	1	
Qu, T., Thürer, M., Wang, J., Wang, Z., Fu, H., Li, C., Huang, G.Q.	System dynamics analysis for an Internet-of-Things-enabled production logistics system	2017	International Journal of Production Research	1	
Hwang, G., Lee, J., Park, J., Chang, T.-W.	Developing performance measurement system for Internet of Things and smart factory environment	2017	International Journal of Production Research	1	
Zhong, R.Y., Xu, C., Chen, C., Huang, G.Q.	Big Data Analytics for Physical Internet-based intelligent manufacturing shop floors	2017	International Journal of Production Research	1	
Beier, G., Niehoff, S., Ziems, T., Xue, B.	Sustainability aspects of a digitalized industry – A comparative study from China and Germany	2017	International Journal of Precision Engineering and Manufacturing - Green Technology	1	
Podgórski, D., Majchrzycka, K., Dąbrowska, A., Gralewicz, G., Okrasa, M.	Towards a conceptual framework of OSH risk management in smart working environments based on smart PPE, ambient intelligence and the Internet of Things technologies	2017	International Journal of Occupational Safety and Ergonomics		1
Lörz, H.	Project platform for collaboration 4.0 [Projektplattform für die zusammenarbeit 4.0]	2017	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Sauer, O.	PLUGandWORK-Upgrade legacy systems for the industrial internet of things [PLUGandWORK-Maschinen und Komponenten für Industrie 4.0 befähigen]	2017	Productivity Management	1	
Zheng, M., Wu, K.	Smart spare parts management systems in semiconductor manufacturing	2017	Industrial Management and Data Systems	1	
Wong, E.Y.C., Wong, W.H.	The development of reusable luggage tag with the internet of things for mobile tracking and environmental sustainability	2017	Sustainability (Switzerland)		1

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
Lin, K.C., Shyu, J.Z., Ding, K.	A cross-strait comparison of innovation policy under industry 4.0 and sustainability development transition	2017	Sustainability (Switzerland)		1
Majeed, M.A.A., Rupasinghe, T.D.	Internet of things (IoT) embedded future supply chains for industry 4.0: An assessment from an ERP-based fashion apparel and footwear industry	2017	International Journal of Supply Chain Management	1	
Wanyama, T.	Using industry 4.0 technologies to support teaching and learning	2017	International Journal of Engineering Education		1
de Bruijn, H., Janssen, M.	Building Cybersecurity Awareness: The need for evidence-based framing strategies	2017	Government Information Quarterly		1
Kumar, M., Graham, G., Hennelly, P., Srai, J.	How will smart city production systems transform supply chain design: a product-level investigation	2016	International Journal of Production Research	1	
Cho, S.P., Kim, J.-G.	E-learning based on internet of things	2016	Advanced Science Letters		1
Venables, M.	No network is an island	2016	Plant Engineer	1	
Mourtzis, D., Vlachou, E.	Cloud-based cyber-physical systems and quality of services	2016	TQM Journal	1	
[No author name available]	The industrial internet of things: The great convergence	2016	Economist (United Kingdom)	1	
Pontarollo, E.	«Industry 4.0»: A new approach to industrial policy [Industria 4.0: Un nuovo approccio alla politica industriale]	2016	Industria	1	
Mülder, W.	The discussion about industry 4.0 (or internet of things) is focussed on technological innovations [Arbeitswelt 4.0 Rolle der Arbeitnehmer in einer hochtechnisierten Industrie]	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Roblek, V., Meško, M., Krapež, A.	A Complex View of Industry 4.0	2016	SAGE Open		1
Rübenach, I.M.	Industry 4.0 - the unsolved revolution security as a challenge for the world of industry 4.0 [Industrie 4.0 - die ungeklärte revolution: Sicherheit als herausforderung für eine industrie 4.0-welt]	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Gerpott, T.J., May, S.	Integration of Internet of Things components into a firm's offering portfolio – a business development framework	2016	Info		1
Neubert, R.	Powering the industrial Internet of things	2016	Plant Engineering	1	

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
[No author name available]	Are we there yet?: Technologies such as the Industrial internet of Things, smart manufacturing and Industry 4.0 digitisation are supposed to be ushering in a new age of innovation. Do they justify the hype? Mark venables investigates	2016	Plant Engineer	1	
Axmann, B.	Digital factory - industry 4.0 (motivation, challenges and solutions) [Digitalisierung der fabrik - industrie 4.0: Motivation, herausforderungen und lösungen]	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Jondral, F.K.	Industrie 4.0 - funk in der fabrik	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Eigner, M., Muggeo, C., Apostolov, H., Schäfer, P.	Kern des system lifecycle management: Im kontext von industrial internet mit industrie 4.0 und internet der dinge und dienste	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Noennig, J.R., Schmiedgen, P., Gäbler, U., Do, M.H.	From smart objects to smart systems: Design guide for the internet of things [Von smart objects zum smart system: Ein design-prozess für das kluge internet der dinge]	2016	Productivity Management	1	
Belov, V.B.	New paradigm of industrial development of Germany - Strategy "industry 4.0"	2016	Sovremennaya Evropa		1
Gronau, N.	Identification of industry 4.0 potentials in factory [Identifikation von potenzialen durch industrie 4.0 in der fabrik]	2016	Productivity Management	1	
Kang, H.S., Lee, J.Y., Choi, S., Kim, H., Park, J.H., Son, J.Y., Kim, B.H., Noh, S.D.	Smart manufacturing: Past research, present findings, and future directions	2016	International Journal of Precision Engineering and Manufacturing - Green Technology	1	
Müller, C., Grunewald, M., Spieckermann, S., Spengler, T.S.	Contribution of smart industry to the robust design of automated flow lines [Potenziale für die robuste Konfiguration automatisierter Fließproduktionssysteme]	2016	Productivity Management	1	
Ransbotham, S., Fichman, R.G., Gopal, R., Gupta, A.	Special section introduction: Ubiquitous IT and digital vulnerabilities	2016	Information Systems Research		1
Wuest, T., Nana, U.M.N.	State-based representation of a product's middle of life	2016	International Journal of Product Lifecycle Management	1	

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
Sanders, A., Elangeswaran, C., Wulfsberg, J.	Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing	2016	Journal of Industrial Engineering and Management	1	
Gładysz, B.	An assessment of RFID applications in manufacturing companies	2015	Management and Production Engineering Review	1	
Sailer, E., Wrehde, J., Vierfuß, R.	Value system plus industry 4.0 - evolution through a smart factory [Wertschöpfungssystem plus Industrie 4.0: Durch Evolution zur Smart Factory]	2015	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Salim, F., Haque, U.	Urban computing in the wild: A survey on large scale participation and citizen engagement with ubiquitous computing, cyber physical systems, and Internet of Things	2015	International Journal of Human Computer Studies		1
Eigner, M., Faißt, K.-G., Apostolov, H., Schäfer, P.	Short description and benefits of system lifecycle management in context of industrial internet including industry 4.0 and internet of thinks and services [Kurzer Begriff und Nutzen des System Lifecycle Management: Industrial Internet mit Industrie 4.0 und Internet der Dinge und Dienste]	2015	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Lin, X.-J., Sun, L., Qu, H.	Insecurity of an anonymous authentication for privacy-preserving IoT target-driven applications	2015	Computers and Security		1
Chang, J.	Smart data, 5G critical to enable the Industrial Internet of Things	2015	Plant Engineering	1	
Roy, D., Mittag, P., Baumeister, M.	Industrie 4.0 – Einfluss der Digitalisierung auf die fünf Lean-Prinzipien Schlank vs. Intelligent [Industrie 4.0 – impact of digitalization on the five lean principles]	2015	Productivity Management	1	
Kukka, H., Foth, M., Dey, A.K.	Transdisciplinary approaches to urban computing	2015	International Journal of Human Computer Studies		1
Lee, I., Lee, K.	The Internet of Things (IoT): Applications, investments, and challenges for enterprises	2015	Business Horizons	1	
Gerlitz, L.	Design for product and service innovation in industry 4.0 and emerging smart society	2015	Journal of Security and Sustainability Issues		1
Sommer, L.	Industrial revolution - Industry 4.0: Are German manufacturing SMEs the first victims of this revolution?	2015	Journal of Industrial Engineering and Management	1	

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
Peßl, E., Ortner, W., Schweiger, J.	Industry 4.0: Information technology fuses with production [Industrie 4.0: Informationstechnologie verschmilzt mit produktion]	2014	Productivity Management	1	
Alcaide, A., Palomar, E., Montero-Castillo, J., Ribagorda, A.	Anonymous authentication for privacy-preserving IoT target-driven applications	2013	Computers and Security		1

2.8 Cloud Computing – Articles and Reviews

"Cloud" is the only term that was input to search for literature regarding cloud computing (together with the ones concerning Industry 4.0). The term alone should permit to obtain articles concerning cloud computing, cloud storage, cloud analytics, cloud cyber-physical systems, and so on. In total, 10 articles were obtained: 9 for "Business, Administration and Accounting" and 1 for "Social Sciences"; there are not so many articles concerning both cloud and Industry 4.0 in the selected areas. The situation drastically changes if, instead of "Industrial Internet" the term "Internet of Things" is input in the process: in this case, 82 articles and reviews can be collected up to 31 August 2017. Nevertheless, the articles retrieved following the first process will be now described as they are related more to Industry 4.0.

As already noticed in the previous literature analyses, several articles are written in German. As the others, they are all from ZWF. Vick and Krüger (2016) present cloud-based production benefits in Industry 4.0 settings and necessary prerequisites to implement such system. Binner (2016a) points out how the integration of different IT tools is a challenge for both responsible managers and IT service itself. Integration of cloud-based services and traditional IT permits to achieve several advantages inside organizations. The same author proposed an organizational model, called "Organization 4.0", to achieve the digitalization, virtualization, automatization, and networking that smart factories want (Binner, 2016b). Eigner et al. (2015) include cloud computing among the most important aspects of Industry 4.0 while Röschinger et al. (2015) discuss the importance of automatic identification of objects for flexibility and efficiency in Industry 4.0 environment and uses for example a cloud-based management system for machining tools.

Among the results, Mourtzis and Vlachou's paper stood out. It was already introduced before as it deals also with Big Data. In their article, the authors not only discuss the evolution and future trend of cloud computing but they also show the results of a detailed literature review of the concept that they performed. First, in their research they noticed that in the literature cloud computing was applied in three distinct fields. These fields are: product development, process optimization, and manufacturing systems management. As for product development, cloud computing can be used to improve collaboration and coordination as it allows several designers to work simultaneously on the same project wherever they are and whenever they want. Processes can be optimized as cloud solutions permit to execute manufacturing tasks in scattered manufacturing resources and to improve efficiency and sustainability. Cloud computing affects also manufacturing systems management: as the authors report, cloud solutions increase productivity and quality and reduce time-to-market (Mourtzis and Vlachou, 2016). Finally, the authors introduce a conceptual framework for cloud computing, whose enabling elements have already been described.

Cloud computing is one of the essential IoT technologies for Lee and Lee (2015), together with radio frequency identification (RFID), wireless sensor networks (WSN), middleware (that is a software layer between applications to facilitate communication and input/output operations for developers), and IoT application software to actually exploit these sensors and networks. For Pontarollo (2016) cloud computing is one of the Industry 4.0 pillars as well as for Frederick (2016).

Ivanov and Sokolov's (2012) paper is aimed at identifying the different modeling methods for supply chains from literature, justifying the necessity of new more dynamic modeling methods and to delineate the challenges that must be overcome in the future. The need to develop these new modeling methods is due to the presence of different structures that must be integrated, like supply batches, enterprise interests, and cloud services.

Table 2.8: Cloud Computing – Articles and Reviews (Author's elaboration)

Authors	**Title**	**Year**	**Source title**	**Business, management, accounting**	**Social Sciences**
Vick, A., Krüger, J.	Cloud and service-based production platforms [Cloud- und dienstebasierte Produktionsplattformen]	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Mourtzis, D., Vlachou, E.	Cloud-based cyber-physical systems and quality of services	2016	TQM Journal	1	
Ellen Frederick, D.	Libraries, data and the fourth industrial revolution (Data Deluge Column)	2016	Library Hi Tech News		1
Pontarollo, E.	«Industry 4.0»: A new approach to industrial policy [Industria 4.0: Un nuovo approccio alla politica industriale]	2016	Industria	1	
Binner, H.F.	Digitale revolution - erfolgreiche umsetzung über organisation 4.0	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	

Binner, H.F.	Paradigmenwechsel in der organisationsentwicklung: Voraussetzung für eine prozessorientierte wertekultur	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Eigner, M., Faißt, K.-G., Apostolov, H., Schäfer, P.	Short description and benefits of system lifecycle management in context of industrial internet including industry 4.0 and internet of thinks and services [Kurzer Begriff und Nutzen des System Lifecycle Management: Industrial Internet mit Industrie 4.0 und Internet der Dinge und Dienste]	2015	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Röschinger, M., Kipouridis, O., Lechner, J., Günthner, W.A.	AutoID-concept for a cloud-based tool management - digitalization and automation of the tool management in the context of industry 4.0. [Autoid-konzept für ein cloud-basiertes werkzeugmanagement: Digitalisierung und automatisierung des werkzeugmanagements für die industrie 4.0]	2015	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
Lee, I., Lee, K.	The Internet of Things (IoT): Applications, investments, and challenges for enterprises	2015	Business Horizons	1	
Ivanov, D., Sokolov, B.	The inter-disciplinary modelling of supply chains in the context of collaborative multi-structural cyber-physical networks	2012	Journal of Manufacturing Technology Management	1	

2.9 Cybersecurity – Articles and Reviews

This research was performed considering the following terms: “cybersecurity” (and also “cyber-security” to consider different wordings of the term), “cyberattack”, “Cyberwarfare” and “Hack” as prefix. Eight articles were found, of which three tagged as “Business, Administration and Accounting” ones.

With companies’ digitization, cybersecurity is likely to grow in importance every day. As a matter of fact, cybersecurity is one of the most important elements Industry 4.0 companies should be concerned with (Pontarollo, 2016). Laso et al. (2017) propose some datasets that companies can exploit to test fault-detection algorithms and have a wider understanding of cyber-physical systems breaches. Taormina et al. (2017) describe a modeling framework concerning possible cyberattacks that a water distribution system may have to withstand. Since cyber-physical system applications are proliferating and cyberattacks could have catastrophic consequences on critical infrastructures, the authors want to provide a framework to understand possible risks. Cyber-physical systems exposure to cyber-attacks is confirmed also by Pollmann

(2017). Cybersecurity concerns not only smart factories but also smart cities and their application (Jin et al., 2016).

De Bruijn and Janssen (2017) believe that cybersecurity is one of the most important challenges for current governments. People depend on the cyberspace and critical cyber-attacks already occurred: one of the most important examples is Stuxnet, which is a virus created to harm an Iranian nuclear infrastructure. This issue is not easy to be dealt with. Governments are haunted by several paradoxes: for example, governments want that companies and individuals protect themselves from cyberthreats and, at the same time, they do not want that they protect with encryption and want backdoors to detect criminal acts and terrorism. Additionally, they would like to cooperate with other countries, but they know of the possibility that they might be already hacking each other; and so on. Nguyen (2013) emphasizes the concept talking about cyber warfare. For him, Governments should specify how to classify a cyber-attack as an “act of war” thus enabling counterattacks.

Ashibani and Mahmoud (2017) thoroughly analyse how cyber-physical systems are particularly exposed to cyberattacks. First, traditional IT security objectives are necessary but not sufficient to design secure cyber-physical systems. “Authenticity” has to be added to confidentiality, integrity, and availability, that are the traditional IT objectives. As the authors explain, without procedures aimed at granting confidentiality, secret data may be retrieved by unwanted parties, integrity mechanisms avoid deception through false data, and availability assures that the system is always accessible. Nevertheless, authenticity is needed: it assures that all communications and transactions occur between authorized parties. In fact, another difference in terms of security between traditional IT systems and CPS is that the former focuses on “addressing security for system components” while the latter is more concerned with interactions. The main challenges in designing a secure cyber-physical system are:

- *Securing access to devices,* in order to grant authentication throughout the whole system;
- *Securing data transmission,* in order to block and immediately identify any malicious activity aimed at retrieving data;
- *Securing data storage*, even at the sensors level. Even if “smart”, sensors are not endowed with strong computing and storage capabilities and data encryption is not sufficient.
- *Securing actuation*, as no actuation action must be started from sources that are not authorized.

Cyber-physical systems must be thoroughly protected, in each one of their layers. Attacks may occur on the perception layer (composed of sensors and actuators), on the transmission layer (wi-fi, Bluetooth, and the Internet, for example), and on the application level (the smart factory itself).

Table 2.9: Cybersecurity – Articles and Reviews (Author's elaboration)

Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
Laso, P.M., Brosset, D., Puentes, J.	Dataset of anomalies and malicious acts in a cyber-physical subsystem	2017	Data in Brief		1
Ashibani, Y., Mahmoud, Q.H.	Cyber physical systems security: Analysis, challenges and solutions	2017	Computers and Security		1
Taormina, R., Galelli, S., Tippenhauer, N.O., Salomons, E., Ostfeld, A.	Characterizing cyber-physical attacks on water distribution systems	2017	Journal of Water Resources Planning and Management		1
Pollmann, M.	Secure production within the iiot - hardware-based security solutions protect data and systems [Sichere produktion im IIoT hardware-basierte sicherheitslösungen schützen daten und systeme]	2017	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	
de Bruijn, H., Janssen, M.	Building Cybersecurity Awareness: The need for evidence-based framing strategies	2017	Government Information Quarterly		1
Jin, D., Hannon, C., Li, Z., Cortes, P., Ramaraju, S., Burgess, P., Buch, N., Shahidehpour, M.	Smart street lighting system: A platform for innovative smart city applications and a new frontier for cyber-security	2016	Electricity Journal	1	1
Pontarollo, E.	«Industry 4.0»: A new approach to industrial policy [Industria 4.0: Un nuovo approccio alla politica industriale]	2016	Industria	1	
Nguyen, R.	Navigating jus ad bellum in the age of cyber warfare	2013	California Law Review		1

2.10 Machine Learning – Articles and Reviews

"Machine Learning" was the input in the first part of the query (see Appendix A). In this case, the research did not provide many articles. As a matter of fact, only one article was found. In this article, machine learning is identified as one of the ways through which automation will be improved in the future (Jodlbauer et al., 2016).

Table 2.10: Machine Learning – Articles and Reviews (Author's elaboration)

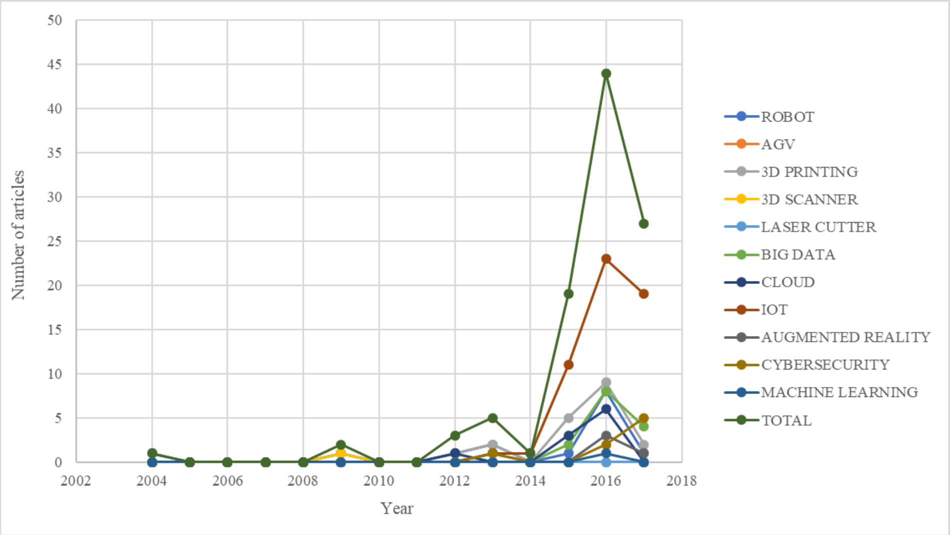
Authors	Title	Year	Source title	Business, management, accounting	Social Sciences
Jodlbauer, H., Schagerl, M., Brunner, M.	Industrie 4.0 versus automation [Industrie 4.0 versus automatisierung]	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	1	

2.11 Final Considerations

Most articles concerned technical aspects of technologies rather than their impact on performances and internal organization. Moreover, articles that are truly more "management-oriented", take into account the whole smart factory rather than the individual technology. Moreover, there were some articles that concern internal changes due to Industry 4.0, but no one studied whether Industry 4.0 technologies affect actual financial performances.

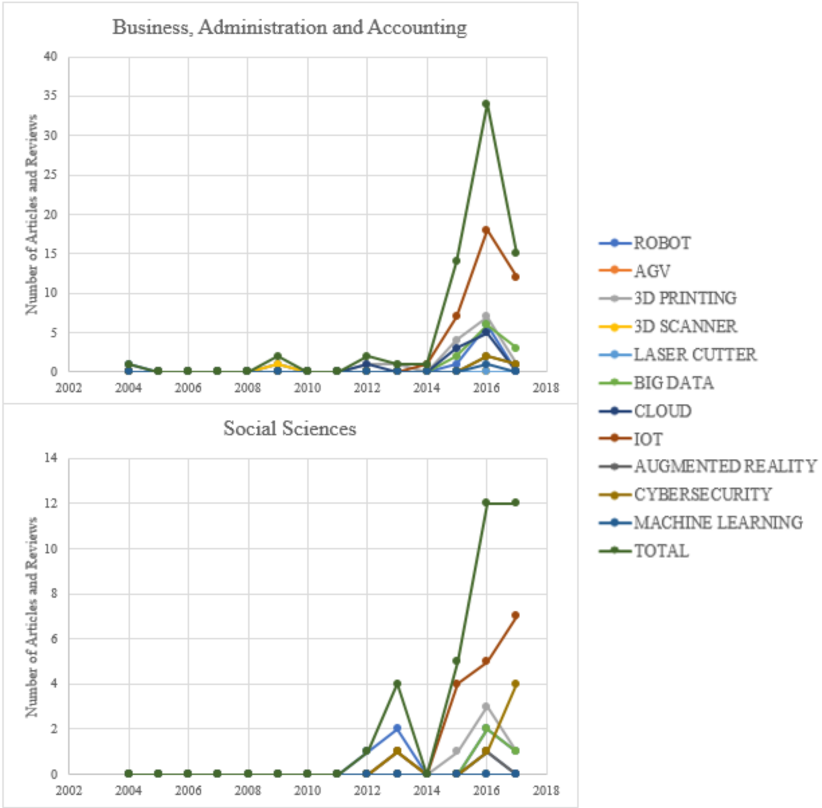
Nevertheless, as it is possible to observe in Figure 2.3, articles and reviews concerning both technologies and Industry 4.0 have been growing continuously, except in 2014. After 2014, articles boomed, reaching a peak in 2016. In total, 102 articles were found. Probably, if articles production continues as it is, 2017 will be characterized by even more papers than 2016. As expected, most articles concerned the Internet of Things, even if few of them regarded smart connected products.

Figure 2.3: Retrieved articles per technology (Author's elaboration)



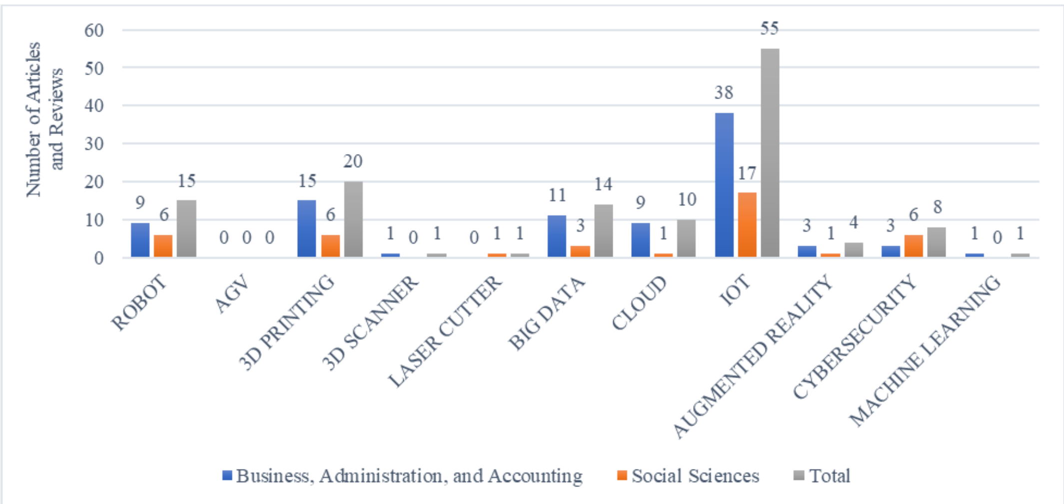
The trend is pretty much similar for both research fields: business, administration, and accounting and social sciences. In the graphs below, it can be observed how most articles belong to the former field. In both fields Internet of Things was the subject with the highest number of articles. The total is not obtained by summing the two sets of articles because some papers were interdisciplinary and belonged to both areas.

Figure 2.4: Retrieved articles per field of research (Author's elaboration)



Figures 2.4 and 2.5 summarizes the number of articles that were retrieved for each technology and area. Articles concerning more management-related aspects will be published, as Industry 4.0 is still at an initial phase of its proliferation.

Figure 2.5: Total articles per field of research (Author's elaboration)



Certainly, the research could have been performed in different ways. For example, since the term "Internet of Things" is often used to replace the term "Industrial Internet", it could have been included in each query for SCOPUS. The output would have been equal or greater. Nevertheless, even if it would have permitted to retrieve a higher number of articles, many would not have regarded Industry 4.0 as the technology has existed for several years; as a matter of fact, Ashton (2009) used the term for the first time in 1999 in a presentation in Procter and Gamble. Moreover, the research for IoT as Industry 4.0 technology, would have been more complex as the term would have been included in both the "technology part" and the "Industry 4.0 part" of the query. Results obtained with this method would not have been coherent with the others. The same could go for "digital manufacturing" which, instead, was included in the research. Even if it consists in a "wide range of engineering and planning tools, software, and information and communication technologies to integrate new technologies into manufacturing processes as quickly and efficiently as possible" (Westkämper, 2007, p.9), digital manufacturing traditionally regards 3D printing, (Gibson et al., 2015) Big Data, IoT and simulation software (Magone and Mazali, 2016). Nevertheless, nowadays this integration between software and hardware is much broader and the term can be used as an Industry 4.0 synonym (Möller, 2016). Traditional interpretations of the term were still considered in the previous analysis.

Future analyses may try to adopt additional or different terms in their queries. Nevertheless, the research performed a first overview about management trends in articles and reviews up to 31 August 2017.

3 DIGITAL MANUFACTURING TECHNOLOGIES AND INDUSTRY 4.0: ANALYSIS OF A SURVEY

In this chapter, the results from a survey collected by a research team composed by several professors, Phd students, and graduate students will be presented and described. The survey was created as part of an SID (which stands for "departmental") project of the Department of Economics and Management "M. Fanno" of the University of Padova. The SID project is entitled "Manufacturing activities and value creation: redesigning firm's competitiveness through digital manufacturing in a circular economy framework". The survey was aimed at studying the rate of adoption of Industry 4.0 technologies and their benefits and issues inside companies.

The survey and the list of firms to be contacted were selected in April 2017. Currently, the SID project is still continuing to collect answers from firms operating in other additional sectors, that were added in July and October 2017. The final database, called "database_4ir", was used not only to propose a first analysis about the level of adoption of Northern Italy manufacturing companies, but also to perform empirical studies about the effect that Industry 4.0 technologies have on financial performance. The information about the adoption of selected technologies allowed to distinguish businesses that are moving towards Industry 4.0 from the ones that have not adopted these tools yet.

In the next sections, the survey that was proposed to interviewees will be presented. Then, the process adopted to "clean" the database will be described and, finally, results of the descriptive analysis of the database are discussed.

3.1 Universe Creation

Sectors were selected using their ATECO Code, which is used by the Italian National Statistical Institute (ISTAT)[21] and other European Institutions[22] to classify firms according to their activity. For this analysis only manufacturing firms were selected. The selected sectors are summarized in the following table.

