UNIVERSITA' DEGLI STUDI DI PADOVA

DIPARTIMENTO DI SCIENZE ECONOMICHE ED AZIENDALI "M.FANNO"

CORSO DI LAUREA MAGISTRALE IN BUSINESS ADMINISTRATION

TESI DI LAUREA

"LEAN AND INDUSTRY 4.0: A QCA ANALYSIS"

RELATORE:

CH.MO PROF. FURLAN ANDREA

LAUREANDA: ZATTA ELENA

MATRICOLA N: 1183771

ANNO ACCADEMICO 2018 – 2019

Il candidato dichiara che il presente lavoro è originale e non è già stato sottoposto, in tutto o in parte, per il conseguimento di un titolo accademico in altre Università italiane o straniere.
Il candidato dichiara altresì che tutti i materiali utilizzati durante la preparazione dell'elaborato sono stati indicati nel testo e nella sezione "Riferimenti bibliografici" e che