Table 3.1: SID Projet: Digital Manufacturing – Sectors and timeline (Author's elaboration)

Description	ATECO	Collection of Data – period
Manufacture of textiles	13	17 July – 30 October 2017
Manufacture of wearing apparel	14	17 July – 30 October 2017

[21] https://www.istat.it/it/strumenti/definizioni-e-classificazioni/ateco-2007 accessed on 14 October 2017

[22] Statistical Classification of Economic Activities in the European Community, Rev. 2 (2008). Information retrieved from RAMON - Reference And Management Of Nomenclatures (accessed on 14 October 2017)

Description	ATECO	Collection of Data – period
Manufacture of leather and related products	15	10 October – Work in progress
Manufacture of rubber and plastic products	22	3 May – 15 September 2017
Manufacture of electrical goods	27.0, 27.1, 27.3, 27.5, 27.9[23]	3 May – 15 September 2017
Manufacture of motor vehicles, trailers and semi-trailers	29	3 May – 15 September 2017
Manufacture of furniture	31	3 May – 15 September 2017
Manufacture of ophthalmic goods, eyeglasses, sunglasses, lenses ground to prescription, contact lenses, safety goggles	32.505	3 May – 15 September 2017
Manufacture of jewellery, bijouterie and related articles	32.121, 32.122, 32.130	3 May – 15 September 2017
Manufacture of sports goods	32.3, 32.9	3 May – 15 September 2017

The retrieval of information about firms that had to be contacted was performed through AIDA ("Analisi Informatizzata delle Aziende Italiane"), a database which stores information about Italian Limited Companies. It does not only store biographical data, but also financial results and data like financial statement (balance sheet and profit and loss statement), most important indexes (like Return on Equity, Return on Sales, Return on Assets, etc.), information about firms' size (number of workers, turnover), etc.

At first, for the selected sectors, only firms with a turnover greater than 1 million euro were selected (for this selection, the information at the end of 2015 was considered). Then, considering cluster size for businesses that manufacture glasses, jewellery, sport goods, and electric lighting equipment it was decided to deepen the analysis concerning these sectors, so the whole universe was considered (in other words, also businesses with a turnover lower than 1 million euro were kept).

As for location, it was decided to search only firms located in Northern Italy. So, the considered regions were: Piedmont, Lombardy, Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, and Emilia Romagna. In total, 5421 companies were selected (see Tables 3.2 – 3.3 and Figure 3.1). It was not possible to contact every firm, because sometimes contact information was missing and/or the company did not exist anymore (in most cases).

[23] This ATECO Code was not considered since the beginning, but was added to the category "Manufacture of electrical motors, batteries, wires, and other equipment" after having analyzed the results.

Table 3.2: Universe assigned to students (SID Project's elaboration)

Ateco	Totale impresе AIDA	Universe <= 1 M €	Universe > 1M €	Universe assigned to students
22 Manufacture of gum and plastic goods	3,832	1,274	2,558	
22-22.1 Manufacture of gum		*184*	413	413
22.2 Manufacture of plastic goods		*1,090*	*2,145*	
27. Manufacture of Electric Equipment	3,641	1,609	2,032	
27.0-27.5 (not 27.4) Electric motors, batteries, wires		*850*	*1,117*	1,117
27.4 Manufacture of electric lighting equipment		*253*	*230*	483
27.9 Manufacture of other electric equipment		*506*	*685*	
29 Manufacture of vehicles and trailers	1,086	384	702	702
31 Manufacture of furniture	3,041	1,414	1,627	1,627
32.1 Manufacture of jewellery	683	377	306	683
32.3-32.9 Manufacture of sport goods	207	98	109	207
32.5 Manufacture of glasses and lenses	189	78	111	189
Total	**12,679**	**5,234**	**7.445**	**5,421**

The universe assigned to students was composed as follows.

Table 3.3: Companies' size and location (SID Project's elaboration)

Universe	Number	%	Region	%
<=1 M €	806	**14.9**	Emilia Romagna	**12.6**
Micro	1,205	**22.2**	Friuli-Venezia Giulia	**6.5**
Small	1,939	**35.8**	Lombardy	**37.4**
Medium	699	**12.9**	Piedmont	**12.5**
Large	772	**14.2**	Trentino-Alto Adige	**2.0**
Total	**5,421**	**100.0**	Veneto	**28.9**
			Total	**100.0**

3.2 The Survey

The survey was realized adopting SurveyMonkey, an online platform which allows user to easily create and manage surveys. Thanks to this platform it was possible to carry out a Computer-Assisted Telephone Interviewing, depending on the availability of the respondents. In fact, most companies requested the survey through a formal request via email, to answer the questions when and if they had availability. In any case, interviewers always tried to reach out to entrepreneurs, operations managers and/or ICT experts inside companies which had the right knowledge to answer all the questions of the survey. The survey consists of 36 questions (see Appendix D), that can be classified into six categories:

1. *Company denomination and industry*. In the very first section, it was input the name and the sector (following the ATECO classification) of the respondent's firm. This input

was automatically input by the interviewer when the survey was compiled through telephone, respondents had to input such data themselves if they obtained the URL for the survey by e-mail. To avoid the indication of wrong sectors, it was included a drop-down menu so that respondents could not write down a wrong sector.

2. *A filter question*. This is probably the main question of the survey. Through this question it was possible to distinguish firms that adopted Industry 4.0 technologies from the ones that did not adopt them. Firms that did not adopt Industry 4.0 technologies were asked to provide a motivation for the previous answer. Firms that were adopting such technologies could go on with the survey and access to the other sections.
3. *Firm's competitiveness*. In this section, it was asked to companies to specify their main activity, the number of workers at the end of 2016, their distribution inside the company, the main competitive advantage and the level of R&D expenditure in 2016 (reported as a percentage on the total revenues). Moreover, it was asked if the R&D expenditure increased during the last 5 years.
4. *Firm's Industry 4.0 technologies*. This huge and complete section concerns several aspects of Industry 4.0 technologies. In detail, it was asked the year of adoption for each technology, the internal function in which Industry 4.0 investments occurred, also considering in detail in which function each kind of technology was exploited. It was even asked if the company was currently adopting other kinds of technology not necessarily related to Industry 4.0 like web sites, e-commerce, Customer Relationship Management software, Supply Chain Management software, CAD/CAM, etc. As for the purchase of Industry 4.0 solutions, it was asked if it was necessary to customize technologies to adapt it to the internal infrastructure. Furthermore, eventual customization was thoroughly studied: it was asked the level of necessary customization and which aspects it concerned (hardware, software, and integration). Following, it was asked which kind of third party was contacted to perform the installation (like system integrators, science parks, universities, etc.). Then, questions were aimed at studying the internal changes due to the application of technologies. Through a multiple-answer multiple-choice question, we asked what main benefits were seized through the installation of Industry 4.0 technologies. Afterwards, the analysis was conducted adopting Likert-scale questions to assess the level of internal changes, work organization, benefits, product design and manufacturing changes, and sustainability improvements.

5. *Firm's supply chain*. In this section, companies were asked to describe with percentages their involvement in B2B and B2C markets, the geographical distribution of their production and suppliers and the main abroad markets.
6. *Respondent's data*. Respondents had the possibility to inform the interviewer about their identity, internal role and contact information. This option allowed to be informed about survey results once that the research project will be completed. Finally, the interviewer had to input (in case of phone interview) the fiscal code of the respondent's firm: this information proved to be particularly useful to retrieve additional information from AIDA. Analyses were conducted considering

3.3 The Final Database

In total, up to 15 September 2017, 668 valid surveys were collected through the interviews. This database was not ready to be analysed, as it included incomplete answers, duplicate items, and companies for which it was not possible to retrieve the information necessary to perform the analyses. As a first step, each respondent's firm (named directly "*Respondents*" or "*Interviewees*" from now on, as managers and employees contacted answered on behalf of the company) was connected to its right fiscal code to permit the retrieval of additional objective information. Several answers, in particular the ones filled directly by respondents, often missed this information, thus making the search for additional information on AIDA more difficult than expected. Unlike the business name, the fiscal code is univocal and there is no risk of mixing up respondents.

So, the item that was used to conduct this research was the fiscal code. Through the fiscal code, information concerning respondents could be retrieved, enabling the processing of analyses on firms' performance. To retrieve the right fiscal code for each respondent, several items were simultaneously used:

- The fiscal code input by the respondent (or interviewer, depending on the subject that actually input the information); this information was taken into account as some company could have changed its fiscal code following a business transformation, acquisition, or another extraordinary operation. Through AIDA, this information was controlled anyway, in order not to download wrong performance indicators.
- Business name and sector input by respondents; in order to look for companies that did not input their fiscal code. This information was used in conjunction with the lists generated on May 2017 including the whole list of firms that had to be contacted for the survey.

- The lists that were generated on May 2017 to start contacting firms. As explained above, these lists proved to be useful to be sure about firms that input their legal information except for the fiscal code. These files were used as an additional check for fiscal codes already inserted by respondents, but those codes were used anyway as the identity of the firms was checked upon phone contact.

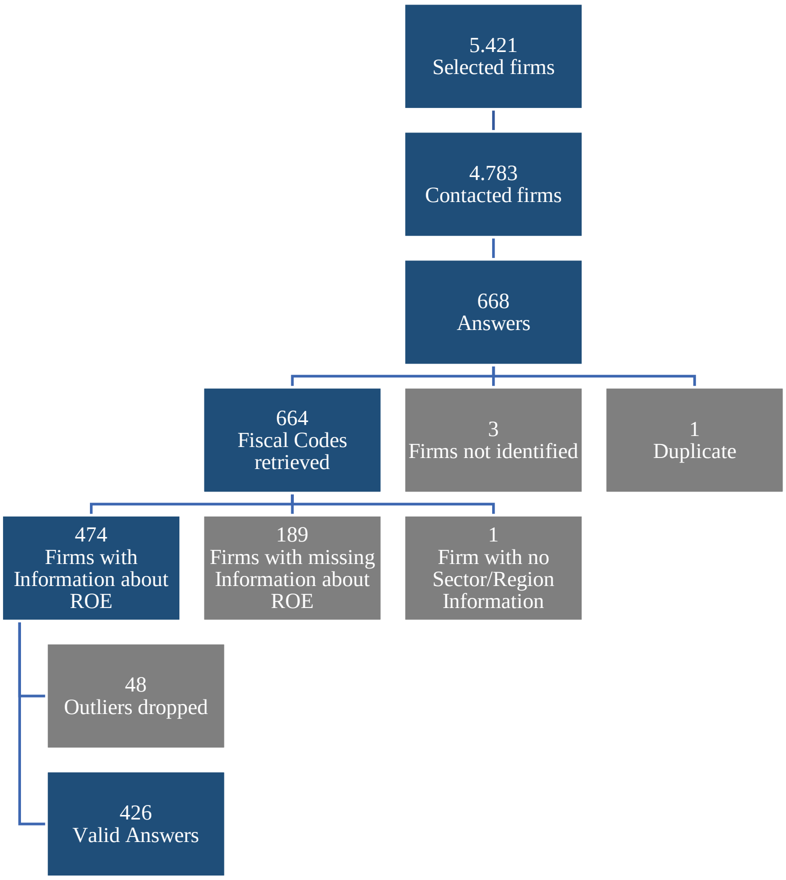
Through this operation it was possible to retrieve an objective fiscal code (in other words, not subject to eventual respondents' biases and errors) for each respondent. This list was additionally saved as a ".fis" file to be input on AIDA whenever required. After this first check, 3 answers were dropped, as they were missing fiscal code information and a valid business name. Moreover, another answer was dropped as it was a duplicate.

Then, additional information for each company was retrieved on AIDA on September 2017. This information concerned financial indexes, results, number of workers, industry, and region. Even if data concerning competitiveness, location, and sector was already asked to respondents, we decided to download it again to perform analyses that were as objective as possible. Financial information was downloaded for 2016, 2015, and 2014. As the empirical analyses described in the next sections are aimed at studying the effects of Industry 4.0 technologies on financial performance, the main retrieved index was the Return on Equity (ROE). The availability of this information for companies was used as the main filter to "clean" the database. As ROE was analysed for years 2016, 2015, and 2014, companies for which this information was not available on AIDA were dropped. This step was conducted on SPSS, selecting and eliminating items for which it was not possible to retrieve the information on AIDA. With this operation, 189 companies were dropped because information for either 2016, 2015, or 2014 was not available. Information concerning the Return on Equity for all the considered years was available for 475 companies. Then, another row was eliminated because, even if it had information concerning its average value of return on equity of the last three-year period, it lacked information for what regards its sector of activity and the Italian region in which it produces. For statistical analyses, the related row would not have been considered anyway, so it was decided to directly drop it at this step.

After this, the database was cleaned deleting outliers. As the average value of ROE over years 2016, 2015, and 2014 is the starting measure that is used to study Industry 4.0 implications on financial performance, its outliers were eliminated to reduce variability in the sample. Indeed, the value ranged between -102% to 77% thus altering the analyses. Hanneman et al. (2012, p.123) suggest "to trim the distribution of cases by ignoring a certain percentage of the highest- and lowest-scoring cases" when the highest and lowest scores are extreme and not typical of high and low values. We decided to drop 10% of the values: as a consequence, after having ordered values for the average ROE for the selected years, the top 5% and the bottom 5% were eliminated (as suggested by Hanneman, 2012). Practically, the top 24 rows and the bottom 24 rows in terms of average ROE (over years 2016, 2015, and 2014) were eliminated. The resulting databases has a range that describes how far apart the 5th and the 95th percentiles are.

The final database obtained consist of 426 respondents and it was the starting point for all the following analyses. In Fig 3.1 it is possible to observe a summarized version about the cleaning of collected answers. The final database is called "*database_4ir*".

Figure 3.1: The Database cleaning process (Author's elaboration)



3.4 Descriptive Statistics

In this section, the final cleaned sample that was adopted for statistical purposes is presented. The analysis of the sample composition is described following the sections that formed the questionnaire. First, biographical data about respondents is described. This data was retrieved from AIDA in order to have a basic set of objective information about firms. Following, information about technology adoption is discussed, together with the motivations provided by non-adopter firms. Then, competitiveness information is presented. After this, technology installation benefits and issues are analysed. Following, the section concerning the supply chain of respondents (distribution and production) is described. To conclude, a respondent's generic profile is presented (see Table 3.28), summarizing all the relevant information.

3.4.1 Biographical Respondents' Information

Figure 3.2 shows in which sectors respondents operate. Following ATECO 2007 codes, companies were grouped (already in the selection phase) into 8 main industries. The ATECO classification is used by the Italian National Statistical Institute (ISTAT) to classify businesses according to their activity sector. Such classification derives from the Statistical Classification of Economic Activities in the European Community[24], and it consists in six-digit code to specify the industry in which each firm operates. For analyses purposes, it was given importance to the first 3 digits (concerning the macro-area of activity). The sectors are the following:

1. *Manufacture of rubber and plastic products,* for firms whose first 2 digits are 22
2. *Manufacture of electrical motors, batteries, wires, and other equipment,* for firms whose first 3 digits are 27.0, 27.1, 27.3, 27.5, and 27.9.
3. *Manufacture of electric lighting equipment*, for firms whose first 3 digits are 27.5.
4. *Manufacture of motor vehicles, trailers and semi-trailers,* for firms whose first 2 digits are 29.
5. *Manufacture of furniture*, for firms whose ATECO starts with "31".
6. *Manufacture of jewellery, bijouterie and related articles,* for firms whose first 3 digits are 32.1.
7. *Manufacture of ophthalmic goods, eyeglasses, sunglasses, lenses ground to prescription, contact lenses, safety goggles*. In this category firms whose code starts with 32.5 were included.
8. *Manufacture of sports goods*, for businesses whose code starts with 32.3 or 32.9.

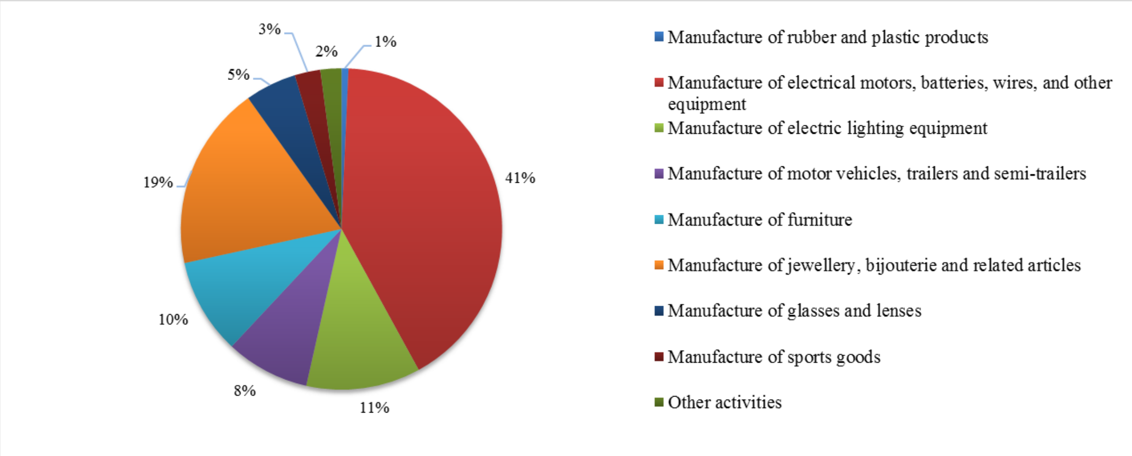
Additionally, one residual category was added, to include all those companies that do not manufacture in one of the previous described sectors. This residual category included mostly firms working in service sectors related to the previous ones, like opticians and businesses for the maintenance and repair of vehicles.

As can be observed in the graph below (Figure 3.2), in the sample the sector with the highest frequency is the manufacturing of electrical motors and components, with a percentage equal to 41%. This information will be useful to gain a better understanding of the analyses. The other relevant ones are: the manufacturing of electric lighting, vehicles and trailers, furniture, and jewellery together build up together another 48% of the analysed sample. Relatively small is,

[24] Definitions retrieved from EUROSTAT (RAMON - Reference And Management Of Nomenclatures)

instead, the number of respondents from the sport goods manufacturing sector, from the glasses manufacturing sector, and from the rubber sector. Only 10% of analysed respondents come from either one of these sectors. Luckily, only a 2% of retained answers concerned companies that operate in other sectors.

Figure 3.2: Sector analysis (Author's elaboration)



Observing the geographical distribution of respondents, it can be observed how Lombardy seems to be the most important region. This fact is not strange, as Lombardy is historically the region with the highest number of businesses[25] (Tremolada, 2014). Moreover, since the creation of the universe to be contacted for the survey, Lombardy has been the region with the highest concentration of firms. In fact, 2029 out of 5421 firms assigned to students are located in Lombardy. So, 37.4% of the universe population was already located in this region, percentage also reflected on respondents (37.8%). Also, the other relative frequencies reflect the initial composition of the sample: Veneto is still the second most important region in the sample (it passed from 29% in the initial selection to 34%); Emilia Romagna, Friuli-Venezia Giulia, and Piedmont present minimum differences and, finally, Trentino-Alto Adige is still the region with the lowest relative frequency (0.005).

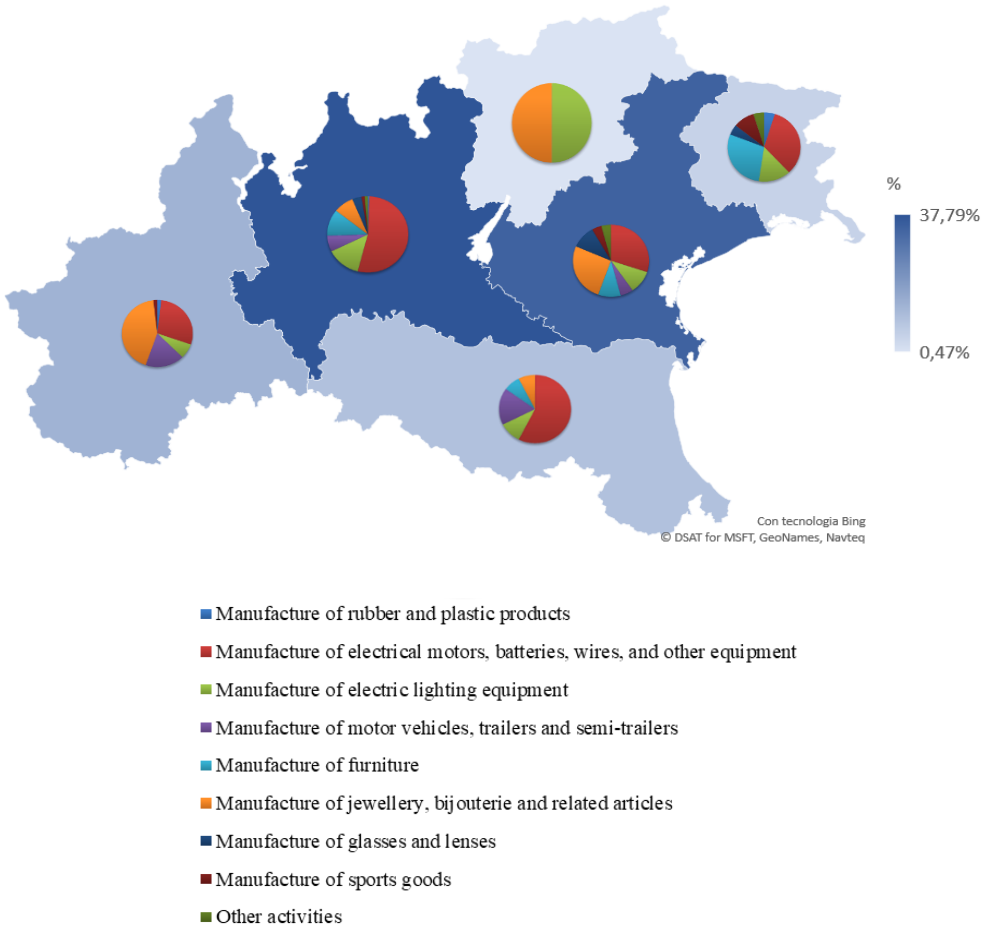
Table 3.4: Geographical distribution – Respondents & Initial Universe (Author's elaboration)

Region	Respondents	Students-assigned Universe
Emilia Romagna	9.4%	12.6%
Friuli-Venezia Giulia	4.9%	6.5%
Lombardy	37.8%	37.4%
Piedmont	13.2%	12.5%
Trentino-Alto Adige	0.5%	2.0%
Veneto	34.3%	28.9%
Total	100.0%	100.0%

[25] http://www.infodata.ilsole24ore.com/2014/11/26/la-mappa-delle-imprese-in-italia-scopri-la-vocazione-di-ciascuna-regione/?refresh_ce=1 accessed on 14 October 2017

In Figure 3.3 both geographical distribution and respondents' sector of activity have been combined. From the figure, it is possible to observe that all the sectors are well distributed among regions (except for Trentino-Alto Adige, as the respondents' number was really low).

Figure 3.3: Regions and sectors (Author's elaboration)



The manufacture of electrical motors, wires, and batteries keeps an important share in each region, while "other activities", "manufacture of glasses and lenses", and the "manufacture of sport goods" are characterized by low relative frequencies in any region. It is important to remind, that initially another geographic category was created, for residual locations. This category was dropped during the database cleaning: in fact, for those respondents it was not possible to retrieve information about their Return on Equity during years 2016, 2015, and 2014, so they were deleted in that phase.

As for size, firms can be classified either considering the number of workers or their revenues. Following European Union's definition[26] of Small and Medium Enterprises (SMEs), which came into force in 1 January 2005, firms can be classified as:

[26] https://ec.europa.eu/growth/smes/business-friendly-environment/sme-definition_en accessed on 14 October, 2017, a summary of EU recommendation 2003/361.

- *Micro Enterprises*, if they have fewer than 10 employees, and either a turnover lower than or equal to 2 million euro or a balance sheet total below or equal to 2 million euro.
- *Small Enterprises*, if they have fewer than 50 employees, and either a turnover lower than or equal to 10 million euro or an annual balance sheet total that does not exceed the same amount.
- *Medium Enterprises*, if they have fewer than 250 employees, and either a turnover lower than or equal to 50 million euro or an annual balance sheet that does not exceed 43 million euro.
- *Large Enterprises*, if they have more than 250 workers, revenues greater than 50 million euro, and/or an annual balance sheet total that exceeds 43 million euro.

Additionally, for what concerns turnover, another category was created for firms whose revenues did not exceed one million euro. So, we considered "Micro" those firms with a turnover greater than 1 million euros but lower than (or equal to) 2 million euros, and "<= 1 M" those companies with a turnover lower than (or equal to) 1 million euros.

Table 3.5: Respondents' size - Turnover (Author's elaboration)

	<= 1 M €	Micro	Small	Medium	Large	Total
Frequency	77	114	170	53	12	426
Percentage	18%	27%	40%	12%	3%	100%

As reported on Table 3.5 (created considering the results at the end of 2016), 85% of the sample consists of micro and small firms. This result is due to the universe structure: indeed, from the beginning, about 73% of firms belonged to these categories. In the initial universe, only 27.1% had a medium or large size; in the current database only 15% of firms exceed the "small enterprise criteria". Considering the author's experience, this alteration could be due to respondents' availability. Often, in medium and large enterprises, managers did not have time to start the survey and, in many cases, the call was transferred from one office to another. For small and micro enterprises, instead, even if we had to pass through the administrative office, the steps to pass through to talk with a manager or ICT expert were lower than for medium and large enterprises. So, completing the survey for small and micro firms was easier, also thanks to the fact that the person picking up the phone was often the manager herself. So, sample structure could be slightly different from the universe not only because of different turnovers (the universe was created considering the turnover at the end of 2015), but also because of this issue.

For individual sectors, the situation is similar, even if there are several exceptions (Figure 3.4). Leaving aside rubber manufacturing firms, whose frequency is low if compared to the others, it is possible to observe how the manufacture of electric lighting equipment and the manufacture of jewellery concerns mostly micro enterprises characterized by a turnover that is lower that is lower than 1 million euro. For each any sector, SMEs represent almost the totality of the respondents.

Figure 3.4: Respondents' size, by sector – Based on turnover (Author's elaboration)

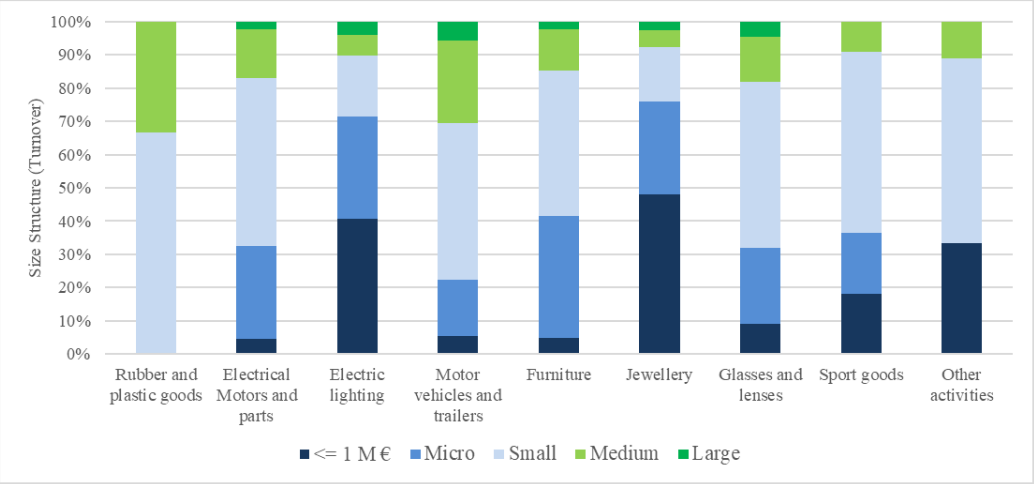
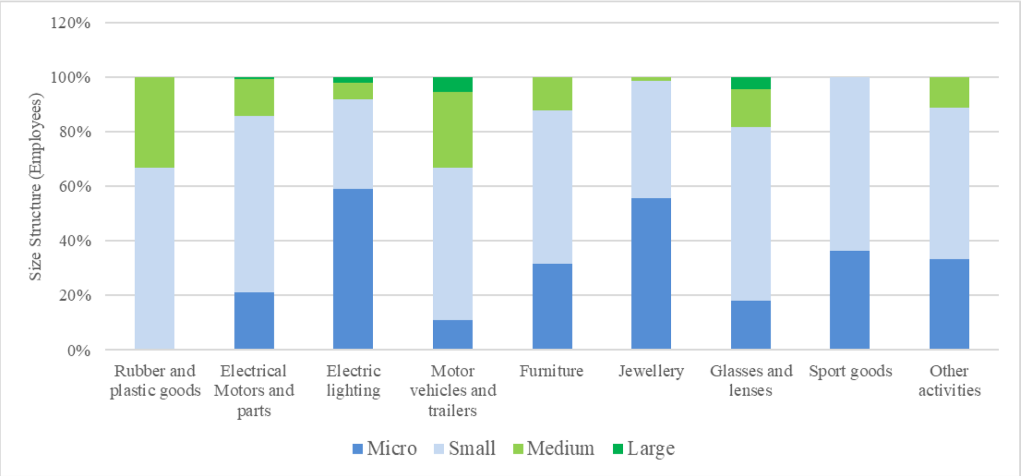


Table 3.6: Respondents' size - Number of employees (Author's elaboration)

	Micro	Small	Medium	Large	Total
Frequency	138	235	48	5	426
Percentage	32%	55%	11%	1%	100%

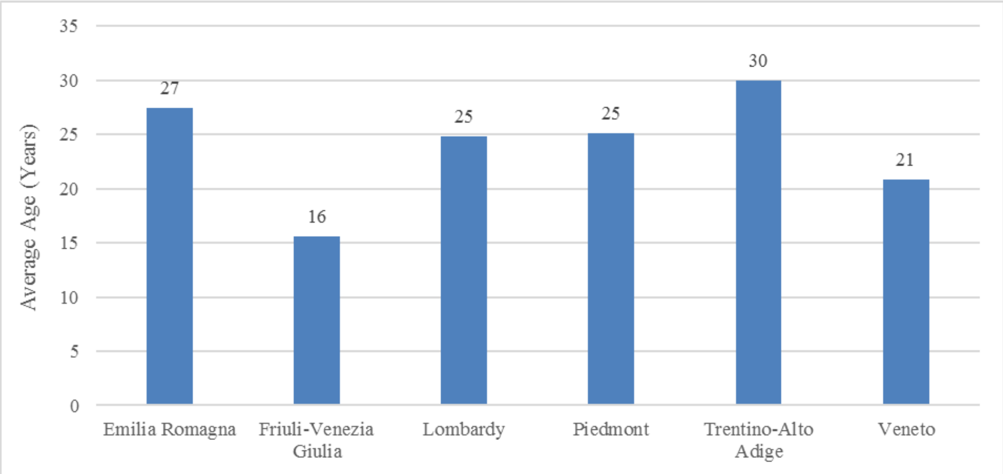
Analysing firms' size considering the number of employees at the end of 2016 confirms the previous results: only 53 firms (12% of the total) have enough workers to be classified as medium or large firm. The sectors that registered the highest number of medium-large firms are the manufacture of vehicles (and vehicle parts) and the manufacture of electrical motors.

Figure 3.5: Respondents' size, by sector – Based on number of employees (Author's elaboration)



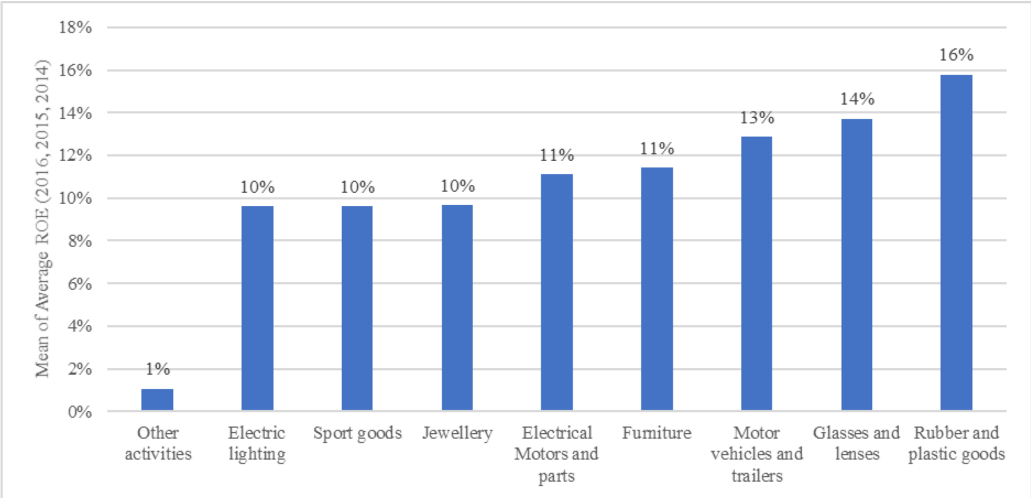
Database_4ir is composed by firms with an average age equal to 23 years. Each region does not present particular differences concerning this aspect. In fact, the most populated regions in the sample (Lombardy, Piedmont, Veneto, and Emilia Romagna) have similar average business age; among these, the region with the highest mean is Emilia Romagna (27 years on average), while the youngest is Veneto (21 years on average).

Figure 3.6: Firms' age, by region (Author's elaboration)



A first look to the mean value of the average return on equity (computed using ROEs of 2016, 2015, and 2014) shows a certain relationship between sector of activity and financial performance.

Figure 3.7: Firms' average ROE, by sector – ranked (Authors' elaboration)



This fact is not unexpected: in 1979, Porter already explained how a firm's performances not only depends on internal capabilities and resources, but also on those "forces" that shape the industry in which it operates. He highlighted the importance of assessing an industry level of profitability evaluating the degree of threat that current competitors, new entrants, bargaining power of customers and suppliers, and substitute products or services represent. Certainly, an individual firm's success depends on its strategy, on the development of sustainable competitive advantages, and on its business model to specify how it will deliver value to customers covering its costs; but industry forces still must be considered.

3.4.2 Technology Adoption

The second step of the descriptive analysis of the samples concerns the third and the fourth questions of the survey. In the third question, we asked what kind of Industry 4.0 technology was currently adopted by the firm. In particular, we asked if the following technologies were exploited in the business:

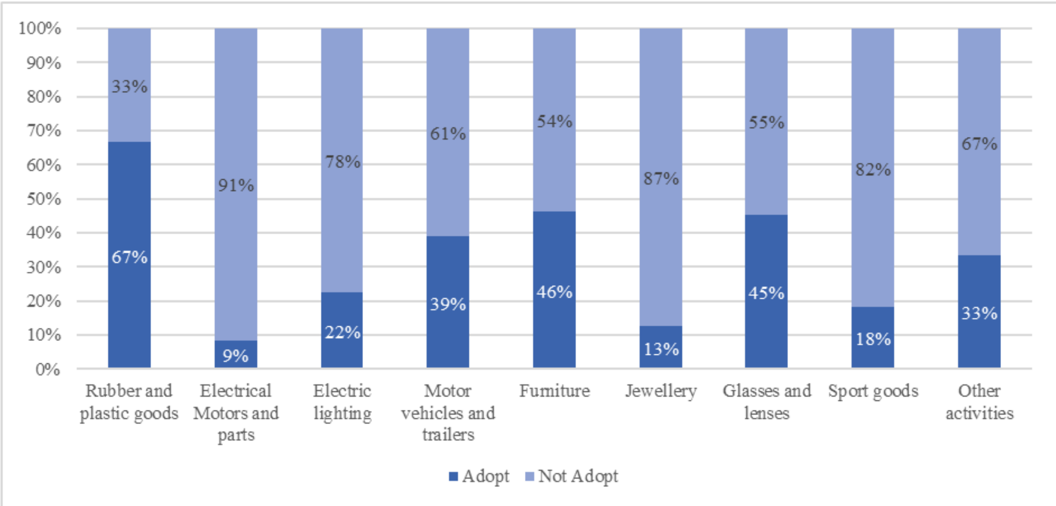
- *Robotics* – As explained before, robots are evolving together with humans and nowadays old robots are upgraded through the installation of sensors and new ones have smaller size to become workers' partners (Magone and Mazali, 2016).
- *Additive Manufacturing (AM)* – This technology is currently being exploited also for production by important "champions" of the heavy industry overseas: General Electrics and Boeing, for example, are not hiding their use of this technology in their plants (D'Aveni, 2015a). AM is one of the methods to quickly transform bits into atoms (Anderson, 2012).
- *Laser Cutters* – As 3D printing, this technology works transforming a digital project into a physical object; indeed, the two technologies are often compared and used together (Anderson, 2012).
- *Big Data and Cloud* – These two analytics tools have been considered together for survey purposes. As stated by several authors (like Gilchrist, 2016; Wagner, 2016; Baur and Wee, 2015), the rapid improvement in terms of data volumes, analytics capabilities and cloud services are some of the main drivers of Industry 4.0.
- *3D Scanners* – They perform the opposite process of 3D printers and laser cutters: starting from a physical object, they digitalize their shape allowing firms to easily carry out reverse engineering (Iuliano and Vezzetti, 2013).
- *Augmented Reality* – This set of technologies enables workers to be informed in real time and to ease the search for information while working (Magone and Mazali, 2016).
- *IoT* – In this question, it concerns mostly smart products. Thanks to miniaturization improvements, sensor energy requirements upgrades, and new connection technologies, sensor are now smart and can be installed in almost any kind of product enabling firms to offer more sophisticated services (Porter and Heppelmann, 2014).

In the sample, only 20% of respondents adopt at least one of the listed technologies (see Table 3.7). This result proved to be a bit below the initial expectations. Analysing this information for all the different sectors allows to understand which proved to be more inclined to adopt Industry 4.0 technologies.

Table 3.7: Adoption of Industry 4.0 technologies (Author's elaboration)

		Adopt	Not Adopt	Total
database_4ir	Frequency	86	340	426
	Percentage	20.19%	79.81%	100%

Figure 3.8: Adoption of technologies for each sector (Author's elaboration)



The table below shows the percentage of adoption for each technology for respondents, calculated as the number of adopters over the total number of members of the considered sector. This computation should permit to understand which technologies are used the most among the adopters of each sector of activity.

Table 3.8: Adoption of individual types of technology for each sector (Author's elaboration)

Sector	Robotics	AM	Laser Cutter	Big Data & Cloud	3D Scanner	Augmented Reality	IoT	Not adopted	Total number of firms
Rubber and plastic goods	33%	0%	0%	33%	0%	0%	0%	33%	3
Electrical Motors and parts	3%	2%	1%	5%	1%	0%	2%	91%	176
Electric lighting	4%	14%	8%	10%	0%	8%	10%	78%	49
Motor vehicles and trailers	31%	11%	14%	17%	11%	3%	8%	61%	36
Furniture	34%	10%	32%	15%	2%	10%	7%	54%	41
Jewellery	3%	8%	10%	3%	5%	4%	1%	87%	79
Glasses and lenses	27%	32%	36%	27%	18%	14%	14%	55%	22
Sport goods	0%	18%	0%	0%	0%	0%	0%	82%	11
Other activities	22%	22%	11%	22%	0%	0%	11%	67%	9

This analysis, together with Table 3.9, provides useful insights to improve the understanding of technology adoption between different sectors, considering reported percentages.

- Robots are one of the driving technologies. This was expected as selected firms are manufacturing businesses, and industrial robots can be used for several tasks in any kind of context. Moreover, their implementation does not represent a change management process like Big Data, Cloud and IoT (Bean, 2017). These technologies require qualified data scientists to be exploited and these professional roles are often difficult to find on the labour market (Blanchet et al., 2014).

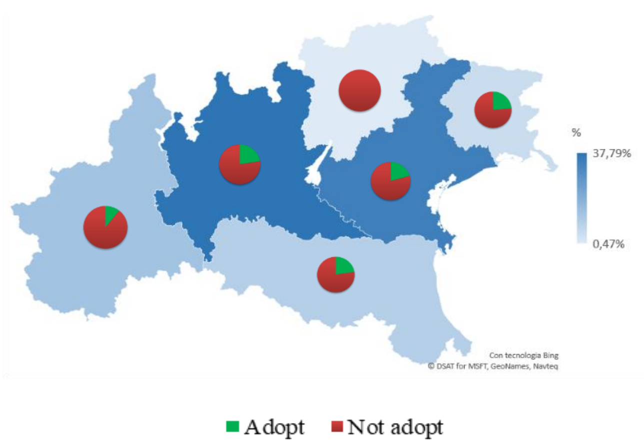
- Following robots, laser cutters are the second most used technology between sectors. As for robots, this depends on the fact that the technology is not new, but has been adapted for pursue the digitalization of companies. As expected, laser cutters are particularly important for companies that manufacture furniture and glasses, as they are used to cut metal and wood following a digital model.
- The other hardware technologies like additive manufacturing, 3D scanners and augmented reality are used more or less often by companies (in particular AM). Even if their installation is not easy and their exploitation needs some sort of "innovative thinking", they have been significantly adopted in the manufacture of vehicles, in the manufacture of glasses and lenses, and in the manufacture of electric lighting.
- IoT is still underperforming, although being one of the most important drivers of Industry 4.0. The collection of huge amounts of data and the adoption of superior analytics methods are significantly adopted, but the installation of connected sensors is still lagging behind.

Table 3.9: Number of companies per technology and sector (Author's elaboration)

Sector	Robotics	AM	Laser Cutter	Big Data & Cloud	3D Scanner	Augmented Reality	IoT	Not adopted
Rubber and plastic goods	1	0	0	1	0	0	0	1
Electrical Motors and parts	5	4	2	9	1	0	3	161
Electric lighting	2	7	4	5	0	4	5	38
Motor vehicles and trailers	11	4	5	6	4	1	3	22
Furniture	14	4	13	6	1	4	3	22
Jewellery	2	6	8	2	4	3	1	69
Glasses and lenses	6	7	8	6	4	3	3	12
Sport goods	0	2	0	0	0	0	0	9
Other activities	2	2	1	2	0	0	1	6
Total	43	36	41	37	14	15	19	340

The analysis of frequencies confirms the previous statements. Numbers reported in Table 3.9 show how many firms adopted each kind of technology. These results confirm again that robotics, additive manufacturing and laser cutter are some of the most applied technologies among firms. Moreover, they enhance the previously analysed insights: from this computation, it is possible to observe that 3D printing, Big Data and cloud are more important than expected. In fact, each one of these tools is adopted by more than 40% of adopters. This analysis confirms also that IoT is lagging behind, but that 3D scanners and augmented reality achieved worse results in terms of adoption. It is important to remind that these results include only partially the effects of the Italian National Plan Industry 4.0, as most of respondents purchased and installed the listed technologies years ago. If the national plan, and its evolution “Enterprise 4.0”, prove to be successful, future analyses should show more promising results.

Figure 3.9: Adoption in each Region (Author’s elaboration)



The analysis of the adoption rate for regions does not show particular differences between areas. No firm based in Trentino-Alto Adige adopted Industry 4.0 technologies, but this is due to the very low number of respondents that are located in that area. In Emilia Romagna, Lombardy, Friuli-Venezia Giulia and Veneto, respondents that adopt Industry 4.0 technologies are between 20 and 25 percent of the category. The result for Piedmont is surprising, as several heavy industry enterprises are located in the region (as Magone and Mazali’s journey confirmed, 2016).

Table 3.10: Variety of technologies adopted (Author’s elaboration)

Sector / Number of Tech.	0	1	2	3	4	5	6	7	Total
Rubber and plastic goods	1	2	0	0	0	0	0	0	3
Electrical Motors and parts	161	9	3	3	0	0	0	0	176
Electric lighting	38	3	3	3	1	1	0	0	49
Motor vehicles and trailers	22	7	2	1	2	1	0	1	36
Furniture	22	6	7	2	2	1	1	0	41
Jewellery	69	2	3	4	0	0	1	0	79
Glasses and lenses	12	1	1	1	5	1	1	0	22
Sport goods	9	2	0	0	0	0	0	0	11
Other activities	6	0	2	0	1	0	0	0	9
Total	340	32	21	14	11	4	3	1	426

At least 1	86
At least 2	54
At least 3	33
At least 4	19
At least 5	8
At least 6	4

Table 3.10 shows that companies which adopted a relevant number (in terms of variety) of technologies are really few. In fact, firms that adopted at least 3 technologies are fewer than

10% of the whole sample, and firms that adopted at least six of the listed technologies, which should be Northern Italy "Industry 4.0 Champions" are only four.

Table 3.11: Technology combination (Author's elaboration)

	Robotics	AM	Laser Cutter	Big Data & Cloud	3D Scanner	Augmented Reality	IoT
Robotics	100%	42%	59%	57%	50%	53%	42%
AM	35%	100%	51%	46%	86%	40%	63%
Laser Cutter	56%	58%	100%	43%	71%	60%	47%
Big Data & Cloud	49%	47%	39%	100%	64%	53%	68%
3D Scanner	16%	33%	24%	24%	100%	13%	21%
Augmented Reality	19%	17%	22%	22%	14%	100%	21%
IoT	19%	33%	22%	35%	29%	27%	100%
Adopters	43	36	41	37	14	15	19

Table 3.11 was realized counting, in each cell, the number of companies that adopt both technologies at the respective column and row. Then, this number was divided for the overall number of adopters of a specific technology. The table must be read considering the columns: for example, in the first column "Robotics", the cell in the row of Additive Manufacturing has to be interpreted as following: 35% of robotics adopters adopt also additive manufacturing tools. This analysis permits us to understand how technologies are used in couples:

- *Robotics* – 56% of firms that exploit robots, adopt laser cutters as well. As stated before, these technologies are not Industry 4.0 exclusive tools and have been acquired for years. It is interesting to observe that 49% of robot adopters are leveraging also on Big Data and cloud. The development of these firms would be interesting to observe to understand these superior analytics tools are used together with hardware technologies to improve performances.
- *Additive Manufacturing* – 3D Printers are used the most together with laser cutter (58%) and big data & cloud analytics (47%). This fact confirms Anderson's (2012) statement about 3D printers: they are one of the tools to turn "bits into atoms". It seems that 3D printing is not exploited for production yet, like in GE, Lockheed Martin and Boeing (d'Aveni, 2015a).
- *Laser Cutters* – Laser cutters column confirms both previous statements: this technology is used the most together with robotics (59%), additive manufacturing (51%), Big Data, and cloud (39%).
- *Big Data & Cloud* – these analytics tools are used the most by firms that adopt also robotics, as stated before (57%).

- *3D Scanners* – As Iuliano and Vezzetti (2013) highlight, the technology enjoys synergies together with 3D printing. The “dot clouds” that are created increase data volumes available to firms, often improving their analytics software: this may be a possible explanation of the combination 3d scanners – Big Data/Cloud (64%).
- *Augmented Reality* – firms that adopt technologies to enhance information of physical objects use also robotics (53%), laser cutter (60%), big data, and cloud (53%).
- *The Internet of Things* – finally, IoT seems to be particularly adopted together with additive manufacturing. The percentage of adoption of Big Data and cloud (68%) is not surprising: sensors permit to collect enormous volumes of data that have to be analysed to be efficiently used to enhance decision making (Gilchrist, 2016)

Table 3.12: Technology adoption and size – Turnover (Author’s elaboration)

	Robotics	AM	Laser Cutter	Big Data & Cloud	3D Scanner	Augmented Reality	IoT	Adopters
< 1 M €	14%	43%	57%	29%	43%	29%	29%	7
Micro	44%	33%	56%	28%	11%	28%	17%	18
Small	47%	44%	44%	47%	15%	9%	21%	34
Medium	62%	43%	43%	48%	19%	19%	24%	21
Large	83%	50%	50%	67%	0%	17%	33%	6
								86

Analysing adopters’ size (Table 3.12), we can observe that robots and laser cutters are, again, the most diffused technologies. Probably, micro-enterprises exploit laser cutter as they perform mostly handcrafting activities. As expected, the diffusion of Big Data and IoT improves as firms’ size increase. These technologies are probably the most difficult to implement (Bean, 2017).

Respondents that did not adopt any of the listed technologies, had to provide a motivation for their choice. The options were the following (listed as they are reported in Tables):

A. *Lack of financial resources*, if the investment was considered too expensive for the firm.
B. *Lack/limited internal competencies*, if there were not adequate capabilities to exploit technologies;
C. *Lack of adequate technology infrastructure*, as all listed technologies cannot be exploited alone and need a certain level of technology infrastructure;
D. *Poor knowledge about the theme*;
E. *Uncertainty about returns on investment*;
F. *Not interesting for the business*, as firms’ size often translated into craftwork that do not require particular technologies;

G. *Under review*, if the firm was still evaluating whether to purchase or not one of the listed technologies
H. *Other*. This category was left with an open space in which respondents could specify if they were not adopting any technology because of a motive different from the ones listed above

Table 3.13: Adoption – Size (Author's elaboration)

Size (Turnover)	Adopt	Not adopt
<= 1 M €	9%	91%
Micro	16%	84%
Small	20%	80%
Medium	40%	60%
Large	50%	50%

If we consider firms' size, we can observe how the rate of adoption increases with the firms' size. This is not an unexpected phenomenon. Some techniques are not expensive and require relatively low investments, like cloud computing, in which users have to pay only for the computational power they exploit, and sensors (beacons, Kinect, smartphone are not expensive if compared with other technologies). Nevertheless, robots, 3D scanners, 3D printers are costly even if more accessible than in the past. Considering that the sample consists of manufacturing firms, the ones listed above are probably the most important ones for production. Leaving aside the financial aspect, Table 3.13 shows that the smallest firms (<= 1 M €) are not even interested in Industry 4.0 technologies (only 9% of micro enterprises are adopters). This theme will be further analysed considering how motivations for not adopting any technology change depending on turnover (which is used as measure for firms' size).

Table 3.14: Failure to adopt - Motivations (Author's elaboration)

	A	B	C	D	E	F	G	H
Frequency	26	17	30	69	23	216	37	86
Percentage	8%	5%	9%	20%	7%	64%	11%	26%

Table 3.15: Failure to adopt – Motivations, by sector (Author's elaboration)

Sector	A	B	C	D	E	F	G	H
Rubber and plastic goods	0%	0%	0%	0%	0%	100%	0%	0%
Electrical Motors and parts	4%	1%	2%	29%	4%	66%	11%	23%
Electric lighting	24%	5%	3%	24%	14%	54%	16%	32%
Motor vehicles and trailers	9%	5%	36%	14%	36%	41%	27%	23%
Furniture	27%	14%	14%	14%	14%	59%	14%	5%
Jewellery	1%	10%	17%	4%	0%	75%	3%	38%
Glasses and lenses	8%	8%	17%	33%	8%	67%	0%	33%
Sport goods	0%	13%	0%	0%	0%	50%	13%	25%
Other activities	17%	17%	17%	17%	0%	67%	17%	0%

Table 3.16: Question 4) Respondents (Author's elaboration)

Sector	Answers	Missing Answer	Total
Rubber and plastic goods	1	0	1
Electrical Motors and parts	160	1	161
Electric lighting	37	1	38
Motor vehicles and trailers	22	0	22
Furniture	22	0	22
Jewellery	69	0	69
Glasses and lenses	12	0	12
Sport goods	8	1	9
Other activities	6	0	6
Total	337	3	340

Motivations provided by respondents have been summarized in the tables above. As it can be observed, only 3 respondents did not provide any motive for their lack of Industry 4.0 technologies. To answer question 4), respondents could provide more than one answer, for this reason the sum of the percentages of each row is greater than 100%. Most respondents are not interested in Industry 4.0 technologies: this choice was picked more than 50% of the times in each sector, with the exception of the manufacturers of motor vehicles and trailers. Considering overall results, 64% of interviewees picked this option to answer the question (see Table 3.14). Probably, these respondents do not know the importance of these tools for other important players in their sector: for example, Luigi Galante (one of the managers of Maserati) stated to be enthusiastic about the possibility to immediately photograph a defect and share it with the team; additionally, the whole plant exploits dynamic and coordinated robots (COMAU ones) which can change continuously location and adapt to the length of the car they are working on (Magone and Mazali, 2016).

Looking at how motivations change depending on firm's size, we can obtain additional insight about these answers (Table 3.17).

Table 3.17: Failure to adopt – Motivations, by size – Turnover (Author's elaboration)

Size (Turnover)	A	B	C	D	E	F	G	H
<= M €	12%	8%	13%	16%	5%	56%	5%	34%
Micro	5%	5%	5%	18%	6%	57%	4%	25%
Small	5%	3%	7%	15%	5%	51%	11%	16%
Medium	6%	0%	4%	17%	6%	34%	15%	8%
Large	0%	0%	0%	8%	0%	25%	17%	8%

From this analysis, it is observable how the relative frequency of answer F decreases as firm's size increases. In fact, as firms get bigger, the percentage of respondents that do not adopt technologies because they are not interested in acquiring them decreases. Nevertheless, it seems that small firms are not interested in the opportunities and benefits that these advanced tools could bring with them. In fact, as it was specified in the option H ("Other"), often respondents commented their lack of interest for the technologies specifying that either their business was too small to adopt them or they were currently handcrafting their goods (and so, superior technologies would make them lose that "quality factor"). Probably these respondents do not thoroughly know that mass customization, flexibility and quality are often central themes when we talk about Industry 4.0. Robots are small and can be used as assistants, 3D printers can immediately craft a complex component, 3D scanners make reverse engineering an immediate and easy activity, huge amounts of data can be collected through sensors and analysed through superior analytics systems to enhance decision-making, and so on. Leaving aside the "complex and long-term" Industry 4.0 advantages, like the creation of a connected supply chain – from raw material suppliers to final customer, individual technologies offer new opportunities to firms, independently from size (Gilchrist, 2016; Magone and Mazali, 2016). Moreover, thanks to the National Plan, these technologies should be even more convenient than traditional ones as their hyper- and super-depreciations allow firms to gain tax benefits.

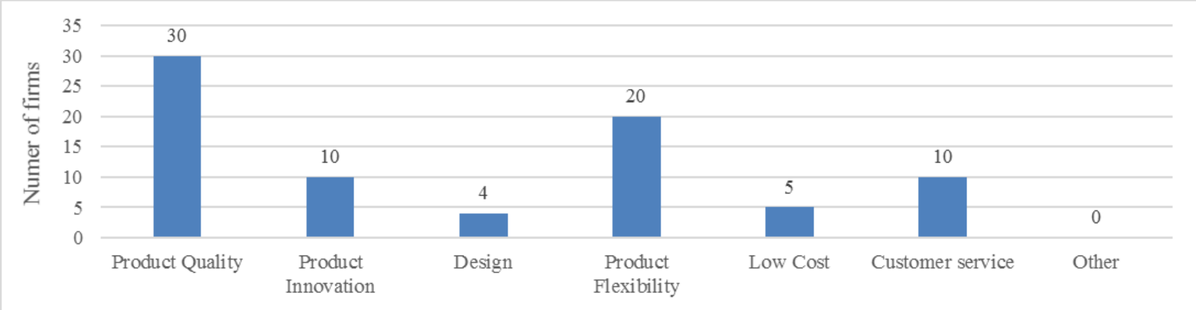
Additionally, as expected, bigger firms are not lacking these technologies because of poor or limited financial resources (A), competencies (B), and internal technology infrastructure (C). What is interesting, is that "poor knowledge about the theme" (D) does not decrease for medium and small firms with respect to micro businesses. Vice versa, medium enterprises did pick this option more than small- and micro-sized ones. This fact could have significant consequences for the Italian National Plan Industry 4.0: not knowing about this phenomenon may limit or slow the investments made leveraging on the incentives offered by the Government. Such information may even be more relevant if we consider that the creation of competence centres has been delayed, as stated in the Government's summary[27] of the results of the first semester of 2017. These centres should be used to help enterprises in performing industrial research and experimental development; the slowing down of their opening and the fact poor knowledge about the theme is diffused independently on firms' size affect negatively the success of the plan. Another interesting (and promising) aspects concerns respondents that are not currently deploying the described digital tools but are evaluating their adoption. It is not strange, as the National Plan was deployed at the start of 2017: many firms are probably currently evaluating whether to exploit it or not.

[27] http://www.sviluppoeconomico.gov.it/index.php/it/198-notizie-stampa/2037096-piano-nazionale-impresa-4-0-i-risultati-del-2017-e-le-linee-guida-per-il-2018 accessed on 27 September 2017

3.4.3 Adopters' Competitiveness

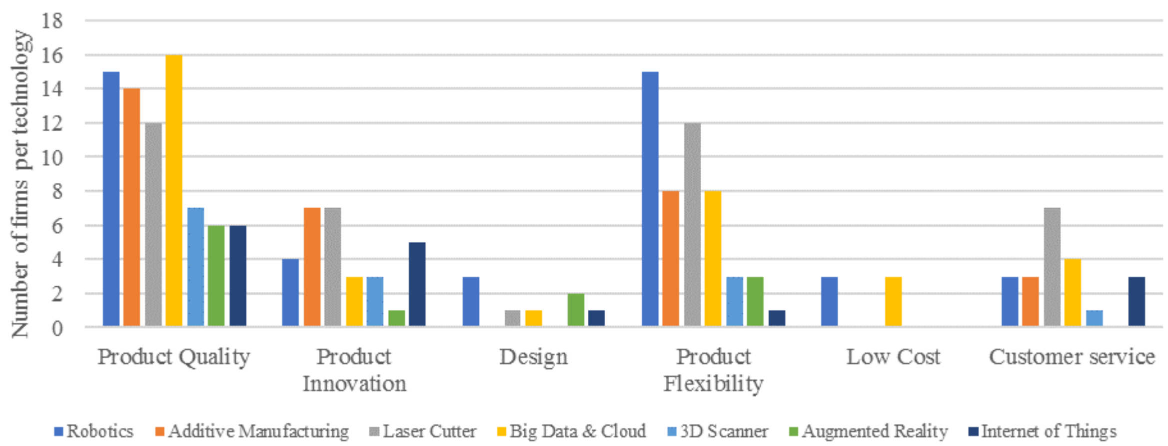
In the survey, this section has been conceived to assess number of workers, turnover, competitive advantage, export, and R&D expenditures. The first two dimensions have already been described in the first section of the descriptive analysis: in the end, we preferred to use information as objective as possible (when available), thus we decided to retrieve that information from AIDA instead of basing that analysis on respondents' answers.

Figure 3.10: Competitive advantages – Frequency (Author's elaboration)



The first aspect that will be discussed is the competitive advantage (question with multiple choices, single answer). Analysing frequencies for the relative question (79 respondents in total), we can observe how most companies deemed "Product Quality" and "Product Flexibility" as their main source of competitive advantage (see Figure 3.10). Few results were recorded for "Design" and "Low Cost", while no one specified a non-listed competitive advantage (there was the possibility to specify alternative competitive advantages if the list was deemed as non-exhaustive).

Figure 3.11: Competitive advantage sought and technologies (Author's elaboration)



The analysis can be deepen looking at the types of technology that have been adopted by respondents depending on their most important competitive advantage. Big Data and cloud computing are the most common technology between companies that focus on product quality: probably, these firms understood the importance of having more available information about customers, in order to satisfy their needs in a more effective way. Years ago, Laney (2001) already discussed the importance of this data with the advent of Big Data as companies started to perform e-commerce activities. Robotics, additive manufacturing, and laser cutters are almost equally diffused among quality-focused firms. Less diffused are 3D scanner, augmented reality and IoT but, as said before, this phenomenon regards the whole sample. Another particular aspect concerns firms focused on product flexibility: the most diffused technologies among these businesses are robots and laser cutters. Probably, these firms understood the potentiality of the new models of industrial robots, which are not restrained in their cages and can help workers like actual assistants. The results for laser cutter are not surprising: the technology is not new and is famous for the opportunities in terms of flexibility it brings (Anderson, 2012). Probably, as 3D printers become even more accessible and easier to run, they will become one of the most adopted industry 4.0 technologies for firms that aim at being as flexible as possible (Steenhuis and Pretorius, 2017). The possibility of creating any kind of complex shape, with the desired material and within few minutes, is the summit of the flexibility concept: nevertheless, the technology still needs several improvements (Ford and Despeisse, 2016).

Technology distribution for product innovation enterprises confirms the advantages proposed by those firms that easily "turn bits into atoms" (Anderson, 2012). In particular, 3D printing was famous from the beginning as "rapid prototyping" (Gibson et al., 2015). Considering this aspect, 3D scanners are underperforming in terms of diffusion: their adoption, if combined with 3D printers, creates a virtuous circle that enhances prototyping and reverse engineering (Iuliano and Vezzetti, 2013).

Considering the percentage of export activity on the total turnover, our sample presents an average value of 51.36%. Table 3.18 summarizes the average amount of export activity over revenues for each sector. The first export destinations are France (13 Respondents) and Germany (12 Respondents). The sample consists of firms that give significant attention to their activity abroad. In fact, with the exception of manufacturers of sport goods, manufacturers of jewellery, and "other sectors", each category obtains abroad about half of its total turnover.

Table 3.18: Export and R&D Expenditure on revenues (Author's elaboration)

Sectors	Export on Revenues (%)	R&D Expenditure on revenues
Rubber and plastic goods	48%	1%
Electrical Motors and parts	67%	4%
Electric lighting	62%	11%
Motor vehicles and trailers	55%	6%
Furniture	54%	5%

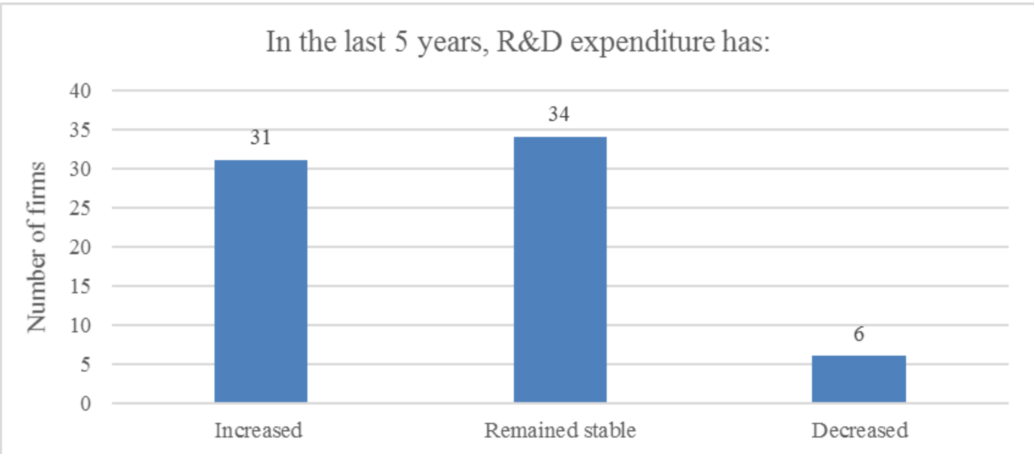
Sectors	Export on Revenues (%)	R&D Expenditure on revenues
Jewellery	35%	16%
Glasses and lenses	50%	6%
Sport goods	6%	3%
Other activities	16%	1%
Respondents:	65	59

Moreover, the average percentage of R&D expenses on revenues seems positive if compared with the most recent data collected by Eurostat concerning research and development expenses over GDP. In fact, on average, respondents input results which are more promising than the EU28's ones. Nevertheless, to gain a more significant and trustworthy understanding of these results, these percentages should be compared with the champions of each sector and or with the average national results for each sector.

Table 3.19: R&D Expenditure - % of GDP (Source: Eurostat[28])

	2011	2012	2013	2014	2015
EU28	1.97	2.01	2.03	2.04	2.03
Italy	1.21	1.27	1.31	1.38	1.33

Figure 3.12: R&D Expenditure trend – Frequency (Author's elaboration)



3.4.4 Adopters' Technologies

This section explores answers concerning the questions from 12) to 27) (see Appendix D). Technology adoption implications are studied and described considering only available answers. In fact, many questions were not answered, because often respondents did not have enough available time. This is also one of the reasons that led us in adopting the largest available sample for statistical purposes: the one that considered the filter question about the adoption of technologies and all the objective data retrieved from AIDA.

[28] Accessed on 25 September 2017

Technologies reported in the database are relatively new. The average year of adoption of the whole database is 2010. The oldest ones are robots and 3D scanners, that were bought on average respectively in 2007 and 2008. As said before, these are not new kinds of technologies, but they are becoming increasingly important considering Industry 4.0 innovations and their improvements. For example, Khalid et al. (2016) developed a method to understand the current "collaboration degree" of each robot considering several key performance indicators; starting from this analysis, the authors suggest the right sensors to potentially transform any kind of robot in a collaborative one. Vice versa, the newest technologies (on average) are IoT sensors and 3D scanners (adopted on average in 2013 and 2014). Table 3.20 summarizes the obtained results.

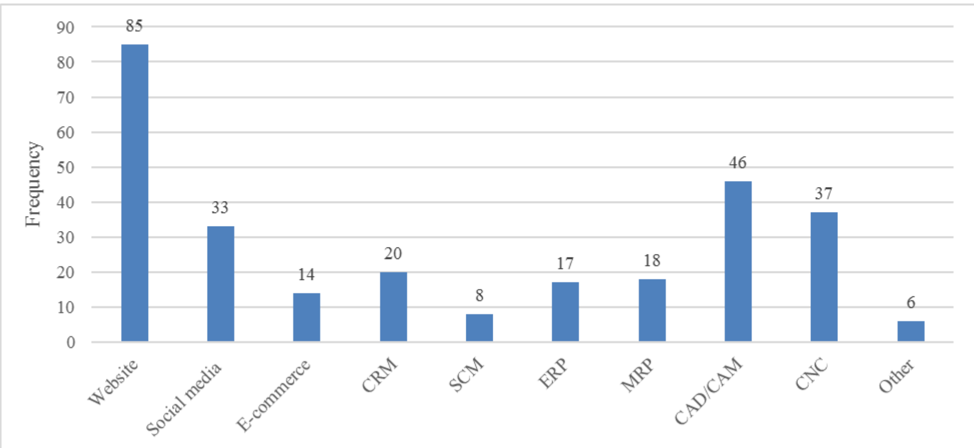
Table 3.20: Average year of technology adoption (Author's elaboration)

	Robotics	AM	Laser Cutter	Big Data & Cloud	3D Scanner	Augmented Reality	IoT	database_4ir
Avg year	2007	2012	2008	2011	2014	2011	2013	2010

In question 13) we asked respondents whether they were using other technologies together with the Industry 4.0 ones. This question regarded:

- *Online services*, like website, e-commerce, and social media (Facebook, Twitter, etc.).
- *Additional software*, like Customer Relationship Management (CRM), Supply Chain Management (SCM), Enterprise Resource Planning (ERP), Material Requirement Planning (MRP), CAD/CAM.
- *Additional hardware in production*, in particular computer numerical control machines.
- *Other tools*.

Figure 3.13: ICT and other technologies (Author's elaboration)



Looking at Figure 3.13, we can observe that the website is the most used additional tool for respondents: it is used by almost all respondents (86, all the adopters in this case), indeed. The usage of ERP is not so much diffused (as it is used only by 17 respondents), but others use singular parts of the software (like SCM and MRP). As expected, since our database regards manufacturing enterprises, CAD/CAM and CNC machines are the other most used additional technologies. CAD/CAM is necessary to work with 3D printers and laser cutter, as they need a digital project (Anderson, 2012).

Table 3.21: Industry 4.0 and traditional technologies: Adoption (Author's elaboration)

Percentages on adopters of each technology	Robotics	AM	Laser Cutter	Big Data & Cloud	3D Scanner	Augmented Reality	IoT
Website	100%	100%	100%	97%	100%	100%	100%
Social media	47%	39%	49%	49%	57%	40%	37%
E-commerce	16%	11%	24%	19%	21%	20%	16%
CRM	23%	39%	32%	30%	57%	20%	37%
SCM	9%	19%	17%	16%	14%	13%	32%
ERP	23%	31%	29%	30%	29%	40%	37%
MRP	28%	22%	24%	35%	29%	40%	37%
CAD/CAM	58%	64%	73%	57%	79%	53%	63%
CNC	49%	53%	63%	54%	64%	60%	53%
Other	2%	6%	5%	8%	0%	7%	11%
Adopters	43	36	41	37	14	15	19

Table 3.21 was realized with the purpose of studying these relationships between technologies and it was created like Table 3.11. It aims at studying relationships between Industry 4.0 technologies and other "traditional" tools. Like the previous ones, this table must be read considering the columns first. We highlight in light-blue values greater than 50%, and in yellow results between 25% and 50%. Results do not seem to depend on the type of technology that each respondent adopted: after websites, CAD/CAM and CNC are the most adopted traditional technologies independently from the Industry 4.0 tools, followed by management software (ERP, CRM, MRP) and by social media. Differences in adoption percentages are little and suggest that this traditional technology background do not influence the variety of exploitation of technologies 4.0; the presence of this background still seems to be important.

Question 15) required respondents to indicate in which function each Industry 4.0 technology is adopted. Many respondents skipped this question, and only 55 answers were collected. Table 3.22 reports the percentage of technology adoption in each function. As before, this table has to be read considering columns headers first. The highest value for each technology is highlighted, to facilitate the identification of the most important function of application for each column.

Table 3.22: Industry 4.0 technologies diffusion per function (Author's elaboration)

Function / Technology	Robotics	AM	Big Data & Cloud	3D Scanner	Augmented Reality	IoT
R&D	41%	46%	20%	50%	30%	29%
Prototyping	19%	77%	20%	67%	20%	36%
Production	100%	42%	44%	42%	40%	57%
Production Management	41%	12%	76%	8%	10%	29%
Logistics and Supply Chain Management	0%	4%	24%	0%	0%	21%
Sales and Marketing	4%	8%	32%	8%	40%	14%
Spare Parts Production / After Sales Activities	15%	4%	12%	0%	0%	7%
Other	0%	8%	8%	0%	0%	0%
Respondents' technologies	27	26	25	12	10	14

These results do not show particular abnormalities: they confirm what we would expect by knowing the considered technologies and the answers to previous questions, indeed.

- Robots are always applied in the production function;
- Additive manufacturing is exploited the most in the prototyping function ("rapid prototyping" system, Gibson et al., 2015). It seems that 3D printing has yet to be used for production purposes, as some Industry 4.0 champions do, like General Electrics (D'Aveni, 2015a).
- Big Data and cloud are applied the most for the production management function.
- 3D scanners are mostly used in the prototyping function (together with additive manufacturing, as said by Iuliano and Vezzetti, 2013).
- Augmented reality is used the most in the production function and in the sales & marketing one. This second kind of application would be interesting to be studied.
- The Internet of Things is leveraged mostly in the production function.

Figure 3.14 provides further insights. To create the graph in Figure 3.14, we calculated the percentages of adoption of each technology in each function. We performed the opposite process that was followed to create Table 3.22, indeed. Here, technology exploitation is clearer. The importance of robots in production (main products and spare parts) is immediate. Also, we can observe how Big Data and cloud computing are important for activities related to operations and supply chain management, marketing and sales and after sales activities. Additive manufacturing is not exploited yet in the production function like some global players do. Its usage is concentrated in the prototyping and R&D activities; so, it seems that the adoption of this technology as "Rapid Prototyping" one is still the most diffused.

Figure 3.14: Functions and technology adoption (Author's elaboration)

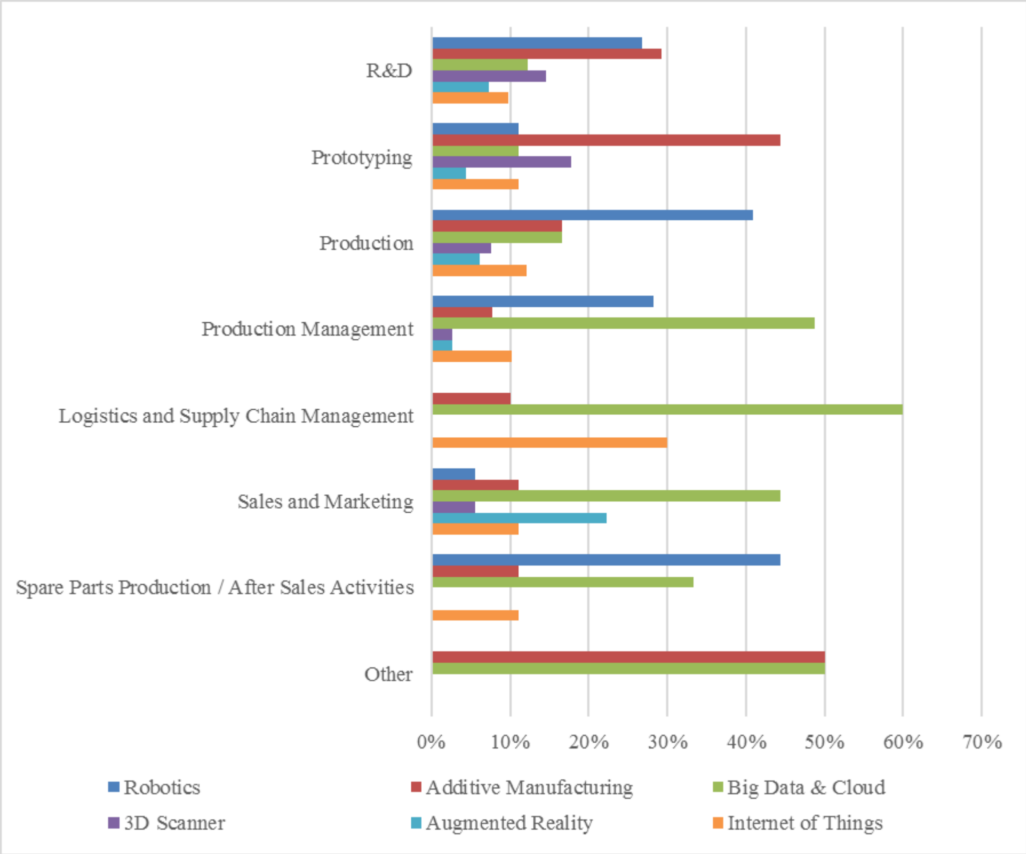
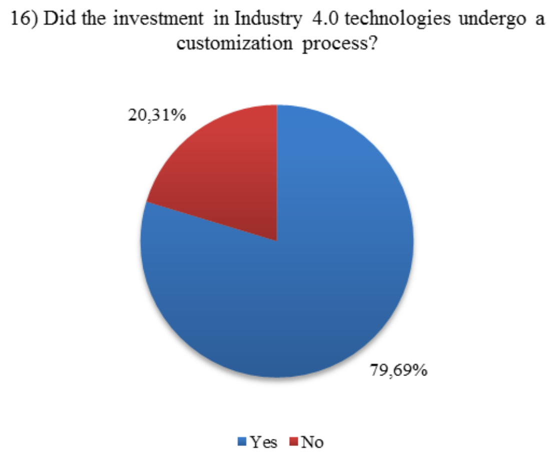


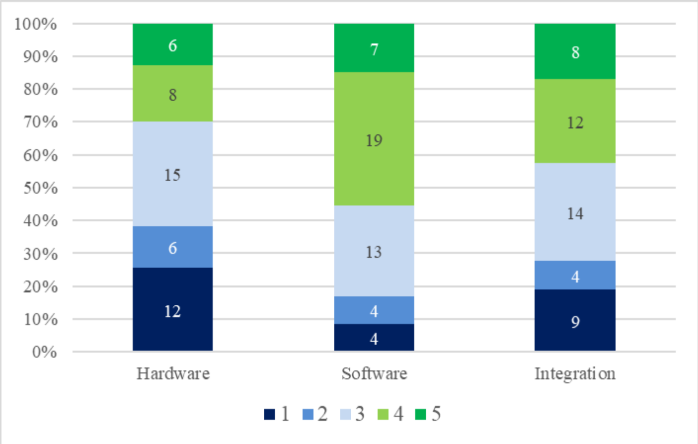
Figure 3.15: Technologies and customization (Author's elaboration)



Almost 80% of the times the investment in Industry 4.0 technologies needed to undergo a customization process (See Figure 3.15). Additional details about the customization process of technology installation were asked through a Likert scale question. The respondent could state the degree of necessary customization from 1 ("not at all") to 5 ("a lot"). We asked firms whether they needed to customize the technology in their software, hardware, or to integrate it with the existing infrastructure.

After having fixed missing values[29], the results are the following: hardware customization has an average score equal to 2.79, software 3.45, and integration 3.10 (47 answers). In fact, Software is the aspect that required the highest levels of customization. The graph below shows that "3" was picked almost equally by firms, while values greater than 3 were picked the most for software customization. So, an average degree of customization was always necessary, but few firms required substantial customizations for what concerns hardware components and technology integration.

Figure 3.16: Industry 4.0 technology customization – Details (Author's elaboration)



Transforming these Likert scales into binary variables (equal to 1 if the answer was "4" and "5", 0 otherwise) highlights this fact (see Table 3.23).

Table 3.23: Relevant customization (Author's elaboration)

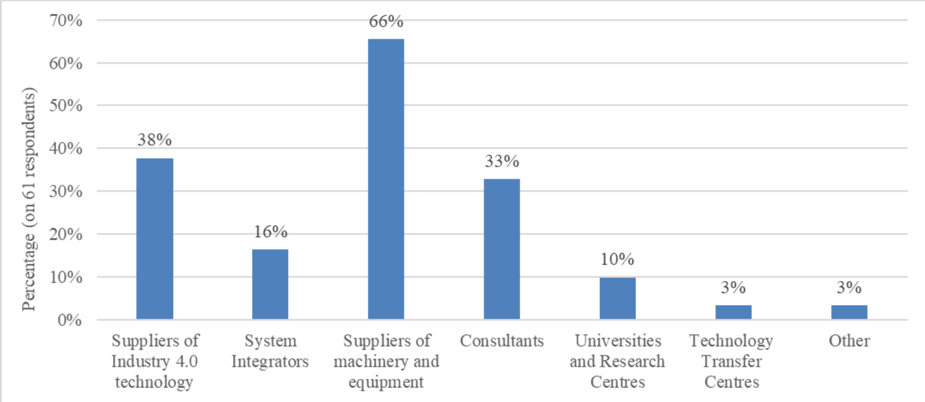
	Hardware	Software	Integration
0	70%	45%	57%
1	30%	55%	43%

Through the survey, we asked also what kind of supplier was contacted to carry out the technology installation. We considered six categories of supplier:

- *Suppliers of Industry 4.0 technology*;
- *System integrators*;
- *Suppliers of machinery and equipment*;
- *Consultants*;
- *Universities and Research Centres*;
- *Technology Transfer Centres* (like Science Parks).

[29] If at least one of the three parts of the likert scale question was filled, "1" (= "Not at all") was input in the empty cells in order to complete the answer. Nevertheless, this approach does not affect the binary analysis of the Likert scale questions.

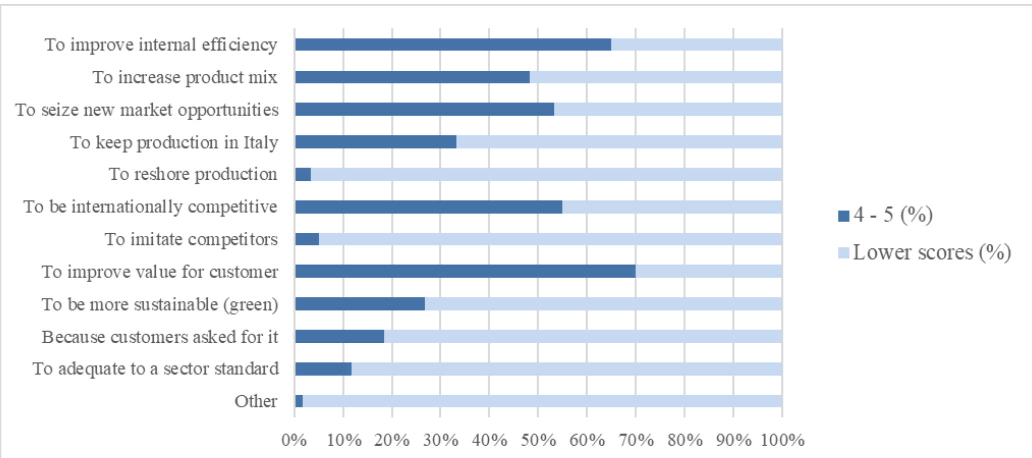
Figure 3.17: Third party responsible for customization (Author's elaboration)



To install technologies, on average respondents required the services of two kinds of suppliers (1.65). Interviewees asked mainly to normal suppliers of equipment and machinery to install technologies purchased; they were contacted by 66% of respondents (61), indeed. The second most diffused kind of supplier between answerers is the supplier of Industry 4.0 technology: in this category, we included suppliers that are focused mainly on providing the described technologies. System integrators, universities, research centres, and technology transfer centres were not so much popular between respondents.

Most respondents wanted Industry 4.0 technologies to increase the value for customers of their offer. Others relevant motives were: the desire to be internationally competitive, to increase the product mix (and so product flexibility), internal efficiency (and so to maximize value while minimizing resources), and to seize eventual new market opportunities. Few companies sought these innovative tools to re-shore their production, but a significant portion did it to keep their production in Italy. Moreover, firms stated that they did not make these improvements because of external impulses: competitors, sector standards, and customers.

Figure 3.18: Industry 4.0 technology – Motivations of adoption (Author's elaboration)



Most of these objectives were confirmed by final benefits that interviewees declared to have obtained thanks to Industry 4.0 technologies. In fact, more than half respondents to question 21 (which concerns the main results obtained) obtained improvements in terms of efficiency, productivity, service to customers, and turnover. Results in terms of international competitiveness are still lagging, instead. Table 3.24 summarizes results for those that picked "4" or "5" to answer, considering also technologies adopted. We highlighted in light blue the greatest value for each column, and in yellow percentages greater than (or equal to) 50%. This table must be read considering columns: for example, 48% in the "Increased turnover" row and "Robotics" column means that 48% of robotics-adopters that answered this question increased a lot their revenues. Results obtained do not seem to change significantly between technologies: in fact, the main relevant benefit achieved is either increased productivity or better service to client independently from technology adopted. Again, the main benefits of those technologies that "turn bits into atoms, and vice versa" are confirmed: 3D printers, 3D scanner, and laser cutters improve customization capabilities of firms.

Table 3.24: Benefits achieved (scores: 4 or 5) – Per type of technology (Author's elaboration)

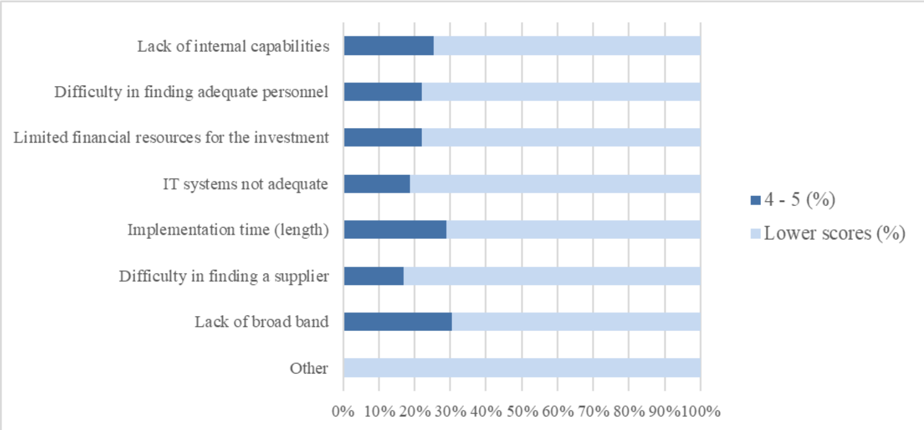
Benefits	Frequency (4 or 5)	%	Robotics	AM	Laser Cutter	Big Data & Cloud	3D Scanner	Augmented Reality	IoT
Increased turnover	26	43%	48%	42%	48%	44%	25%	55%	53%
Cost reduction (more efficiency)	40	67%	71%	54%	64%	67%	58%	55%	60%
Increased productivity	39	65%	77%	62%	76%	67%	58%	82%	53%
Product mix/variety increase	23	38%	48%	50%	48%	37%	50%	64%	33%
Customization improvements	19	32%	32%	42%	42%	37%	50%	55%	40%
Better service to client	34	57%	52%	62%	55%	70%	75%	55%	73%
Entry in new markets	15	25%	29%	27%	30%	30%	33%	45%	40%
Re-organization of the activities Italy-abroad	7	12%	16%	19%	18%	19%	8%	27%	27%
International competitiveness	14	23%	32%	23%	33%	26%	17%	36%	27%
Environmental sustainability	12	20%	32%	19%	27%	22%	17%	45%	27%
Other	3	5%	6%	0%	3%	11%	0%	18%	7%
Respondents	60	100%	31	26	33	27	12	11	15

The installation of these technologies did not occur without problems. The most important problems were the length for the implementation of the technologies and the lack of broad band. The second is particularly preoccupying: as reported in Speedtest Global Index Ranking[30], in October 2017 Italy is at the 51st position for what concerns fixed broadband. For future developments of the National Plan Industry 4.0, this aspect probably will be considered again. As for the length of implementation, it was expected the obtained result, in particular if compared with the other encountered issues. Often, Industry 4.0 technologies represent a change management phenomenon and require time to be fully integrated (like Big Data, for

[30] http://www.speedtest.net/global-index accessed on 17 October 2017

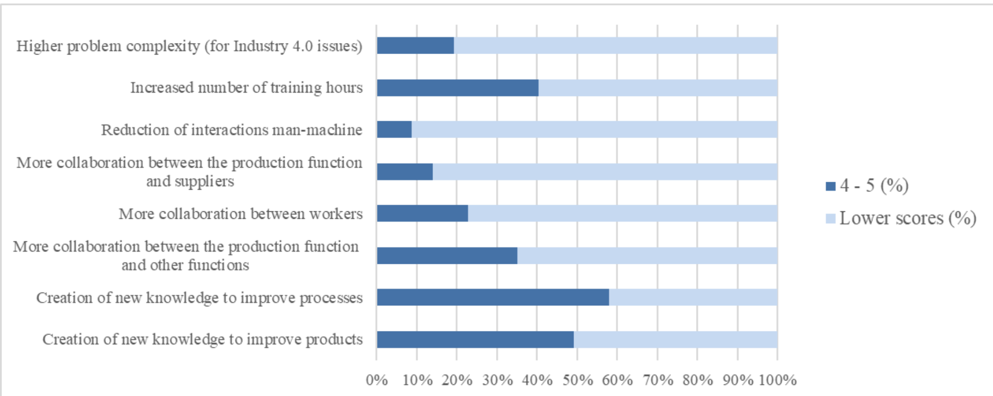
Bean, 2017). Moreover, even robots, which are the most common adopted technology, should be installed by system integrators in order to fit the tools with all the equipment. As the presence of other ICT technologies inside firms confirmed, often firms need some other "Qualifying" technologies in order to prepare the right setting to make the "4.0" upgrade.

Figure 3.19: Difficulties in the adoption of Industry 4.0 technologies (source: Author's elaboration)[31]



The most important internal changes were the increase of training hours (necessary to let workers learn about new technologies) and the creation of new knowledge to improve both processes and products. There has not been a significant impact on interactions between men and machines yet, as well as on collaboration between workers, functions, and supply chain. As a matter of fact, only 14% of answerers picked "4" or "5" to indicate the degree of improvement of collaboration between production function and suppliers due to the introduction of Industry 4.0 technologies. Nevertheless, this kind of improvement requires that also suppliers seek digitalization; for this reason, it is more complex to achieve.

Figure 3.20: Internal changes due to the adoption of Industry 4.0 technologies (Author's elaboration)[32]



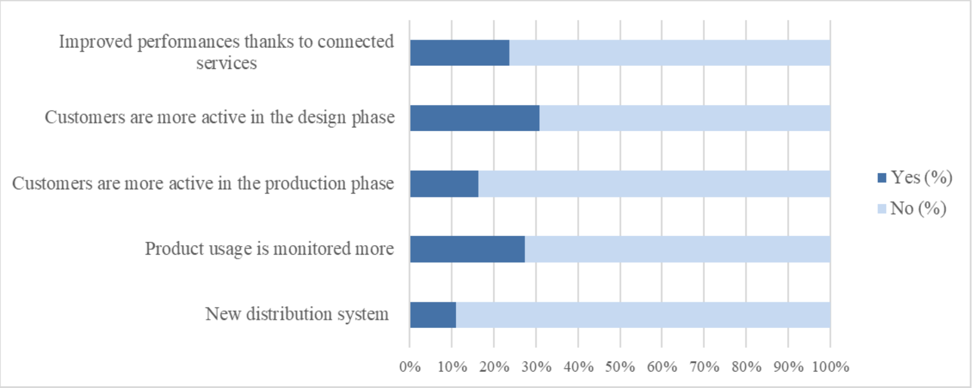
As for occupation, interviewees declared that the adoption of Industry 4.0 technologies did not provoke the reduction of workers: 41% of companies recorded an increase of their workforce

[31] This analysis was performed considering as actual problems only those issues that were assigned "4" or "5" in the Likert scale question by respondents. 59 Respondents answered this question.
[32] Number of respondents: 57

because of the investment in Industry 4.0 technologies, all the others did not change their number of employees. No interviewee signalled a reduction in the workforce because of the adoption of the cited technologies. We cannot know if those answers are due to respondents' bias; nevertheless, this data is promising.

Industrie 4.0 was presented since the beginning as a phenomenon that "will lead to the development of new business and partnership models that are far more geared towards meeting individual, last-minute customer requirements" (Kagermann et al., 2013, p.22). Kagermann et al. (2013) predict a scenario in which "the new business models will provide solutions to issues such as dynamic pricing that takes account of customers' and competitors' situations and issues relating to the quality of service level agreements (SLAs) in a context characterised by networking and cooperation between business partners" (p.22). For this reason, we decided to ask managers and ICT experts whether technologies 4.0 are impacting the role of customers and the services offered to them. The answers that have been collected are below the expectations. As the question required interviewees to indicate the degree of impact of Industry 4.0 technologies following a Likert Scale (where 1 mean "Not at all" and 5 stands for "very much"), we decided to consider as significant changes only the elements that were evaluated with a 4 or 5, as in all the other Likert Scale questions. As a matter of fact, no listed item was achieved by more than 31% of question respondents (55). Even if only 60% of adopters answered this question, results do not suggest a particular impact on both customer empowerment and services yet.

Figure 3.21: Product changes due to the adoption of Industry 4.0 technologies (Author's elaboration)[33]



Instead, firms declared to have increased their innovation capabilities thanks to the investments: 86% of respondents (58) enhanced this aspect of their performances. Sustainability improvements had a similar trend of customers' empowerment: only 30% of answerers achieved significant reductions of waste and input usage thanks to the installation of smart

[33] Number of respondents: 55

manufacturing technologies. Other potential green benefits, like the recycling of waste, a more traceable and greener supply chain, and the emissions reduction have been achieved by a significant smaller portion of the sample. Again, we asked interviewees to assess through a Likert Scale their degree of sustainable improvements achieved through the studied investments. In this scale, 5 stands for “very much” and 1 for “not at all”. To facilitate the interpretation of answers, we decided to retain as significant impacts only those elements evaluated with a 4 or a 5. With this interpretation, “Yes” refers to “significant changes”, while “No” to “Not significant Changes”. Table 3.25 summarizes results (top scores are in light blue).

Table 3.25: Sustainability benefits – Industry 4.0 technologies (Author’s Elaboration)

Benefits	4 - 5 (Freq.)	Lower scores (Freq.)	4 - 5 (%)	Lower scores (%)
Waste reduction	17	40	30%	70%
Input reduction	17	40	30%	70%
Adoption of more sustainable materials	9	48	16%	84%
Improved supply chain traceability	12	45	21%	79%
Recycling of waste	8	49	14%	86%
Reduction of environmental impact	12	45	21%	79%
Recycling of waste from other companies	3	54	5%	95%
"Greener" supply chain	2	55	4%	96%
Other	0	57	0%	100%
Respondents	57			

3.4.5 Supply Chain – Distribution

In the last section of the questionnaire, we investigated mainly the supply chain of firms. For example, we asked the weight of the most important customer on turnover, how much B2B activity is performed, how much of the production occurs abroad, and so on. We considered “finished products for final consumers” as B2C activity, and “finished products for other companies”, “semi-finished products”, and “components” as B2B.

Table 3.26: Customers and production distribution – Average values (Author’s elaboration)

Sectors	Customers			Production (% of its value)		
	First customer weight (% of turnover)	B2C (% of turnover)	B2B (% of turnover)	Region	Other Italian regions	Foreign countries
Electrical Motors and parts	23%	11%	89%	64%	28%	8%
Electric lighting	23%	68%	32%	74%	18%	9%
Motor vehicles and trailers	30%	6%	94%	48%	40%	12%
Furniture	26%	69%	31%	48%	51%	2%
Jewellery	29%	41%	59%	69%	31%	0%
Glasses and lenses	43%	33%	67%	94%	2%	4%
Sport goods	29%	0%	100%	98%	0%	2%
Other activities	23%	5%	95%	50%	50%	0%
Respondents	60	63		66		

The sample is characterized by firms that depend significantly on their most important customer: on average, the first customer is responsible for 28.69% of turnover. Tables 3.26 and 3.27, summarize results for what concerns supply chain distribution and type of production for respondents.

The majority of firms realizes components, semi-finished goods, and parts for B2B customers (see Table 3.26). Few sectors focus more on the final customer, like electric lighting and furniture (68% and 69%, respectively). As for production, most companies perform their operations in the region in which they are located (for this reason, it was also decided to use the operational headquarters location to include geographical controls in the regressions of the empirical analysis), and almost the totality in Italy: only the manufacture of vehicles and trailers performs abroad more than 10% of their production value (12%) on average. The sectors with the highest average production portion in the region in which the firm is located are the manufacture of glasses and lenses and the manufacture of good sports.

Table 3.27: Suppliers' distribution and type of production (Author's elaboration)

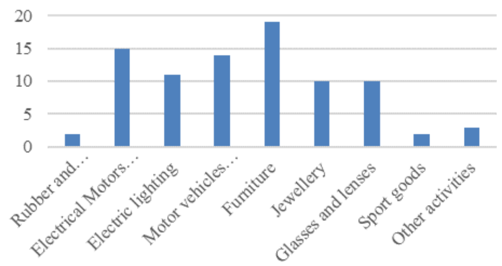
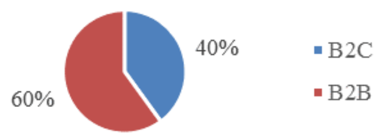
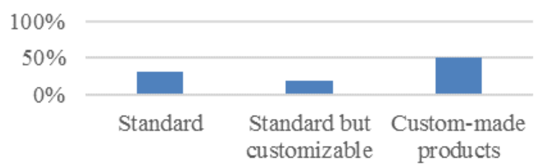
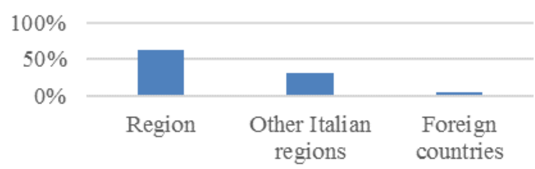
Sectors	Suppliers			Type of production (% of its value)		
	Region	Other Italian regions	Foreign countries	Standard	Standard but customizable	Custom-made products
Electrical Motors and parts	24%	49%	27%	42%	27%	31%
Electric lighting	46%	33%	21%	42%	19%	40%
Motor vehicles and trailers	32%	51%	17%	14%	21%	65%
Furniture	38%	52%	10%	33%	19%	49%
Jewellery	43%	40%	17%	27%	28%	46%
Glasses and lenses	41%	32%	27%	27%	3%	70%
Sport goods	70%	30%	0%	0%	0%	100%
Other activities	0%	85%	15%	30%	13%	58%
Respondents	62			66		

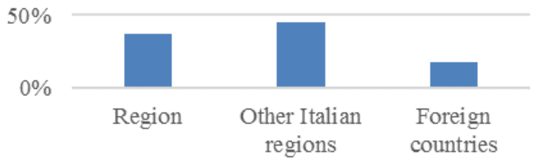
Even suppliers are mostly located in Italy, on average. What is interesting to observe it that sectors characterized by high percentages of production in Italy rely relatively more on foreign suppliers: for example, manufacturers of glasses and lenses produce 98% of their goods in the region in which they are located but purchase 27% of their inputs from foreign suppliers. Similar situations are evident with the manufacture of electrical motors and parts (27% foreign suppliers) and the manufacture of jewellery, which has no production abroad.

As expected from the analysis of the B2B-B2C portions of firms' activity, respondents produce mostly customizable and custom-made products: as they work for other producers, they have to comply with specific demands and requirements to satisfy the needs of their customers. Moreover, most companies are small and micro ones and rely significantly on human capital.

Finally, combining all information collected about adopters, we can present an "adopters' profile" to describe their principal characteristics (Table 3.28).

Table 3.28: Adopters' Profile (Author's elaboration)

Category	**Description**
Size - turnover	Micro / Small (below 10 million euro) ~ 85%
Size - workers	Micro / Small (fewer than 50 workers) ~ 88%
Location	Lombardy or Veneto ~ 77%
Sector	
Most adopted Industry 4.0 technologies	Robotics, Additive Manufacturing, Laser Cutters, Big Data & Cloud. 94% of adopters purchased at least one of these four technologies between 2007 and 2013 (on average)
Most adopted information technologies	Website, CAD/CAM, CNC, Social Media Website is present in 99% of adopters.
ROE 2016	~ 11%
First customer weight	~ 29% of total turnover
B2B – B2C	
Type of output	
Operations location	

Suppliers location	

4 THE RELATIONSHIP BETWEEN INDUSTRY 4.0 TECHNOLOGY AND FINANCIAL PERFORMANCE

Since the diffusion of the concept, Industry 4.0 has been promoted as the solution to achieve benefits in terms of flexibility, productivity, revenues. Gilchrist (2016), for example, prepared a list of main benefits that Small and Medium Enterprises (SMEs) should achieve thanks to Industry 4.0:

1. *Increased competitiveness of business*. SMEs could start to cooperate more to challenge large companies. Small firms could act as a unique organization to increase their bargaining power and/or to achieve economies of scale.
2. *Increased productivity*. Industry 4.0 tools should enable companies to improve their efficiency: their operational costs reduction should lead to improvements in productivity.
3. *Increased revenues*. the author expects benefits in terms of increased turnover for manufacturing firms. Moreover, returns on investments are expected to drastically increase.
4. *Improvements in employment rates*. Industry 4.0 has the potential to improve the demand for talented workers in the following fields: engineering, data sciences, mechanical and technical work, etc.
5. *Optimization of manufacturing processes*. The integration of Information Technologies (IT) with Operational Technologies (OT) should lead to improvements in efficiency.
6. *Development of exponential technologies*. Industry 4.0 technologies are only the starting point to develop newer technologies: in other words, they should start a virtuous circle in which technologies are exponentially improved.
7. *Delivery of better customer service*. New technologies allow to monitor product performances and improve supply chain traceability, thus improving customer service.

Kagermann et al. (2013) pointed out the importance that Industry 4.0[34] has for the creation of innovative business models. "Industry 4.0" is a paradigm that needs to be gradually applied: the value of existing production systems must be preserved, and it is important to come up with "migration strategies that deliver benefits from an early stage" (p.19).

Nevertheless, studies that discuss the effects of Industry 4.0 technologies on a firm's financial performances are still lacking. As a matter of fact, in the literature review conducted through

[34] They actually referred to Industrie 4.0, but the idea behind is the same.

SCOPUS, mostly technical articles were retrieved, even if they were tagged as “business, administration, and accounting” ones. There were no papers that studied if there are differences in financial performances between firms that adopt these innovative tools and the ones that do not.

From this idea, the first Research Question was developed.

Q1: What is the impact of Industry 4.0 technologies on financial performance?

Often the focus is on technologies and the accumulation of all these tools to improve performances. Magone and Mazali (2016) visited several Industry 4.0 “champions” that are using simultaneously all the technologies that the fourth industrial revolution promotes. For this reason, studying the impact of Industry 4.0 technologies implies studying also what is the optimal number of type of tools that firms should adopt and verifying the existence of a cumulative effect of the described innovative technologies.

For the analysis, it was chosen to ask Italian manufacturing companies to answer a survey. This fact affected the creation of another last question. In fact, Italy currently is lagging behind several European countries for what concerns ICT skills and training inside businesses (see Table 4.1). So, it should be more difficult for technologies that need data scientists and analysist to affect financial performances; while technologies that have a direct and ‘physical’ impact in the production function should be the most effective ones.

Table 4.1: Percentage of firms that hire ICT specialists (source: Eurostat[35])

GEO/TIME	2012	2014	2015	2016
EU28	21%	20%	20%	20%
Spain	22%	25%	25%	25%
France	15%	15%	16%	16%
Italy	14%	15%	17%	17%
Germany	21%	22%	21%	22%
United Kingdom	30%	24%	22%	23%

So, here the last question:

Q2: Which technologies or technology combinations do affect financial performance?

To answer this question, we tried to verify if the adoption of a technology bundle that contains a particular technology is superior to others. Finally, to confirm previous results, we analysed if a non-adopter of a specific technology gains from making that particular investment, inputting all individual technologies in the same model.

[35] Accessed on 25 September 2017

4.1 The Financial Performance Measurement

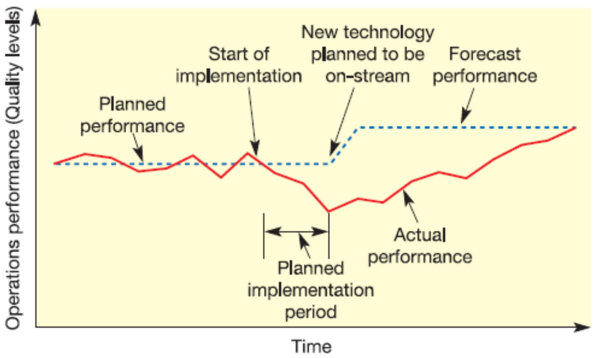
As for the right financial performance index to consider, we decided to use ROE as "it tells you what percentage of profit you make for every dollar of equity invested in your company", as said by Joe Knight, author of "HBR Tools: Return on Investment" (Gallo, 2016). Nevertheless, one analysis was performed also considering Return on Assets in order to control that all the effects investigated were not due only to extraordinary activities. Both values were directly downloaded from AIDA. The formula for the ROE is:

$$ROE = \frac{Net\ Income}{Equity}\%$$

To select the years to analyse technology-related effects on financial performance, we had to balance four main facts:

1. We took into consideration that the adoption of any technology always needs to overcome some "adjustment" issues that occur when important internal changes are made. Slack et al. (2013) refer to "adjustments" as "the losses that could be incurred before the improvement is functioning as intended" (p.245). The authors discussed implications of Murphy's Law on process-technology adoption. This effect seems to prevail for any technology-related change. So, any benefit sought is achieved later than planned, and the path that must be followed is not as easy as planned. Figure 4.2 provides an example of this concept.

Figure 4.1: The reduction in performance during and after the implementation of a new process (Slack et al., 2013)



2. The samples that we analysed (both adopters and non-adopters) are big, but limited: considering only technologies adopted up to a certain year would decrease adopter's group. In fact, once the year (or years) to monitor performance was chosen, the next step consisted in clearing the database considering those technologies that were adopted after the considered period of time.

3. Adopting a single distant year would provide biased results: in the period of time that ranges between technology adoption and financial results other unknown phenomena could have occurred; so, any relationship between Industry 4.0 technology and performance could be casually provoked.
4. To avoid the adoption of final year performances biased by exceptional events, it was necessary to consider a period of time. Moreover, a period of time of three years was deemed as minimum to observe performance trend in relation with the previous adoption of technologies.

Considering these aspects, it was decided to consider the average value of Return on Equity over years 2016, 2015, and 2014. As a direct consequence, we had to consider only those technologies adopted before 31 December 2014. In this way, we limited both adopters' sample reduction, and technology-related effects are less dispersed as we are not considering a single recent year (like 2016 alone). Unfortunately, the considered span of time takes into account also those adjustments related to process-technology adoption (Slack et al., 2013), in particular for those technologies adopted during 2014. Nevertheless, this choice was deemed as the most appropriate one.

Table 4.2 provides descriptive statistics of the variable *avg_roe*, which includes the average return on equity over years 2016, 2015, and 2014.

Table 4.2: Average ROE over 2016, 2015, and 2014 (Author's elaboration)

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
avg_roe	426	-.2142	.4501	.107682	.1270307
Valid N (listwise)	426				

In the following analyses, to take sectors in which respondents work into account, it was decided to consider as main variable a normalized average Return on Equity. We decided to normalize ROE using the mean value for each sector.

To compute this variable, AIDA was used. We selected all sectors that have been analysed and we downloaded information about return on equity for years 2016, 2015, and 2014. We considered the first two digits of the ATECO code of each firm in order to download information. Each sector was input in an individual spreadsheet to avoid confusion. Then, through the Excel formula "*mean*", the average value over the years selected was computed for each downloaded row. Rows for which the return on equity was not available for one of the three considered years were dropped. Then, for each sector, the mean average ROE was computed. In the database, the original average ROE value for each firm was divided by this "sectorial mean average ROE", depending on the sector of activity.

A particular process had to be followed to obtain a normalized average ROE for the firms that were classified in the sector "other". In fact, these companies did belong to several sectors. For this reason, we decided to download information from AIDA for each one of these "other" sectors. Then, for each sector we performed the same procedure described before: we computed the average ROE value for each row, we dropped the rows with missing information and we calculated the mean value of the whole sector. Then, to have a unique value to normalize the average ROE of these firms, we calculated the weighted mean of this data; we used as weights the number of companies "in other" that belonged to the same sector. The simple mean was not feasible because two companies belonged to the same sector. We could have considered these firms in "other sector" individually, but we preferred to keep considering them as a single category. Nevertheless, differences in results would have been only marginal as the category consists of few firms (9 companies).

As previously stated, the choice concerning the period of time to measure performance impacted the variable for technology-adoption. To distinguish adopters from non-adopters, a dummy variable was created. This variable was created considering the answers to questions 3) and 12) of the survey, in which we asked interviewees whether they were adopting one of the listed technologies (robotics, additive manufacturing, laser cutter, Big Data and cloud, 3D scanner, augmented reality, and/or the Internet of Things) or not, and the year of adoption for each one of the listed technologies. We adopted the following procedure:

1. We created a dummy variable for each technology included in question 3). This step was already performed during the analysis of the survey. These variables assumed value 1 if the considered technology was adopted, 0 otherwise; independently from the year of adoption.
2. We dropped those technologies that were adopted in 2015, 2016 and 2017. The effect of these technologies on financial performance could not be studied yet.
3. We summed the number of technologies (variety) for each respondent.
4. We created a dummy variable that assumes value 1 if the sum of technologies is greater than 0. After this phase, we obtained a lower number of adopters than the one obtained during the descriptive analysis. As a matter of fact, adopters decreased from 86 to 77.

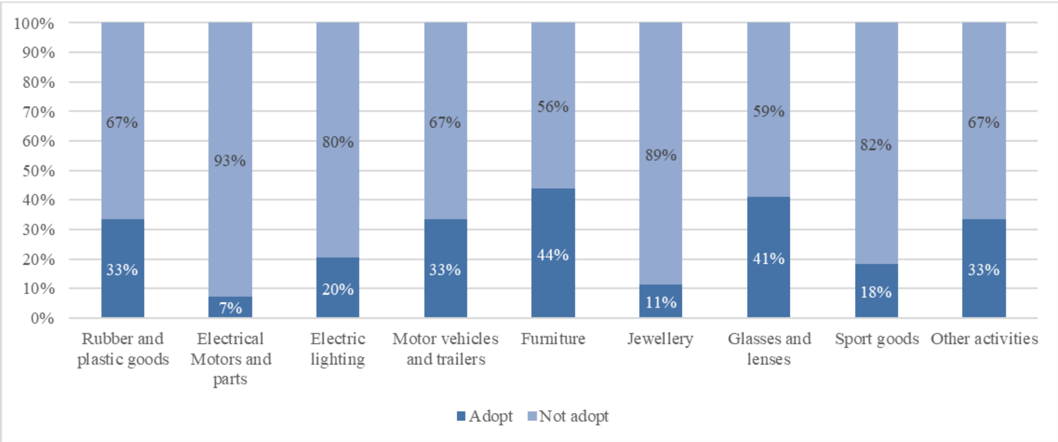
Table 4.3 summarize the main differences with the initial cleaned database.

Table 4.3: Adoption of technology – 31/12/2014 (Author's elaboration)

	Robotics	AM	Laser Cutter	Big Data & Cloud	3D Scanner	Augmented Reality	IoT	Not adopted
All technologies	43	36	41	37	14	15	19	340
Technologies up to 31 December 2014	36	33	36	30	10	11	13	349
Difference	7	3	5	7	4	4	6	-9

On average, each technology decreased by 5.14 adoptions. The initial choice concerning the range of time to compute the average ROE limited the reduction of adopters to be analysed. Their composition was not subject to major changes: except for rubber (with low respondents), each sector reduced by more or less 2% its percentage of adoption (See Figure 4.3).

Figure 4.2: Adopters, per sector – 31/12/2014 (Author's elaboration)



As for geographical distribution of adopters, there were not important differences again (see Figures 4.4 and 4.5). Percentages are equal or lower because some firms purchased their Industry 4.0 technologies only after 31 December 2014.

Figure 4.3: Adopters, per region – 31/12/2014 (Author's elaboration)

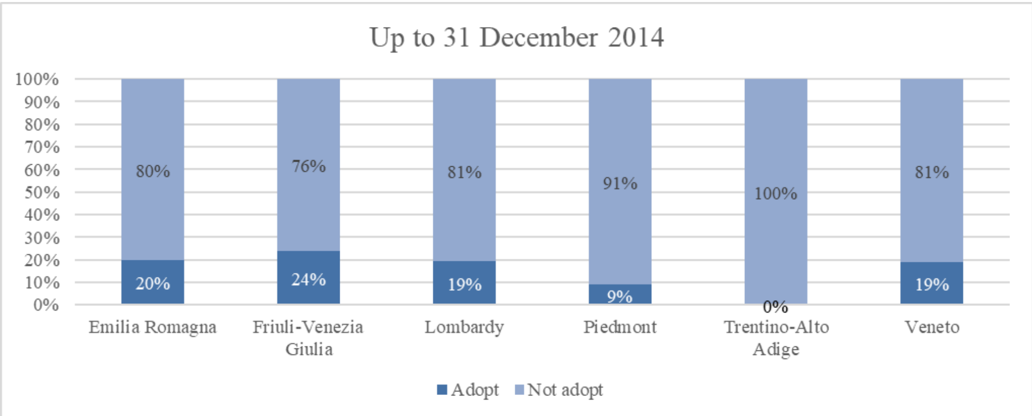
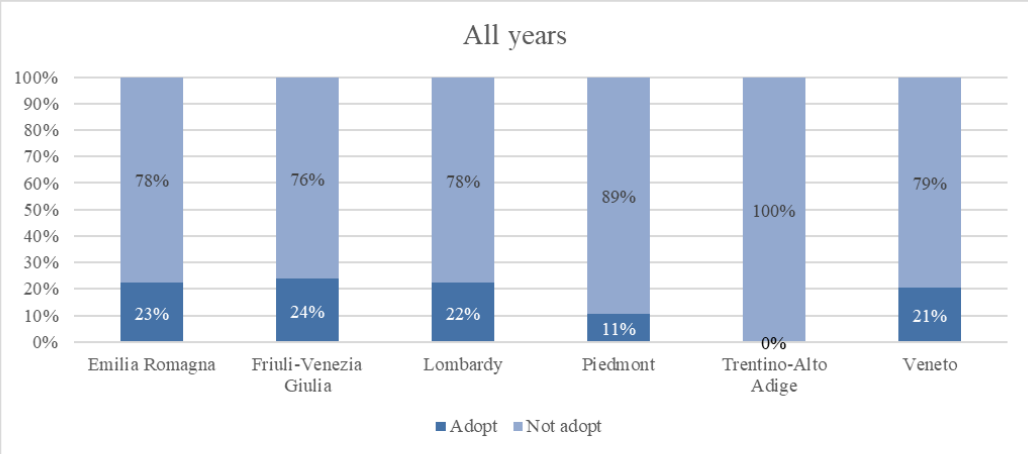


Figure 4.4: Adopters, per region – 15/09/2017 (Author's elaboration)



4.2 Performance Differences Between Adopters and Non-Adopters

After having decided how to compute the main variable to measure financial performances and having arranged the dummy variable concerning the adoption of Industry 4.0 technologies, analyses took place.

In this section, we try to answer the first question, concerning the presence of a significant and positive effect of Industry 4.0 technologies on financial performance. This check was performed comparing the means of the normalized average value of the return on equity of adopters and non-adopters. In other words, we tested for equality of means.

Additionally, we performed also a t-test to check whether there are differences in size between adopters and non-adopters. In both cases we looked at the confidence interval at the 95% level.

First, the variables that will be input to run these tests are described. Then the assumptions of the t-test are presented and discussed. Finally, analysis results are commented.

4.2.1 Variables

Since the main aim of this thesis consists in understanding whether Industry 4.0 technology could affect significantly financial performance or not, we decided to consider for each respondent the average value of return on equity over 2016, 2015, and 2014. In fact, this variable has been the most important criterium to clean the database since the beginning. To consider sector-related effects on ROE we decided to normalize values. The variables are:

- *Normalized Average ROE*. This variable was obtained as described before: for each firm, we divided individual average ROE (computed considering years 2016, 2015, and 2014) for sectorial average ROE; this information was retrieved from AIDA.

- *Normalized Average Number of Workers*. To compute this variable, AIDA was used again. As a matter of fact, the information used to normalize the average number of workers was already downloaded together with the information concerning the return on equity. Again, rows that did not have enough data to calculate the average number of workers were dropped. Then, the mean of the remaining average values was computed for each sector. Afterwards, in *database_4ir* the average number of workers for each row was divided by sector average values, in order to create the normalized variable. For "Other Sector" we used a weighted mean to normalize, as for average ROE.

Table 4.4: AIDA – Information per sector (Authors' elaboration)[36]

ATECO	Description	Number of firms	ROE		Number of workers	
			Number of firms with ROE	Mean of Average ROE	Number of firms with No. workers	Mean of Average Number of Workers
22	Manufacture of rubber and plastic goods	8,180	4,104	10.72%	4,491	28.83
27	Manufacture of electric goods (motors, batteries, wires, and lighting devices)	7,689	3,852	9.78%	3,397	31.18
29	Manufacture of vehicles and trailers	2,493	1,187	9.16%	1,033	113.20
31	Manufacture of furniture	9,103	3,760	7.81%	3,151	19.78
32	Manufacture of other goods (glasses and lenses, jewellery, sport goods)	7,085	3,198	8.58%	2,809	28.83
Other sectors						
16, 25, 28, 45, 46, 47, 70, 81	Support activities, like manufacture of metal parts, maintenance of vehicles, etc.	418,090	149,338	10.22%	159,515	21.86

- *Adoption of technology*. To divide the whole sample into two independent ones, we used the dichotomous variable that assumes value "1" if the respondent adopted a technology up to 31 December 2014, "0" otherwise. As described before, this variable was obtained deleting those technologies that were adopted in years 2015, 2016, and 2017. Through SPSS, it was possible to specify that the first independent sample was composed by only

[36] We did not round values to normalize. We kept all decimals. Information was downloaded on 21 October 2017

those firms that adopted technologies before 31 December 2014, while the second one was composed by companies that did not adopt technologies yet.

Table 4.5: t-test – Variables (Author's elaboration)

	Variabile Name	Variable lable	Description
A)	avg_roe	Average ROE (over 2016, 2015, 2014)	It is the mean of the returns on equity achieved by each firm in the years 2014, 2015, and 2016
B)	sector_avg_roe	Sector Mean of the average ROE (over 2016, 2015, 2014)	It is the mean for the sector of the average ROE over years 2014, 2015, and 2016. It was calculated considering all the firms with enough information that belong to a specific ATECO code (only the first 2 digits were considered)
C)	norm_avg_roe	Normalized average ROE	C = A / B
D)	tech_adop	Adoption of Industry 4.0 technology	Dummy (0,1): this variable assumes value 1 if the firms adopted an Industry 4.0 technology up to 31 December 2014.

4.2.2 Assumptions

The assumptions to be verified are the following:

1. The two samples must be casually independent from one another;
2. Each sample must have a normal distribution.

Moreover, through SPSS we could analyse both cases concerning the equality of variances of the two independent samples.

As for normality, we looked at histograms of both samples. The samples created for the comparison of normalized average ROE present a distribution that seems to fit a normal one, while the ones that have been created for the comparison of normalized average number of workers are characterized by a skewed distribution (see Appendix B): this is due to the fact that the sample is composed mostly by micro- and small-enterprises, thus making values lean on the y axis. Nevertheless, samples are big enough. Often, dependent variable scores are not normally distributed, "but most of the techniques are reasonably robust or tolerant of violations of this assumption" (Pallant, 2007). With samples with more than 30 elements, the violation of this assumption should not be a relevant problem. Moreover, from the central limit theorem, we know that in big samples "the sampling distribution tends to be normal […] regardless of the shape of the data that we actually collected" (Field, 2009). This procedure was confirmed by considering other authors' works like Elliott and Woodward's one, which remind that "if your sample size (for each group) is large (say, greater than 40), you can invoke the central limit theorem to justify using parametric procedures based on means, even when the data are not normally distributed" (2007, p.26).

4.2.3 T-Test – Normalized Average ROE

The test was run using SPSS, a software by IBM. Following, tables concerning normalized average ROE comparison are presented and discussed.

Table 4.6: Normalized average ROE – Group Statistics and t-test (Author's elaboration)

Group Statistics					
	Adoption of Industry 4.0 technology	N	Mean	Std. Deviation	Std. Error Mean
Normalized average ROE	1.00	77	1.502904	1.6256372	.1852585
	.00	349	1.102854	1.3250118	.0709263

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Normalized average ROE	Equal variances assumed	7.363	.007	2.296	424	.022	.4000501	.1742175	.0576125	.7424877
	Equal variances not assumed			2.017	99.445	.046	.4000501	.1983715	.0064597	.7936404

Even before performing the test, it was immediately observable that the mean of normalized average ROE is greater for adopters than for non-adopters. Nevertheless, this information was insufficient to state that the difference between the two means is significant.

First, we should look at the row "Equal variances not assumed", as Levene's test is significant. As shown in the output tables above, there seems to be a difference in normalized average ROE values between adopters and non-adopters. We can reach this conclusion looking at the value of *t*, at *p-values,* or at the *Confidence Interval of the difference*.

The 2-tailed significance is below 0.05 and 0 does not belong to the 95% confidence interval of the difference. Therefore, there actually is a significant difference between the mean of the normalized average ROE values (at the 0.05 level).

Using r equivalent (Rosenthal and Rubin, 2003) we can assess effect size (Field, 2009). The formula adopted is:

$$r = \sqrt{\frac{t^2}{t^2+df}} = \sqrt{\frac{2{,}017^2}{2{,}017^2+99.445}} = 0.1982$$

The formula gave an r equivalent equal to 0.1982, which indicates a small-medium effect.

4.2.4 T-Test – Normalized Average Number of Workers

A first look at mean values of normalized average number of worker shows greater values for adopters of Industry 4.0 technologies. Nevertheless, this is not sufficient to prove the existence of a significant difference between mean values. Therefore, it was necessary to perform the t-test as before.

Table 4.7: Normalized average number of workers – Group Statistics and t-test (Author's elaboration)

Group Statistics					
	Adoption of Industry 4.0 technology	N	Mean	Std. Deviation	Std. Error Mean
Normalized average number of workers	1.00	77	1.913147	2.7700164	.3156727
	.00	349	.664427	.7720059	.0413245

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Normalized average number of workers	Equal variances assumed	98.052	.000	7.263	424	.000	1.2487197	.1719211	.9107959	1.5866435
	Equal variances not assumed			3.922	78.622	.000	1.2487197	.3183661	.6149806	1.8824588

Also in this case, Levene's Test rejects the null hypothesis that the variances are equal (sign. lower than 0.05), so it is necessary to look at the bottom row. Again, firms' size is confirmed to be significantly greater on average for adopters rather than for non-adopters. P-value is below 0.05, thus confirming that there is a chance lower than 0.05 that "a value of t this big could happen if the null hypothesis were true" (Field, 2009, p.331). As a matter of fact, the 95% Confidence Interval of the Difference does not comprise 0, thus rejecting the null hypothesis that the mean values are equal.

Rosenthal's r equivalent has the following value:

$$r = \sqrt{\frac{t^2}{t^2+df}} = \sqrt{\frac{3.922^2}{3.922^2+78{,}622}} = 0.4045$$

The obtained value confirms a medium-large effect.

The first research question has been partially answered. We were able to find significant differences concerning financial performance and size between firms that adopted Industry 4.0 technologies and the ones that did not. Nevertheless, this analysis, and in particular the first t-test concerning the normalized average ROE value, are not sufficient to study the effect of the adoption of Industry 4.0 devices.

4.3 Technology Adoption and Financial Performance

To confirm previous results and answer to the other research question, we decided to run multiple linear regression analyses. We built up several models in order to study the effect of technology adoption when it is considered together with other variables, like firm's size, age, sector ("included" in the dependent variable), and region. We decided to adopt this method because the interpretation of the level of significance of individual coefficients is used to accept or reject the null hypothesis that the considered Beta may be equal to zero given the presence of all other independent variables in the model. Moreover, given the sign of the beta, we were able to assess the effect of a selected independent variable on the dependent one. We were looking for a positive and significant coefficient for the dummy variable concerning the adoption of Industry 4.0 technology, indeed: such event would be translated into a positive and significant effect of the described tools on financial performance.

4.3.1 The Main Dependent Variable

This section aims at studying what is the effect of Industry 4.0 technologies on financial performance. As described before, we decided to use the average return on equity over years 2016, 2015, and 2014 as the starting point. It was used as main criterium to "clean" the database since the beginning, as it was used to drop missing values and outliers (5% top and 5% bottom value). Moreover, we took already into account in this phase the impact of each sector: as dependent variable, we picked the normalized value of the average ROE, as we did to perform the t-test to compare means of adopters and non-adopters. In this way, the financial performance measure picked already considers sector-related effects.

Tables 4.8 and 4.9 presents the details concerning the main dependent variable.

Table 4.8: Dependent variable – Details (Author's elaboration)

Variable Name	Variable Label	Type	Description
avg_roe_norm	Normalized Average ROE (over years 2016, 2015, 2014)	Dependent Variable	Calculated from the information downloaded from AIDA. It is obtained as individual average of the ROE at the end of the years 2016, 2015, and 2014 divided by the sectorial mean average ROE for the same years.

Table 4.9: Dependent variable – Descriptive Statistics (Author's elaboration)

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
avg_roe_norm	426	-2.19	5.23	1.1752	1.39065
Valid N (listwise)	426				

4.3.2 The Independent Variables

The main independent variables that have been used are presented in Table 4.10. These variables concern firms' adoption of Industry 4.0 technologies, firms' size, age, sector of activity, and region. For the analyses concerning both number and type of technology that affect financial performance the most, additional variables will be presented in the following sections.

Table 4.10: Independent variables – Model 1 (Author's elaboration)

Variable Name	Variable Label	Type	Description
tech_adopt	Adoption of Industry 4.0 technology	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firms adopted Industry 4.0 technologies before 31 December 2014.
avg_size	Average number of workers (2016, 2015, 2014)	Independent variable	Calculated from the information downloaded from AIDA. It is the average value of the number of workers at the end of years 2014, 2015 and 2016.
avg_age	Average Age (2016, 2015, 2014)	Independent variable	Calculated from the information downloaded from AIDA. It is the average number of years obtained as difference between the date of foundation and the following dates: 31/12/2016, 31/12/2015, and 31/12/2014.
reg_emiliar	Business location: Emilia Romagna	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm is located in Emilia Romagna.
reg_friulivg	Business location: Friuli-Venezia Giulia	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm is located in Friuli-Venezia Giulia.
reg_lombardy	Business location: Lombardy	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm is located in Lombardy.
reg_piedmont	Business location: Piedmont	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm is located in Piedmont.
reg_trentinoaa	Business location: Trentino-Alto Adige	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm is located in Trentino-Alto Adige.

Variable Name	Variable Label	Type	Description
reg_veneto	Business location: Veneto	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm is located in Veneto.

As direct consequence of including sector-related effects in the dependent variable, we did not have to include dummy variables for each sector in the model. The other independent variables are:

- *Adoption of Industry 4.0 technology*: this is the variable that was created considering the answers to the questions 3) and 12) of the survey, concerning the type of technology adopted (industrial robots, additive manufacturing, laser cutter, Big Data and cloud, 3D scanner, augmented reality, and/or the Internet of Things) and the year of individual technology-adoption. As described before, adopters were reduced after this processing: they were 86, then they became 77. Those 9 companies of difference adopted Industry 4.0 technologies only in 2015, 2016, or in the first months of 2017. This dummy variable assumes value equal to 1 if the interviewee adopted an Industry 4.0 technology before 31 December 2014; 0 if they did not adopt any technology up to that date.
- *Average number of workers*: for this variable, we used the information downloaded from AIDA. For each row, we calculated the average number of employees over the three years considered (2016, 2015, 2014). Then, we created a specific new variable to input this information. The database cleaning described in Chapter 3 already eliminated those rows that did not have this information available.
- *Average Age (2016)*: to create this variable, information retrieved from AIDA was used again. This variable regards the average age of respondents. To compute this variable:
    1. We downloaded information about the date of foundation;
    2. We computed the difference, in years, between the date of foundation and the following dates: 31/12/2016, 31/12/2015, and 31/12/2014.
    3. We calculated the average value for each row and input results in a new variable: *avg_age*.
- *Region*: this information was retrieved from AIDA too. As for sectors, also in this case we created a dummy variable for each region. Each dummy assumes value 1 only if the business is located in that specific region. Dummy variables for the following regions were created: Piedmont, Lombardy, Friuli-Venezia Giulia, Trentino-Alto Adige, Veneto, and Emilia Romagna. Companies that had a location different from these ones were already dropped during the database cleaning: they did not have enough

information available to compute the average value of ROE. For this reason, it was not necessary to create a seventh variable to include those residual locations.

The main variable is the one concerning the adoption of technologies up to 31 December 2014. The others have been included as control variables to isolate technology-related effects as much as possible with the available information. The comparison of means t-test between adopters and non-adopters already showed some differences between the two categories. But, that analysis did not isolate technology-related effects: different compositions in terms of age, region, and size could have affected normalized average ROE too, even if we took into consideration sectorial differences by normalizing values.

Table 4.11 summarizes the basic statistics of the main variables.

Table 4.11: Independent variables – Model 1 – Descriptive Statistics (Author's elaboration)

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
tech_adopt	426	.00	1.00	.1808	.38526
avg_size	426	.00	599.00	27.0599	50.48887
avg_age	426	1.00	104.00	22.3357	13.85989
reg_emiliar	426	.00	1.00	.0939	.29203
reg_friulivg	426	.00	1.00	.0493	.21674
reg_lombardy	426	.00	1.00	.3779	.48544
reg_piedmont	426	.00	1.00	.1315	.33830
reg_trentinoaa	426	.00	1.00	.0047	.06844
reg_veneto	426	.00	1.00	.3427	.47518
Valid N (listwise)	426				

4.3.3 The Model and Discussion

In the first regression, we wanted to control if a significant and positive relationship between technology and financial performance exist. The model is the following:

$$\begin{aligned} Y_i = cons + \ & \beta tech\_adopt_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i \\ & + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i \\ & + \beta reg\_trentinoaa_i + \epsilon_i \end{aligned}$$

Variable *reg_veneto* was dropped from the model to avoid perfect multicollinearity, as in all the following models. The analysis was conducted through SPSS. It was decided to obtain as output the following information for coefficients: unstandardized coefficients, standardized coefficients, t statistic, and significance level. Independent variables were forced inside the model as it was chosen the "enter" method. Nevertheless, SPSS did not automatically drop any variable, this result was expected as dummy variables were carefully created.

Table 4.12: Multiple linear regression – Model 1 (Author's elaboration)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.608	.151		10.632	.000
	tech_adopt	.438	.180	.121	2.426	.016
	avg_size	.000	.001	-.005	-.106	.916
	avg_age	-.024	.005	-.237	-4.863	.000
	reg_emiliar	.182	.243	.038	.746	.456
	reg_friulivg	-.018	.317	-.003	-.058	.954
	reg_lombardy	-.051	.156	-.018	-.330	.742
	reg_piedmont	.222	.214	.054	1.034	.302
	reg_trentinoaa	-.532	.964	-.026	-.552	.581

a. Dependent Variable: avg_roe_norm

Table 4.12 summarizes the results obtained through the multiple linear regression model. The regression provided the results sought. Average age has a significant and negative effect on normalized average ROE while size and region do not have a significant impact. But the most important result is the one concerning the coefficient of the adoption of Industry 4.0 technology: it is positive and strongly significant; its p-value is equal to 0.016, so it is significant at even the 5% level. This means that we can reject the null hypothesis by which the beta is tested to be equal to 0. This first model confirms what was already seen running the t-test to compare normalized mean values: Industry 4.0 technologies seem to affect positively and significantly financial performance. Considering unstandardized coefficients, we can observe how the adoption of an Industry 4.0 technology increases normalized average ROE by 0.438: this means that, holding information about average size, age, and location constant, firms that adopt at least one technology increase, on average, their normalized average ROE by 0.438. Considering that the dependent variable is a ratio, technology-related effects are not marginal.

The standardized coefficient "are in many ways easier to interpret - because they are not dependent on the units of measurement of the variables […] and they tell us the number of standard deviations that the outcome will change as a result of one standard deviation change in the predictor" (Field, 2009, p.239). For this reason, standardized coefficients are directly comparable. Considering this, *tech_adopt* is the most influent variable in the model, second only to average age. Nervertheless, we performed this analysis to verify the presence of a positive sign and significance for what concerns *tech_adopt* coefficient, we are not really interested in quantifying the impact of these technologies.

4.3.4 Multiple Linear Regression: Assumptions

Finally, for the previous model, we checked whether multiple linear regression assumptions were respected or not. We checked the assumptions only for Model 1 (Table 4.12), which is the most important one. In particular, we gave particular importance in avoiding the presence of multicollinearity in the model.

First, we checked that the mean value of residuals was equal to 0. SPSS output confirms this assumption (see Table 4.11). For this control, we saved residuals from the regression as a new variable, called RES_1. Then we computed descriptive statistics for this new variable.

Table 4.13: Residuals – Model 1 (Author's elaboration)

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
RES_1	426	-3.51486	3.65504	.0000000	1.33922298
Valid N (listwise)	426				

The second assumption we tested is the uncorrelation between predicted values and residuals. We created a variable for all the predicted values (obtained applying the model). These values were input in a new variable, called PRE_1.

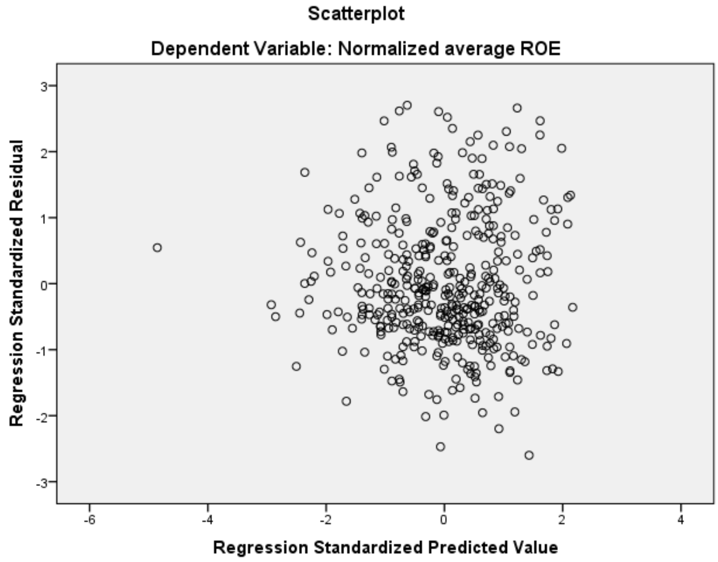
Table 4.14: Predicted values and residuals – Model 1 (Author's elaboration)

Correlations			
		PRE_1	RES_1
PRE_1	Pearson Correlation	1	.000
	Sig. (2-tailed)		1.000
	N	426	426
RES_1	Pearson Correlation	.000	1
	Sig. (2-tailed)	1.000	
	N	426	426

As it can be observed, considering Pearson Correlation and its significance, there is not significant correlation between residuals and predicted values (two-tailed significance is equal to 1.000).

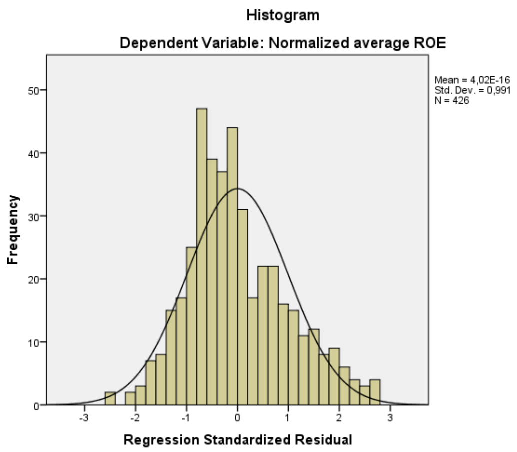
Moreover, standardized residuals and standardized predicted values were plotted running again the regression model. The scatterplot does not show any significant relationship between predicted values and residuals. The majority of dots is included between +3 and -3 of both axes. Only one outlier was detected.

Figure 4.5: Scatterplot – Standardized predicted values and residuals – Model 1 (Author's elaboration)



As for normality, we checked the histogram of residuals. Figure 4.6 shows a particular concentration around the mean value, but the histogram fits pretty well the normal curve. The histogram was obtained running again the regression model previously described.

Figure 4.6: Residuals distribution – Model 1 (Author's elaboration)



For multicollinearity, we checked Variance Inflation Factors (VIF) and condition indexes. As a rule of thumb, these values should not be greater than 10, or there could be problems of multicollinearity.

Table 4.15: Control for multicollinearity – Model 1 (Author's elaboration)

Coefficients[a]			
		Collinearity Statistics	
Model		Tolerance	VIF
1	tech_adopt_2014	.890	1.124
	avg_size	.877	1.140
	avg_age	.937	1.067

Coefficients[a]			
Model		Collinearity Statistics	
		Tolerance	VIF
	reg_emiliar	.851	1.175
	reg_friulivg	.913	1.095
	reg_lombardy	.753	1.329
	reg_piedmont	.817	1.224
	reg_trentinoaa	.988	1.012

a. Dependent Variable: avg_roe_norm

The largest VIF is the one concerning *reg_lombardy* but:

- Its VIF is far from exceeding 10, which is the threshold to be concerned about multicollinearity (Bowerman and O'Connell, 1990; Myers, 1990; Field, 2009). Moreover, the average VIF is the following:

  $\overline{VIF} = \frac{\sum_{j=1}^{k} VIF_j}{k} = 1.14575$ with k = number of predictors

  This value is close to one, thus confirming again that multicollinearity is not a problem of the model (Field, 2009).
- It is a control variable so, even if it had a greater value, it would not have been an issue (Allison, 2012).

Additionally, we controlled the condition index. As can be observed in the Appendix C, the largest condition index is equal to 5.011, which confirms that multicollinearity is not a problem besetting input data (Belsley et al., 1980).

4.3.5 A Test on Operating Performance

After having confirmed the presence of a significant and positive relationship between Industry 4.0 technology adoption and financial performance, we run a test on operating performance, in order to increase the robustness of the model proposed.

As dependent variable for this analysis, we decided to use the normalized average Return on Assets. First, we downloaded from AIDA (on 30 October 2017) information about ROA for years 2016, 2015, and 2014 for each element of the final database. Additionally, we downloaded this information for each involved sector. The formula used by AIDA is the one reported below.

$$ROA = \frac{EBIT}{TOTAL\ ASSETS}\%$$

Then, we calculated the average ROA over years 2016, 2015, 2014 for each respondent.

We performed the same operation also for each sector, in order to obtain a sectorial mean of the average ROA. To normalize the average ROA of each interviewed firm, we divided this value by its sectorial mean value. This procedure was performed considering the method followed to assign each firm to a specific sector. Again, for firms belonging to the category "Other", we used a weighted average mean as sectorial mean of the average ROA: we could also have considered each individual "Other" sector, in any case changes would have been only marginal (see Appendix C). Following the described process, we created two variables: "*roa_avg*" first and then "*avg_roa_norm*".

Table 4.16: Descriptive statistics – Normalized Average ROA (Author's elaboration)

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
roa_avg	426	-.09	.37	.0686	.06792
avg_roa_norm	426	-3.05	36.08	2.8008	3.37539
Valid N (listwise)	426				

The independent variables and controls are the same ones of the first model.
The multiple linear regression model used for this control is the following:

$$
\begin{aligned}
avg\_roa\_norm_i \\
&= cons + \beta tech\_adopt_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i \\
&+ \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i \\
&+ \beta reg\_trentinoaa_i + \epsilon_i
\end{aligned}
$$

Table 4.17: Multiple linear regression – Model 2 (Author's elaboration)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
2	(Constant)	3.156	.370		8.533	.000
	tech_adopt	1.892	.441	.216	4.285	.000
	avg_size	-.002	.003	-.026	-.514	.608
	avg_age	-.028	.012	-.115	-2.333	.020
	reg_emiliar	.039	.596	.003	.066	.948
	reg_friulivg	-.189	.775	-.012	-.244	.808
	reg_lombardy	.008	.381	.001	.021	.983
	reg_piedmont	-.154	.525	-.015	-.293	.770
	reg_trentinoaa	-.936	2.359	-.019	-.397	.692

a. Dependent Variable: avg_roa_norm

Results are reported on Table 4.17. Adopting Industry 4.0 technology has a positive and significant effect even on normalized average ROA. The analysis should be replicated on a database cleaned with a method centred on ROA, but these results are already reassuring. The p-value associated with *tech_adopt* is even lower than with ROE. For our analyses, we focused on ROE because we wanted to observe if technologies of the fourth industrial revolution could have a positive and significant effect on financial performance and final profitability. A suggestion for further developments of the present work would be to study the relationship of Industry 4.0 technologies on operating performance.

4.4 Technology Adoption: Cumulative Effects

After assessing the presence of a significant and positive relationship between Industry 4.0 technology adoption and financial performance, we tried to study if firms' performances are also related to the number of different tools they decided to implement. Most adopters (49 out of 77) relied on more than one technology up to 31 December 2014, indeed. For this reason, and given the fact that famous Industry 4.0 "champions" do not rely on a single technology (Magone and Mazali, 2016), we decided to check if the number of different technologies exploited affected financial performance too.

4.4.1 Variables

The main changes in the following models are due to the fact that the variable related to the adoption of Industry 4.0 technology was replaced with other ones to classify adopters considering the number of tools they were exploiting.

Table 4.18: Independent variables – Number of technologies (Author's elaboration)

Model	Name	Label	Type	Description
3	number_tech	Number of different adopted technologies (Variety)	Independent Variable	It is the number of different Industry 4.0 technologies each firm adopted up to 31/12/2014. Non-adopters have this variable equal to 0 (zero).
4	one_tech	Adoption of only one technology	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the enterprise adopts only one Industry 4.0 technology.
	two_tech	Adoption of two technologies	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the enterprise adopts only two Industry 4.0 technologies.
	three_tech	Adoption of three technologies	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the enterprise adopts

Model	Name	Label	Type	Description
				only three Industry 4.0 technologies.
	more_tech	Adoption of at least four technologies	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the enterprise adopts four or more Industry 4.0 technologies.
	Zero_tech	Adoption of no technologies	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the enterprise does not adopt any Industry 4.0 technology.

The variables created are the following:

- *Number of different adopted technologies*: this variable was computed by simply counting the number of technology types that each interviewee adopted (considering question 3 of the survey) before 31 December 2014. For enterprises that did not adopt any Industry 4.0 technology, this variable has value 0.
- *Adoption of only one technology*: to create this dummy variable, we checked which firm was adopting only a single Industry 4.0 tool. Its value is 1 if the firm adopted only one technology, 0 otherwise.
- *Adoption of two technologies*: to create this dummy variable, we checked which firm was adopting only two different Industry 4.0 tools. Its value is 1 if the firm adopted only two technologies, 0 otherwise.
- *Adoption of three technologies*: to create this dummy variable, we checked which firm was adopting only three different Industry 4.0 tools. Its value is 1 if the firm adopted only three technologies, 0 otherwise.
- *Adoption of at least four technologies*: to create this dummy variable, we checked which firm was adopting at least four different Industry 4.0 tools. Its value is 1 if the firm adopted more than three technologies, 0 otherwise.
- *Adoption of no technologies*: to create this dummy variable, we checked which firm was not adopting any Industry 4.0 tool. Its value is 1 if the firm adopted no technologies, 0 otherwise. To avoid multicollinearity, it was decided to drop this dummy from the multiple linear regression model to have a better understanding of coefficients.

The control variables included in the models are the same as before: average size, average age, and region dummy variables (again, *reg_veneto* was excluded from the model to avoid multicollinearity). Table 4.19 summarizes descriptive statistics for these new variables.

Table 4.19: Descriptive Statistics – Number of technologies (Author's elaboration)

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
number_tech	426	.00	6.00	.3967	.99877
one_tech	426	.00	1.00	.0657	.24810
two_tech	426	.00	1.00	.0540	.22626
three_tech	426	.00	1.00	.0352	.18453
more_tech	426	.00	1.00	.0258	.15879
zero_tech	426	.00	1.00	.8192	.38526
Valid N (listwise)	426				

4.4.2 The First Model and Discussion

First, we wanted to observe the relationship between number – as ordinal variable – and financial performance. The model is the following:

$$Y_i = cons + \beta number\_adopt_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

Results are the ones showed in table 4.20.

Table 4.20: Multiple linear regression – Model 3 (Author's elaboration)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
3	(Constant)	1.639	.151		10.882	.000
	number_tech	.122	.070	.088	1.742	.082
	avg_size	.000	.001	.005	.094	.926
	avg_age	-.024	.005	-.240	-4.908	.000
	reg_emiliar	.184	.244	.039	.752	.453
	reg_friulivg	.011	.318	.002	.035	.972
	reg_lombardy	-.053	.156	-.018	-.338	.735
	reg_piedmont	.206	.215	.050	.956	.339
	reg_trentinoaa	-.560	.967	-.028	-.578	.563

a. Dependent Variable: avg_roe_norm

The number of different Industry 4.0 technologies adopted seems to be positively and significantly related to financial performance. Nevertheless, even if with the prefixed significance level (0.10) we reject the null hypothesis about the coefficient being equal to 0 (given the presence of the other variables in the model), in this model the variable of interest has a higher p-value than before (see Table 4.12). So, even if there is a positive and significant relationship between number of technologies and financial performance, it seems that – for companies – it is more important to adopt Industry 4.0 technologies rather than variety in their exploitation. Further studies concerning the adoption of different kinds of technologies are needed; for this reason, we performed a second multiple linear regression to study the phenomenon considering the number of types of technology as categorical variables in order to identify what are the most significant levels of variety.

4.4.3 The Second Model and Discussion

This time, to investigate the adoption of different kinds of technology, a categorical variable was created for each possibility considered. Each one of these dummies was input in the model, except for the adoption of no technologies in order to avoid multicollinearity.

The model is the following:

$$Y_i = cons + \beta one\_tech_i + \beta two\_tech_i + \beta three\_tech_i + \beta more\_tech_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

Table 4.21: Multiple linear regression – Model 4 (Author's elaboration)

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
4	(Constant)	1.600	.152		10.534	.000
	one_tech	.553	.275	.099	2.012	.045
	two_tech	.497	.294	.081	1.690	.092
	three_tech	.168	.362	.022	.465	.642
	more_tech	.389	.444	.044	.877	.381
	avg_size	.000	.001	-.004	-.078	.938
	avg_age	-.023	.005	-.234	-4.776	.000
	reg_emiliar	.178	.244	.037	.730	.466
	reg_friulivg	-.038	.318	-.006	-.119	.905
	reg_lombardy	-.051	.156	-.018	-.327	.744
	reg_piedmont	.233	.216	.057	1.082	.280
	reg_trentinoaa	-.533	.967	-.026	-.552	.581

a. Dependent Variable: avg_roe_norm

Considering which technology-related dummy variables were included and which one was excluded, each coefficient should be interpreted as the average variation in financial performance (which is measured by normalized average ROE, as in previous models) due to the adoption of a specific technology variety starting from a situation in which a firm is not adopting anything. For variables of interest, we highlighted in light blue significant coefficients, as in all the other models (significance level: 10%).

First, it can be observed that each category has a positive coefficient. Again, the adoption of any number of types of technology does not have negative effects on financial performance. But only two categories do have a significant effect too: the adoption of a single kind of technology and the adoption of two kinds of technology. Both coefficients are significant as their p-values are, respectively, 0.045 and 0.092. Probably, these two categories drove significance for number of technologies in the previous model (Model 3).

For this reason, in the following analyses we wanted to study whether this phenomenon concerned a specific type of technology or it was independent from the type of technology adopted.

From model 4, we have no evidence that adopting more than two kinds of Industry 4.0 technology affects financial performance.

4.5 Technology Combination and Financial Performance.

In this section, we present results obtained from multiple linear regression models built to study what are the technologies that affects financial performance the most. To do so, we had to run several multiple linear regression models in order to consider several contexts for each technology. Indeed, 29 variables were created to compute 15 additional models (even if two of them could not be run). Following, new variables are presented.

Before proceeding with the analyses, we should consider that after dropping those technologies adopted after 31 December 2014, we have different percentages than the ones reported in Table 3.11. Table 4.22 shows, again, which is the most present adopted technology for each column. Because of the lower number of technologies, a negative effect seems to prevail: not only technologies are fewer, but they are also combined together less often.

Table 4.22: Technology combinations (couples) – 31/12/2014 (Author's elaboration)

	Robotics	AM	Laser Cutter	Big Data & Cloud	3D Scanner	Augmented Reality	IoT
Robotics	100%	33%	56%	47%	40%	36%	38%
AM	31%	100%	47%	43%	80%	45%	54%
Laser Cutter	56%	52%	100%	40%	60%	45%	46%
Big Data & Cloud	39%	39%	33%	100%	80%	36%	54%
3D Scanner	11%	24%	17%	27%	100%	18%	15%
Augmented Reality	11%	15%	14%	13%	20%	100%	8%
IoT	14%	21%	17%	23%	20%	9%	100%

For completeness, we decided to consider each time also the case in which a specific technology is adopted alone: these analyses will need to be performed again with a bigger sample because, except for robots, few companies adopted an Industry 4.0 tool individually.

4.5.1 Variables

Table 4.23: Technology combinations – Independent variables (Author's elaboration)

Model	Name	Label	Type	Description
Robot	comb_robot	Adoption of at least robots	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts at least robots.
	only_robot	Adoption of only robots	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts only robots.
	Robot_other	Combination with robots and other technologies	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts robots together with other technologies.
	comb_no_rob	Combination with no robots	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts a combination without robots.
AM	comb_am	Adoption of at least AM	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts at least AM.
	only_am	Adoption of only AM	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts only AM.
	am_other	Combination with AM and other technologies	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts AM together with other technologies.
	comb_no_am	Combination with no AM	Independent Variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts a combination without AM.
Laser Cutter	comb_lc	Adoption of at least laser cutters	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts at least laser cutters.
	only_lc	Adoption of only laser cutters	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts only laser cutters.
	lc_other	Combination with laser cutters and other technologies	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts laser cutters together with other technologies.
	comb_no_lc	Combination with no laser cutters	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts a combination without laser cutters

Model	Name	Label	Type	Description
Big Data OR Cloud	comb_bd	Adoption of at least Big Data or cloud	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts at least Big Data or cloud.
	only_bd	Adoption of only Big Data or cloud	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts only Big Data or cloud.
	bd_other	Combination with Big Data or cloud and other technologies	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts Big Data or cloud together with other technologies.
	comb_no_bd	Combination with no Big Data or cloud	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts a combination without Big Data or cloud.
3D Scanner	comb_3ds	Adoption of at least 3D scanners	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts at least 3D scanners.
	only_3ds	Adoption of only 3D scanners	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts only 3D scanners.
	Threeds_other	Combination with 3D scanners and other technologies	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts 3D scanners together with other technologies.
	comb_no_3ds	Combination with no 3D scanners	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts a combination without 3D scanner.
AR	comb_AR	Adoption of at least AR	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts at least AR.
	only_AR	Adoption of only AR	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts only AR.
	AR_other	Combination with AR and other technologies	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts AR together with other technologies.
	comb_no_AR	Combination with no AR	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts a combination without AR.
IOT	comb_iot	Adoption of at least IoT	Independent vIOTiable	Dummy (0, 1): this viable is equal to 1 if the firm adopts at least IoT.
	only_iot	Adoption of only IoT	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts only IoT.

Model	Name	Label	Type	Description
	iot_other	Combination with IoT and other technologies	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts IoT together with other technologies
	comb_no_iot	Combination with no IoT	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm adopts a combination without IoT
General	No_tech	Do not adopt technologies	Independent variable	Dummy (0, 1): this variable is equal to 1 if the firm does not adopt Industry 4.0 technologies.

For each technology included in the survey we created two group of dummies, and each group regarded a different multiple linear regression model. In the first group, we created a dummy that assumes value 1 if the firm adopted a combination with the selected technology, 0 otherwise; a dummy that assumes value 1 if the firms adopted a combination without that technology, 0 otherwise; and a dummy that assumes value 1 if the firms did not adopt any combination of technology, 0 otherwise. The second group is equal, the only difference is that we “split” the dummy about combinations with the selected technology into two other dummies (that replace the first one): one dummy variable that assumes value 1 if the firm adopted only the selected technology, 0 otherwise, and a dummy variable that assumes value 1 if the firm adopted a combination with the selected and other technologies, 0 otherwise. To summarize, the two groups are the following:

- First group of dummies (Labels):
    - Adoption of at least the considered technology;
    - Adoption of a combination without the considered technology;
    - Do not adopt any combination (Dummy dropped to avoid multicollinearity).
- Second group of dummies (Labels):
    - Adoption of only the considered technology;
    - Adoption of a combination with the considered technology and other ones;
    - Adoption of a combination without the considered technology;
    - Do not adopt any combination (Dummy dropped to avoid multicollinearity).

4.5.2 Combinations with Robots

The considered models for robots are:

$$Y_i = cons + \beta comb\_robot_i + \beta comb\_no\_robot_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

$$Y_i = cons + \beta only\_robot_i + \beta robot\_other_i + \beta comb\_no\_robot_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

SPSS outputs for the models are reported below.

Table 4.24: Multiple linear regression – Models 5 & 6 (Author's elaboration)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
5	(Constant)	1.621	.152		10.683	.000
	comb_robot	.623	.254	.125	2.456	.014
	comb_no_robot	.296	.227	.063	1.305	.193
	avg_size	.000	.001	-.014	-.274	.784
	avg_age	-.024	.005	-.239	-4.901	.000
	reg_emiliar	.159	.244	.033	.652	.515
	reg_friulivg	-.020	.317	-.003	-.063	.950
	reg_lombardy	-.058	.156	-.020	-.373	.709
	reg_piedmont	.225	.214	.055	1.048	.295
	reg_trentinoaa	-.535	.964	-.026	-.555	.579
6	(Constant)	1.626	.152		10.694	.000
	only_robot	.852	.442	.093	1.928	.054
	robot_other	.532	.292	.092	1.820	.070
	comb_no_robot	.294	.227	.062	1.297	.195
	avg_size	.000	.001	-.012	-.242	.809
	avg_age	-.024	.005	-.240	-4.913	.000
	reg_emiliar	.153	.245	.032	.624	.533
	reg_friulivg	-.031	.317	-.005	-.099	.921
	reg_lombardy	-.063	.156	-.022	-.406	.685
	reg_piedmont	.217	.215	.053	1.008	.314
	reg_trentinoaa	-.539	.965	-.027	-.559	.577

a. Dependent Variable: avg_roe_norm

From these results (Table 4.24), it is relevant that robots do have a positive and significant impact on financial performance. Combinations with robots have a positive and significant impact (with respect to combinations without robots) in both cases: when considered as a whole and when we split the variable to monitor robot-related effects when they are adopted alone or together with other technologies. Analysing also other technologies, the importance of robots for the sample appears to be more and more relevant.

Adopting only robots or a combination of robots and other technologies is significant (significance level 0.10), and outperforms the adoption of any combination of technologies that does not include them. Indeed, robots were the most purchased technology among respondents (together with laser cutter, see Table 4.3).

Next models will be presented showing only the interested variables concerning technology combinations, we only indicate the presence of the other controls.

4.5.3 Combinations with Additive Manufacturing

The models are the following:

$$\begin{aligned} Y_i = cons + \beta comb\_am_i + \beta comb\_no\_am_i + \beta avg\_size_i + \beta avg\_age_i \\ + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i \\ + \beta reg\_trentinoaa_i + \epsilon_i \end{aligned}$$

$$\begin{aligned} Y_i = cons + \beta only\_am_i + \beta am\_other_i + \beta comb\_no\_am_i + \beta avg\_size_i + \beta avg\_age_i \\ + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i \\ + \beta reg\_trentinoaa_i + \epsilon_i \end{aligned}$$

Models are reported below.

Table 4.25 Multiple linear regression – Models 7 & 8 (Author's elaboration)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
7	(Constant)	1.612	.151		10.661	.000
	comb_am	.231	.255	.044	.906	.365
	comb_no_am	.591	.224	.129	2.639	.009
	Size control	Yes				
	Age control	Yes				
	Region control	Yes				
8	(Constant)	1.623	.152		10.660	.000
	only_am	-.098	.561	-.008	-.175	.861
	am_other	.310	.282	.054	1.100	.272
	comb_no_am	.596	.224	.131	2.656	.008
	Size control	Yes				
	Age control	Yes				
	Region control	Yes				

a. Dependent Variable: avg_roe_norm

Results (Table 4.25) do not show a significant positive impact for additive manufacturing: 3D printing is significant neither when adopted alone nor when adopted together with other technologies (in both models). Vice versa, the adoption of combinations without additive manufacturing has a positive impact on financial performance with a significance level below 0.01.

Considering Table 4.18 this result may confirm the importance of robots: industrial robots are used together with AM only in 31% of the cases; vice versa, only 33% of AM-adopters adopt also robots.

4.5.4 Combinations with Laser Cutter

Models are the following:

$$Y_i = cons + \beta comb\_lc_i + \beta comb\_no\_lc_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

$$Y_i = cons + \beta only\_lc_i + \beta lc\_other_i + \beta comb\_no\_lc_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

Table 4.26: Multiple linear regression – Models 9 & 10 (Author's elaboration)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
9	(Constant)	1.606	.151		10.624	.000
	comb_lc	.271	.244	.054	1.108	.269
	comb_no_lc	.586	.232	.124	2.527	.012
	Size control	Yes				
	Age control	Yes				
	Region control	Yes				
10	(Constant)	1.597	.151		10.542	.000
	only_lc	1.058	.814	.064	1.300	.194
	lc_other	.212	.251	.041	.843	.400
	comb_no_lc	.596	.232	.127	2.570	.011
	Size control	Yes				
	Age control	Yes				
	Region control	Yes				

a. Dependent Variable: avg_roe_norm

Results are reported in Table 4.26. Again, only those combinations without the considered technology do have a significant and positive impact on financial performance. The p-values associated with their coefficients allow to reject the null Hypothesis (about the coefficient being equal to 0, given the other variables) with a significance level of even 5% in both models. Laser cutters, instead, when compared to these combinations, do have a significant impact neither when applied alone nor when exploited together with other technologies.

4.5.5 Combinations with Big Data or Cloud

Models adopted are:

$$Y_i = cons + \beta comb\_bd_i + \beta comb\_no\_bd_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

$$Y_i = cons + \beta only\_bd_i + \beta bd\_other_i + \beta comb\_no\_bd_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

Table 4.27: Multiple linear regression – Models 11 & 12 (Author's elaboration)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
11	(Constant)	1.604	.151		10.586	.000
	comb_bd	.329	.269	.061	1.225	.221
	comb_no_bd	.503	.216	.113	2.323	.021
	Size control	Yes				
	Age control	Yes				
	Region control	Yes				
12	(Constant)	1.604	.152		10.575	.000
	only_bd	.247	.565	.021	.438	.662
	bd_other	.350	.296	.058	1.181	.238
	comb_no_bd	.503	.217	.113	2.321	.021
	Size control	Yes				
	Age control	Yes				
	Region control	Yes				

a. Dependent Variable: avg_roe_norm

Combinations with Big Data and cloud do not have a significant impact on performance yet, either when adopted alone or when adopted together with other technologies (Table 4.27).

Again, only technology combinations without the considered tool do have a positive and significant impact on financial performance.

4.5.6 Combinations with 3D Scanner

Models adopted are:

$$Y_i = cons + \beta comb\_3ds_i + \beta comb\_no\_3ds_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

$$Y_i = cons + \beta only\_3ds_i + \beta 3ds\_other_i + \beta comb\_no\_3ds_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

In this case, it was not possible to run the second model because no company adopted 3D scanners alone. Nevertheless, the first model is sufficient to observe again that only adopting technology combinations without 3D scanners has a positive and significant impact on financial performance. Table 4.28 show results that are similar to the ones obtained with other technologies, except for robots.

Table 4.28: Multiple linear regression – Models 13 & 14 (Author's elaboration)

Coefficients[a]						
		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
13	(Constant)	1.611	.152		10.629	.000
	comb_3ds	.612	.439	.067	1.394	.164
	comb_no_3ds	.411	.191	.108	2.151	.032
	Size control	Yes				
	Age control	Yes				
	Region control	Yes				
14	No company adopted 3D scanners alone; *only_3ds* (dummy) does never assume value 1, indeed.					

a. Dependent Variable: avg_roe_norm

4.5.7 Combinations with Augmented Reality

Models adopted are:

$$Y_i = cons + \beta comb\_ar_i + \beta comb\_no\_ar_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

$$Y_i = cons + \beta only\_ar_i + \beta ar\_other_i + \beta comb\_no\_ar_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

This analysis provided conflicting results: combinations with Augmented Reality do have a positive and significant impact on financial performance, as well as combinations with only other technologies. But, dividing AR-application into two variables ("only AR" and "AR with other technologies") increases the p-values of AR-related variables, thus making us accept the null hypothesis by which coefficients may be equal to zero (given the presence of all the other coefficients). Probably, too few companies adopted Augmented Reality (11 in total, alone or in a combination), and it is still difficult to understand if this technology has a significant and positive impact also when adopted alone. Nevertheless, if compared with previous technologies, except for robots, this is a surprising result.

Table 4.29: Multiple linear regression – Models 15 & 16 (Author's elaboration)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
15	(Constant)	1.605	.151		10.614	.000
	comb_ar	.852	.417	.097	2.044	.042
	comb_no_ar	.365	.192	.095	1.897	.059
	Size control	Yes				
	Age control	Yes				
	Region control	Yes				
16	(Constant)	1.603	.152		10.572	.000
	only_ar	1.023	.792	.062	1.291	.197
	ar_other	.787	.489	.077	1.608	.109
	comb_no_ar	.364	.193	.095	1.889	.060
	Size control	Yes				
	Age control	Yes				
	Region control	Yes				

a. Dependent Variable: avg_roe_norm

4.5.8 Combinations with IoT

Models adopted are:

$$Y_i = cons + \beta comb\_iot_i + \beta comb\_no\_iot_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

$$Y_i = cons + \beta only\_iot_i + \beta iot\_other_i + \beta comb\_no\_iot_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

Results are reported in Table 4.30.

Table 4.30: Multiple linear regression – Models 17 & 18 (Author's elaboration)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
17	(Constant)	1.609	.151		10.637	.000
	comb_iot	.174	.392	.022	.443	.658
	comb_no_iot	.488	.192	.125	2.538	.012
	Size control	Yes				
	Age control	Yes				
	Region control	Yes				
18	No company adopted IoT alone; *only_iot* (dummy) does never assume value 1, indeed.					

a. Dependent Variable: avg_roe_norm

Adopting a combination with IoT does not significantly impact financial performance. The related p-value is way above 0.10, while the one related to any other combination of technologies has a p-value below the prefixed level. Again, even IoT confirms the importance of robots. It was not possible to verify the effect of IoT alone because it was always adopted together with another technology.

4.5.9 Which Technology to Adopt?

We decided to perform one last analysis in order to control ultimately which technology has a positive and significant effect on financial performance. In this multiple linear regression model, we included all technologies together. Each coefficient should show the change on financial performance of a non-adopter of a specific technology when she decides to exploit that particular tool. The model is the following:

$$Y_i = cons + \beta comb\_robot_i + \beta comb\_am_i + \beta comb\_lc_i + \beta comb\_bd_i + \beta comb\_3ds_i + \beta comb\_ar_i + \beta comb\_iot_i + \beta avg\_size_i + \beta avg\_age_i + \beta reg\_emiliar_i + \beta reg\_friulivg_i + \beta reg\_lombardy_i + \beta reg\_piedmont_i + \beta reg\_trentinoaa_i + \epsilon_i$$

Each variable has to be interpreted as the answer to question 3 of the survey: "Does this company adopt this specific technology?". If "Yes", variable *comb_[technology]* assumes value 1, otherwise 0.

Table 4.31: Multiple linear regression – Model 19 (Author's elaboration)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
19	(Constant)	1.659	.152		10.943	.000
	comb_robot	.620	.297	.124	2.088	.037
	comb_am	-.075	.305	-.014	-.246	.806
	comb_lc	-.208	.302	-.042	-.688	.492
	comb_bd	-.077	.321	-.014	-.240	.811
	comb_3ds	.460	.518	.050	.887	.376
	comb_ar	.671	.434	.077	1.546	.123
	comb_iot	-.043	.418	-.005	-.103	.918
	Size control	Yes				
	Age control	Yes				
	Region control	Yes				

a. Dependent Variable: avg_roe_norm

Again, the importance of robots is clear. Robots are the only technology that is both significant and positive. Some reported coefficients are negative because if a variable is equal to 0, it means either that a respondent did not apply any technology or that it adopted another combination of technologies that did not include that specific technology.

Because of the particular interpretation of this model, we computed it for last as final check on previous results, to confirm robot-related performance effects. This analysis confirms that robots are the only technology that non-adopters should exploit to improve their financial performance. A complete overview of these results is proposed in the conclusions. We tried to interpret results to explain both importance of robots and non-significance of other technologies with respect to financial performance.

CONCLUSIONS

With our work, we wanted to verify if Northern Italy Manufacturing companies are already benefitting from their past investments in Industry 4.0 technologies. We find out that these investments have a positive and significant effect on financial performance. We confirm this result with both t-test and multiple linear regression analyses. While the former shows us the existence of a difference in financial performances between adopters and non-adopters, the latter allow us to confirm the importance of Industry 4.0 technologies by taking some control variables into account, thus isolating technology-related effects. To balance sample size and robustness of results, we had to include a bit of time overlapping for what regards technology adoption and performance: it is difficult for technologies adopted in 2014 to already show their benefits at the end of the same year. Nevertheless, at the end of 2014, older technologies were probably already affecting financial performances. Moreover, as explained before, considering a larger period of time between adoption and performance would have probably entailed more biased results (as other events may be occurred during that period). For this reason, the chosen compromise was deemed as the most appropriate one. We show that Industry 4.0 technology affects financial performance: so, an investor (often, in our sample, the entrepreneur herself) should support decisions concerning the adoption of these innovative manufacturing tools. To confirm our results, we prove that Industry 4.0 technologies impact operating performances too. These results are hopeful if we consider that our sample comprises mostly small and micro enterprises: digital manufacturing technologies are not an exclusive of larger firms.

We also show that a cumulative effect exists: adopting more and more types of Industry 4.0 technology has a positive and significant impact on financial performance. Going into details, we identify that superior performances are obtained leveraging on one or two types of technology. So, our companies are still far away from those “Industry 4.0” champions that are thoroughly digitalized and exploit simultaneously and successfully robotics, additive manufacturing, Big Data, IoT, etc. Despite that, differences in size between those firms and the ones in our samples should be taken in account. Therefore, our results should not be underestimated.

Robots are the most important technology in our sample: not only they were already exploited by 47% of adopters, but they are drivers in any technology-combination. Each combination with a specific different technology is no match for other combinations that, probably, include more often robots (because of their proliferation in the sample). Furthermore, a firm that did not adopt robots (so, a firm that adopts no technology or another combination of tools) had convenience in purchasing them, as they are the only technology in Model 19 (Table 4.29) that has a positive and significant coefficient. Their diffusion was not unexpected, as our sample consists of manufacturing enterprises. Probably, they have such an impact on performances because they are the most “tangible” technology: they are applied almost always in the production function, so they can directly affect performances. We must remind that this category includes also caged robots, as they can be potentially transformed into collaborative robots with the installation of sensors. Robots are probably the technology with which companies have more confidence as their presence inside shop floors is not a novelty. They were important already in the third industrial revolution, with the fourth one they are just upgraded and connected, thus confirming their role on shop floors. For the same reasons, given the results obtained with robots, we expected similar answers from laser cutters, but this was not the case.

In our sample, additive manufacturing and 3D scanners are mostly applied in R&D and prototyping activities. They are not adopted in the production function and it could be that adopters of these technologies do not have many devices (a single 3D printer may be deemed as “sufficient” to perform prototyping activities in a small firm). For these reasons, the impact of these other physical technologies is not as significant as the one due to robots.

Big Data Analytics, Cloud Computing, Augmented Reality, and the Internet of Things are different from other listed technologies. These tools are more similar to IT technologies. The multiple linear regression models we ran shows that, except for Augmented Reality (which needs to be investigated with a larger sample), no one of these technologies has a positive and significant impact on financial performances. Instead, our last model shows that a firm with no-technologies or with a combination of technologies that did not include these tools could lower its financial performances adopting one of them (see Table 4.29 about Model 19). In fact, coefficients associated with these technologies have a negative sign, even if they are not significant. These technologies are particular because their installation and exploitation involve the whole company and it is not limited to specific functions. In fact, the application of this software technologies presents similar issues to the installation of an ERP (Enterprise Resource Planning) in a company (Slack et al., 2013). Instead, Robots are used mainly in the production function, additive manufacturing is used in the R&D department and, as Industry 4.0 promotes, it should be used to mass produce too (even if our sample is characterized by few firms that do so). Laser cutters are used mainly in the production department, and 3D scanners are usually complementary to 3D printers (Iuliano and Vezzetti, 2013). For example, for Bean (2017), the most important challenges that concern Big Data exploitation are not related to technology but to cultural challenges like organizational alignment, resistance or lack of understanding, and change management. The same argument could be held for cloud computing, AR, and IoT. Already in 2013, Bean stated that, for a company that wants to launch Big Data initiatives, a roadmap or a plan are essential (Kiron, 2013). He highlighted the fact that, hearing about Big Data and their diffusion, many managers may be tempted in making a related investment without knowing very well the concept. Moreover, they may invest in Big Data (IoT sensors to collect data and superior computing services to analyse information) without a final goal or a plan.

The installation of IoT presents similar issues. Bughin, Chui, and Manyika (2015) of McKinsey focus on challenges that IoT adopters must overcome. They individuate three IoT main challenges: organizational alignment, interoperability and analytics hurdles, and security issues. The Internet of Things is a technology that encompasses assets, inventories, and operations. The role of the IT function is enhanced, as IT experts need to work together with line managers to continuously improve efficiency in top and bottom lines. Moreover, effective IoT-based strategies leverage on the possibility to let different systems communicate one another. Firms that strive to adopt IoT must make clear strategic choices for several aspects. They must decide what features and capabilities should their products have, how much capabilities should be left in the cloud, whether the firm should develop internally the whole functionality or not, how to manage data collection, whether to change business model or not, and so on. Porter and Heppelmann (2014) include the overestimation of internal capabilities as one of the most important mistakes to avoid when exploiting IoT. Moreover, firms should not add functionalities that customers do not want to pay for. In our sample, we do not know why adopters of IoT devices were not having significant performance improvement; their situation may be characterized by a mix of the described mistakes.

The fact that companies may have invested on these software technologies just because they are proliferating among successful global competitors is a possibility that should not be ignored. If this were the case, companies may have invested in these technologies without really understanding how they can be exploited in a company. This last possibility should be investigated and avoided. This situation can be described through the term “Mimetic Isomorphism”. When there is uncertainty, organizations are driven to imitate others. “When organizational technologies are poorly understood (March and Olsen, 1976), when goals are ambiguous, or when the environment creates symbolic uncertainty, organizations may model themselves on other organizations” (Di Maggio and Powell, 1983, p. 151). So, enterprises may have decided to imitate other more important global players even if they did not really understand Industry 4.0 technologies. DiMaggio and Powell (1983), who recognized three categories of isomorphism for the first time (coercive isomorphism, mimetic isomorphism, and normative isomorphism), suggested that when either goals or relationship between means and end are not clear, an organization is pressured to model itself "after other organizations that it perceives as successful" (p.154). This description may fit our sample. So, Big Data, cloud, and IoT may be installed without a proper strategy. From a policy point of view, with the introduction of the National Italian Government Plan "Industry 4.0" and "Enterprise 4.0", the risk that businesses purchase Industry 4.0 technologies without a strategy is enhanced. One of the focal point of these plans consists in the possibility for firms to apply a super- or hyper-depreciation on investments aimed at digitalizing the company. This incentive is certainly positive to help firms upgrading themselves, but there is the risk that firms perform these investments without an actual strategy.

Another possible interpretation of the results concerns the possibility of creating new business models through the adoption of Industry 4.0 technologies. Several authors (like Kagermann et al., 2013; Prause, 2015; and Gilchrist, 2016) link Industry 4.0 to the possibility of transforming current business models, indeed. Changing business models is not something that can be achieved in the short term. It may be possible that the other technologies are not already affecting performance because they require more time or because adopters are lacking dynamic capabilities. These capabilities "can be disaggregated into the capacity to sense and shape opportunities and threats, to seize opportunities, and to maintain competitiveness through enhancing, combining, protecting, and, when necessary, reconfiguring the business enterprise's intangible and tangible assets" (Teece, 2007, p. 1). These capabilities concern a firm's capacity to "shape the ecosystem it occupies, develop new products and processes, and design and implement viable business models" (p.2).

Finally, we should consider three other aspects to correctly interpret results. First, it could be that robots were installed in processes that were already optimized. Vice versa, the other technologies may have been applied in processes without thoroughly preparing the right settings. Digitalization is okay, but waste should not be digitalized. Second, we did not ask companies the amount of investment for each individual technology. A company pursuing automation may invest a relevant amount of resources to buy robots while, for example, a single 3D printer may be deemed sufficient to improve R&D activities. Considering the number of adopted devices may change results concerning individual technologies. Third, we should not rule out the possibility that newer technologies (adopted during 2015 or 2016) may have already affected performances.

To conclude, we propose some adjustments for future analyses.

First, we suggest deepening the investigation of non-adopters' industrial settings. Studying their competitiveness profile and IT infrastructure should allow the running of more detailed studies. Then, still on the subject of the survey, more information about Industry 4.0 investments should be asked to interviewees: information about investment amount and number of devices purchased would be helpful to enhance models proposed in this thesis. Additionally, future surveys should ask firms information about the processes in which technologies are installed. With this data, we would have been able to include an additional control in our models to verify that technologies installed in efficient processes have superior performances. Other additional questions may regard strategic implications of technology adoption: investigating the context in which each investment was decided should permit to determine if each decision was made as part of a strategy. As alternative analyses, we propose also to deepen the study of the relationship between the adoption of technologies and operating performances.

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SID Project Members

"Manufacturing activities and value creation: redesigning firm's competitiveness through digital manufacturing in a circular economy framework"

Department of Economics and Management (University of Padova)

Professors: Bettiol, M., Di Maria, E., De Marchi, V., Furlan, A., Sedita, S.R.

Other members (PhD): Burlina, C., Capestro, M., Galeazzo, A.

Former students: Cadelli, M., Inì, P., Pagliuca, N., Polli, M., Scirè, G. (Sectors: 3 May – 15 September 2017)[37]

I would like to express my sincere gratitude to all the members of the departmental project for letting me participate at this research and helping me build the database analysed.

[37] Currently, the research is continuing with other additional students to analyse other sectors.

APPENDIX

Appendix A – Scopus Queries

Industrial Robots and Automated Guided Vehicles

(TITLE-ABS-KEY ("robot" OR "automated guided vehicle" OR "agv") AND TITLE-ABS-KEY ("Industria 4.0" OR "Industry 4.0" OR "Industrie 4.0" OR "Cyber-physical system" OR “Cyberphysical system” OR "Industrial internet" OR "Digital Manufacturing" OR "fourth industrial revolution" OR "4th industrial revolution" OR "smart factory" OR "smart manufacturing" OR "Industrie du futur" OR "High value manufacturing" OR "Fabbrica intelligente")) AND DOCTYPE (ar OR re) AND (LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , " BUSI "))*

Additive Manufacturing

(TITLE-ABS-KEY ("3D Print" OR "3D-Print*" OR "3-D Print*" OR "Additive manufacturing" OR "Rapid prototyping" OR "automated fabrication" OR "Freeform fabrication" OR "Layer-based manufacturing" OR "stereolithography") AND TITLE-ABS-KEY ("Industria 4.0" OR "Industry 4.0" OR "Industrie 4.0" OR "Cyber-physical system" OR “cyberphysical system” OR "Industrial Internet" OR "Digital Manufacturing" OR "fourth industrial revolution" OR "4th industrial revolution" OR "smart factory" OR "smart manufacturing" OR "Industrie du futur" OR "High value manufacturing" OR "Fabbrica intelligente")) AND DOCTYPE (ar OR re) AND (LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , " BUSI "))*

3D Scanner

(TITLE-ABS-KEY (“3D Scan” OR “3D Model acquisition” OR “3D Imaging” OR “Laser Scanning” OR “Laser Digitizing” OR “Digital Shape Sampling and Processing” OR “DSSP” OR “Digital Shape Sampling & Processing”) AND TITLE-ABS-KEY ("Industria 4.0" OR "Industry 4.0" OR "Industrie 4.0" OR "Cyber-physical system" OR “Cyberphysical System” OR "Industrial Internet" OR "Digital Manufacturing" OR "fourth industrial revolution" OR "4th industrial revolution" OR "smart factory" OR "smart manufacturing" OR "Industrie du futur" OR "High value manufacturing" OR "Fabbrica intelligente")) AND DOCTYPE (ar OR re) AND (LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , " BUSI "))*

3D Scanner

(TITLE-ABS-KEY ("Laser cut") AND TITLE-ABS-KEY ("Industria 4.0" OR "Industry 4.0" OR "Industrie 4.0" OR "Cyber-physical system" OR "Cyberphysical System" OR "Industrial Internet" OR "Digital Manufacturing" OR "fourth industrial revolution" OR "4th industrial revolution" OR "smart factory" OR "smart manufacturing" OR "Industrie du futur" OR "High value manufacturing" OR "Fabbrica intelligente")) AND DOCTYPE (ar OR re) AND (LIMIT-TO (SUBJAREA,"SOCI ") OR LIMIT-TO (SUBJAREA," BUSI "))*

Big Data

(TITLE-ABS-KEY ("Big Data" OR "Big data analytics") AND TITLE-ABS-KEY ("Industria 4.0" OR "Industry 4.0" OR "Industrie 4.0" OR "Cyber-physical system" OR "Cyberphysical System" OR "Industrial Internet" OR "Digital Manufacturing" OR "fourth industrial revolution" OR "4th industrial revolution" OR "smart factory" OR "smart manufacturing" OR "Industrie du futur" OR "High value manufacturing" OR "Fabbrica intelligente")) AND DOCTYPE (ar OR re) AND (LIMIT-TO (SUBJAREA,"SOCI ") OR LIMIT-TO (SUBJAREA," BUSI "))

The Internet of Things

(TITLE-ABS-KEY ("Internet of things" OR "Internet-of-things") AND TITLE-ABS-KEY ("Industria 4.0" OR "Industry 4.0" OR "Industrie 4.0" OR "Cyber-physical system" OR "Cyberphysical System" OR "Industrial Internet" OR "Digital Manufacturing" OR "fourth industrial revolution" OR "4th industrial revolution" OR "smart factory" OR "smart manufacturing" OR "Industrie du futur" OR "High value manufacturing" OR "Fabbrica intelligente")) AND DOCTYPE (ar OR re) AND (LIMIT-TO (SUBJAREA,"SOCI ") OR LIMIT-TO (SUBJAREA," BUSI "))

Augmented Reality

(TITLE-ABS-KEY ("Augmented reality[38]") AND TITLE-ABS-KEY ("Industria 4.0" OR "Industry 4.0" OR "Industrie 4.0" OR "Cyber-physical system" OR "Cyberphysical System" OR "Industrial Internet" OR "Digital Manufacturing" OR "fourth industrial revolution" OR "4th industrial revolution" OR "smart factory" OR "smart manufacturing" OR "Industrie du futur" OR "High value manufacturing" OR "Fabbrica intelligente")) AND DOCTYPE (ar OR re) AND (LIMIT-TO (SUBJAREA,"SOCI ") OR LIMIT-TO (SUBJAREA," BUSI "))

[38] Including "AR" would have been too dispersive

Cybersecurity

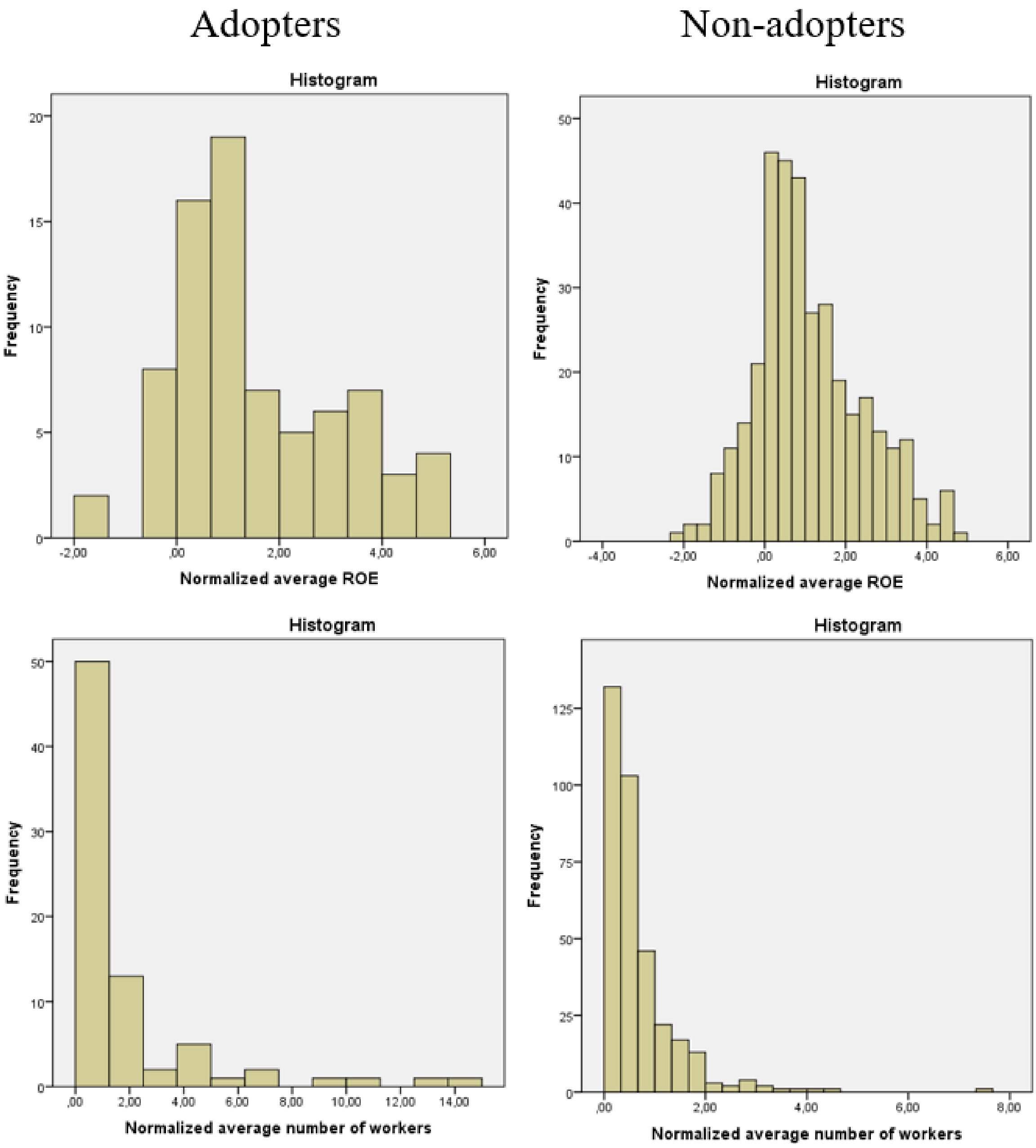
(TITLE-ABS-KEY ("Cybersecurity" OR “Cyber-security” OR “Cyber-attack” OR “cyberattack” OR “Cyberwarfare” OR “Cyber-warfare” OR “Hack”) AND TITLE-ABS-KEY ("Industria 4.0" OR "Industry 4.0" OR "Industrie 4.0" OR "Cyber-physical system" OR “Cyberphysical System” OR "Industrial Internet" OR "Digital Manufacturing" OR "fourth industrial revolution" OR "4th industrial revolution" OR "smart factory" OR "smart manufacturing" OR "Industrie du futur" OR "High value manufacturing" OR "Fabbrica intelligente")) AND DOCTYPE (ar OR re) AND (LIMIT-TO (SUBJAREA,"SOCI ") OR LIMIT-TO (SUBJAREA," BUSI "))*

Machine Learning

(TITLE-ABS-KEY ("machine learning”) AND TITLE-ABS-KEY ("Industria 4.0" OR "Industry 4.0" OR "Industrie 4.0" OR "Cyber-physical system" OR “Cyberphysical System” OR "Industrial Internet" OR "Digital Manufacturing" OR "fourth industrial revolution" OR "4th industrial revolution" OR "smart factory" OR "smart manufacturing" OR "Industrie du futur" OR "High value manufacturing" OR "Fabbrica intelligente")) AND DOCTYPE (ar OR re) AND (LIMIT-TO (SUBJAREA,"SOCI ") OR LIMIT-TO (SUBJAREA," BUSI "))

Appendix B – Independent Samples T-Test

Distribution of Independent Samples used for the t-test



Appendix C – Multiple Linear Regressions

Condition Index – Model 1 (Author's Elaboration)

Model	Dimension	Eigenvalue	Condition Index
1	1	3.179	1.000
	2	1.057	1.734
	3	1.004	1.780
	4	1.001	1.782
	5	1.000	1.783
	6	.832	1.954
	7	.539	2.429
	8	.262	3.481
	9	.127	5.011

Average ROA over 2016, 2015, and 2014 per sector – Model 2[39] (Author's Elaboration)

ATECO	Description	Number of firms	ROA	
			Number of firms with ROA	Mean of Average ROA
22	Manufacture of gum and plastic goods	8,187	4,562	4.77%
27	Manufacture of electric goods (motors, batteries, wires, and lighting devices)	7,688	3,946	3.06%
29	Manufacture of vehicles and trailers	2,495	1,215	2.41%
31	Manufacture of furniture	9,105	3,893	0.78%
32	Manufacture of other goods (glasses and lenses, sport goods)	7,090	3,310	3.09%
Other Sectors				
16, 25, 28, 45, 46, 47, 70, 81	Support activities, like manufacture of metal parts, maintenance of vehicles, etc.	419,434	165,595	2.63%

[39] Information was downloaded on 30 October 2017

Appendix D – Survey

Industria 4.0: manifattura e competitività d'impresa tra tecnologie digitali e economia circolare

Spett.le Azienda,

un gruppo di ricerca del Dipartimento di Scienze Economiche e Aziendali "Marco Fanno" (DSEA) dell'Università di Padova da me coordinato sta conducendo uno studio sui processi di adozione delle tecnologie digitali che rientrano sotto l'etichetta "Industria 4.0" e sulle implicazioni legate alle attività di produzione e innovazione.

Il tema è particolarmente attuale, per cui la Vostra partecipazione è importante per contribuire ad accrescere le conoscenze relative alle modalità con cui le imprese stanno affrontando le sfide attuali e le opportunità offerte da tali tecnologie sul fronte produttivo e dei rapporti con il mercato.

Siete stati selezionati nell'ambito del campione di imprese oggetto di indagine e per questo chiediamo la Vostra collaborazione per la compilazione del questionario, assicurandoVi che il trattamento dei dati avverrà unicamente in forma aggregata e per finalità scientifiche.

Vi ringrazio per l'attenzione e resto a disposizione per qualsiasi chiarimento.

Prof.ssa Eleonora Di Maria – DSEA
eleonora.dimaria@unipd.it

Industria 4.0: manifattura e competitività d'impresa tra tecnologie digitali e economia circolare

* 1. Denominazione azienda

* 2. Settore (specificare settore di riferimento)

* 3. L'impresa utilizza una o più delle seguenti tecnologie (industria 4.0)?

- ☐ Robotica in produzione (Es. robot industriali classici (nelle gabbie), robotica cooperativa, sistemi "intelligenti" che adattano le attività a seconda dei processi es. robot con videocamere ecc.)
- ☐ Manifattura additiva (Stampanti 3D, Stereolitografia, ecc.)
- ☐ Laser cutting
- ☐ Sistemi di raccolta ed elaborazione dati di produzione/processo (Big Data – cloud)
- ☐ Scanner 3d
- ☐ Realtà aumentata (per la progettazione del prodotto e/o per la visualizzazione prodotto finale)
- ☐ Internet of things/prodotti intelligenti: (RFID, sensoristica nel prodotto)
- ☐ Nessuna

Industria 4.0: manifattura e competitività d'impresa tra tecnologie digitali e economia circolare

* 4. Se l'impresa non utilizza nessuna delle tecnologie sopra indicate, quali sono le ragioni?

- ☐ Mancanza di risorse economiche
- ☐ Mancanza/limitate competenze interne
- ☐ Mancanza di una infrastruttura tecnologica interna adeguata
- ☐ Scarsa conoscenza del tema
- ☐ Incertezza dei ritorni dell'investimento
- ☐ Non è di interesse per il nostro business
- ☐ Sono in fase di valutazione
- ☐ Altro

Altro (specificare)

Industria 4.0: manifattura e competitività d'impresa tra tecnologie digitali e economia circolare

5. Attività svolta (Settore e specializzazione produttiva)

6. Numero addetti (a fine 2016)

totali

in produzione

nella funzione di R&D (se esiste la funzione) oppure che si occupano di innovazione

nella funzione marketing (se esiste la funzione)

7. Fatturato 2016 (Migliaia euro)

8. Il primo fattore di vantaggio competitivo per l'impresa:

- Qualità dei prodotti
- Innovazione di prodotto
- Design
- Flessibilità produttiva
- Riduzione costi di produzione
- Servizio al cliente
- Altro

Altro (specificare)

9. Export

In % sul fatturato

Primo paese di vendita estero

% primo paese di vendita estero

10. Spesa in R&D (% sul fatturato anno 2016)

11. La spesa in R&D è:

- Aumentata nel corso degli ultimi 5 anni
- Rimasta stabile
- Diminuita nel corso degli ultimi 5 anni

Industria 4.0: manifattura e competitività d'impresa tra tecnologie digitali e economia circolare

12. In quale anno sono state adottate le tecnologie di industria 4.0?

Robotica in produzione

Manifattura additiva

Laser cutting

Big Data – cloud

Scanner 3d

Realtà aumentata

IoT (RFID, sensoristica nel prodotto)

13. In aggiunta alle tecnologie legate all'industria 4.0 sopra indicate, quali altre tecnologie ha adottato l'impresa?

- [ ] Sito web
- [ ] Social media (es. facebook, twitter, linkedin, ecc.)
- [ ] E-commerce
- [ ] CRM Customer Relationship Management
- [ ] SCM Supply Chain Management
- [ ] ERP Enterprise Resource Planning
- [ ] MRP Material Requirement Planning
- [ ] CAD/CAM
- [ ] Macchine a controllo numerico (CNC)
- [ ] Altro

Altro (specificare)

14. In quali delle seguenti attività della catena del valore/processi si è concentrato l'investimento in tecnologie industria 4.0?

- [ ] Sviluppo nuovi prodotti (R&D)
- [ ] Prototipazione
- [ ] Attività di produzione
- [ ] Gestione della produzione
- [ ] Logistica e gestione della supply chain
- [ ] Attività di marketing/commerciali
- [ ] Produzione di parti di ricambio/Servizio post-vendita
- [ ] Altro

Altro (specificare)

15. Rispetto alle attività sopra indicate, specificate le tecnologie adottate

	Robotica	Manifattura additiva	Big data/cloud	Scanner 3	Realtà aumentata	IoT (RFID, sensoristica...)
Sviluppo nuovi prodotti (R&D)	☐	☐	☐	☐	☐	☐
Prototipazione	☐	☐	☐	☐	☐	☐
Attività di produzione	☐	☐	☐	☐	☐	☐
Gestione della produzione	☐	☐	☐	☐	☐	☐
Logistica e gestione della supply chain	☐	☐	☐	☐	☐	☐
Attività di marketing/commerciali	☐	☐	☐	☐	☐	☐
Produzione di parti di ricambio/Servizio post-vendita	☐	☐	☐	☐	☐	☐
Altro	☐	☐	☐	☐	☐	☐

Altro (specificare)

16. L'investimento in tecnologie industria 4.0 ha richiesto un processo di personalizzazione delle soluzioni tecnologiche adottate?

◯ Sì

◯ No

17. Se sì, con quale livello di dettaglio?

	per niente	poco	abbastanza	molto	moltissimo
Componente hardware	◯	◯	◯	◯	◯
Componente software	◯	◯	◯	◯	◯
Integrazione di sistema con le altre tecnologie già in dotazione	◯	◯	◯	◯	◯

18. Per la scelta e l'implementazione di tecnologie industria 4.0 l'impresa si è avvalsa di:

☐ fornitori di tecnologia industria 4.0

☐ system integrator

☐ fornitori di impianti e macchinari

☐ consulenti

☐ università/centri di ricerca

☐ centri di trasferimento tecnologico (parchi ecc.)

☐ Altro

Altro (specificare)

19. Le motivazioni dell'investimento nelle tecnologie 4.0 hanno riguardato:

	per niente	poco	abbastanza	molto	moltissimo
ricerca di efficienza interna	◯	◯	◯	◯	◯
aumento della varietà dei prodotti	◯	◯	◯	◯	◯
nuove opportunità di mercato (nuovi prodotti/nuovi mercati)	◯	◯	◯	◯	◯
mantenimento della produzione in Italia	◯	◯	◯	◯	◯
rilocalizzazione in Italia di attività produttive prima realizzate all'estero (reshoring)	◯	◯	◯	◯	◯
mantenimento della competitività a livello internazionale	◯	◯	◯	◯	◯
imitazione dei concorrenti	◯	◯	◯	◯	◯
migliore servizio al cliente	◯	◯	◯	◯	◯
sostenibilità ambientale	◯	◯	◯	◯	◯
richiesta da parte dei clienti (es. grandi multinazionali)	◯	◯	◯	◯	◯
adeguamento ad uno standard di settore	◯	◯	◯	◯	◯
altro	◯	◯	◯	◯	◯

* 20. L'investimento in tecnologie industria 4.0 ha avuto un impatto sul fronte dell'occupazione?

◯ Un aumento degli occupati

◯ Una diminuzione degli occupati

◯ Il numero degli occupati è rimasto stabile

21. Dopo l'implementazione delle tecnologie 4.0, quali sono i risultati raggiunti

- [ ] Incremento del fatturato
- [ ] Riduzione dei costi di produzione/aumento dell'efficienza interna
- [ ] Aumento della produttività
- [ ] Diversificazione produttiva /aumento della gamma dei prodotti
- [ ] Aumento della quota di prodotti personalizzati
- [ ] Migliore servizio al cliente
- [ ] Entrata in nuovi mercati
- [ ] Riorganizzazione delle attività tra Italia/estero
- [ ] mantenimento della competitività a livello internazionale
- [ ] Sostenibilità ambientale
- [ ] Altro

22. Qual è stato l'investimento nell'ambito dell'industria 4.0 (sia tecnologie in senso stretto che a livello complessivo di progetti realizzati) in % sul fatturato?

____

23. Quali sono state le principali difficoltà nell'adozione di tecnologie 4.0?

	per niente	poco	abbastanza	molto	moltissimo
Carenza di competenze interne	○	○	○	○	○
Difficoltà a reperire figure professionali adeguate nel mercato	○	○	○	○	○
Limitate risorse finanziarie per far fronte all'investimento	○	○	○	○	○
Sistemi informativi interni inadeguati	○	○	○	○	○
Lunghezza nei tempi di implementazione	○	○	○	○	○
Difficoltà ad identificare il/i fornitore/i	○	○	○	○	○
Mancanza di banda larga	○	○	○	○	○
Altro	○	○	○	○	○

24. L'adozione di tecnologie legate all'industria 4.0 ha comportato un cambiamento del lavoro in fabbrica in termini di:

	per niente	poco	abbastanza	molto	moltissimo
Maggiore complessità dei problemi legati alle tecnologie dell'Industria 4.0					
Aumento della formazione per lo sviluppo delle competenze dei lavoratori					
Riduzione dell'interazione tra il lavoratore e i macchinari					
Aumento della collaborazione tra la funzione di produzione e i fornitori					
Aumento della collaborazione tra i lavoratori della fabbrica					
Aumento della collaborazione della funzione di produzione con le altre funzioni aziendali					
Creazione di nuova conoscenza per migliorare i processi produttivi					
Creazione di nuova conoscenza per migliorare i prodotti					

25. Dal punto di vista del prodotto offerto dall'impresa, l'adozione di tecnologie legate all'industria 4.0 ha portato a

	per niente	poco	abbastanza	molto	moltissimo
un aumento nelle prestazioni offerte attraverso i servizi collegati (prodotti intelligenti, ecc.)					
un ruolo più attivo del cliente in fase di progettazione dei prodotti					
un ruolo più attivo del cliente in fase di produzione dei prodotti					
un maggior controllo sul prodotto durante il suo utilizzo (es. manutenzione a distanza, raccolta di informazioni sull'utilizzo, gestione del fine vita, ecc.)					
un diverso processo distributivo dei prodotti (nuovi intermediari…)					

26. L'utilizzo di tecnologie per l'industria 4.0 ha migliorato la vostra capacità di innovazione?

- ◯ Sì
- ◯ No

27. L'adozione di tecnologie legate all'industria 4.0 ha comportato un impatto in termini ambientali?

	per niente	poco	abbastanza	molto	moltissimo
Riduzione degli sprechi	◯	◯	◯	◯	◯
Riduzione della quantità dei materiali/input utilizzati (es. energia, materie prime..)	◯	◯	◯	◯	◯
Adozione di materiali/input più sostenibili (es. riciclabili/riciclati, ecc)	◯	◯	◯	◯	◯
Tracciabilità della filiera/consumo	◯	◯	◯	◯	◯
(ri)utilizzo di materiali di scarto dei processi dell'impresa	◯	◯	◯	◯	◯
Riduzione degli impatti ambientali dei processi dell'impresa (es. sull'aria, nell'acqua)	◯	◯	◯	◯	◯
Utilizzo di input provenienti da scarti/rifiuti di altre imprese/settori	◯	◯	◯	◯	◯
Modifica delle reti di fornitura (in chiave green)	◯	◯	◯	◯	◯
Altro	◯	◯	◯	◯	◯

28. Il primo cliente quanto pesa in % sul fatturato totale?

29. Se vendete ad altre imprese di produzione (B2B), quali sono i principali settori in cui operate?

Settore 1

Settore 2

Settore 3

30. Fatto 100 il volume della produzione, l'impresa realizza (totale uguale al 100%)

prodotti finiti per il consumatore finale

prodotti finiti per altre imprese di produzione

componenti

semilavorati

31. Fatto 100 il valore della produzione, i prodotti dell'impresa sono realizzati (totale uguale al 100%):

nella regione

in Italia

all'estero

32. I vostri fornitori sono localizzati (in % sul numero totale fornitori) (totale uguale al 100%)

Nella regione

In Italia

All'estero

33. Se i prodotti dell'impresa sono realizzati all'estero (direttamente o tramite fornitori), specificate i principali 3 paesi di produzione

1° paese

2° paese

3° paese

* 34. Fatto 100 il volume della produzione, specificate come si suddivide la produzione dell'impresa (totale uguale al 100%):

Prodotti standard / a catalogo

Prodotti che possono essere personalizzati partendo da modelli standard a catalogo

Prodotti personalizzati su misura

Grazie per aver partecipato all'indagine!

35. Se volete essere informati sui risultati dello studio lasciateci i vostri riferimenti:

Nome

Cognome

Ruolo ricoperto in azienda

E-mail

36. Codice Fiscale impresa intervistata (a cura dell'intervistatore)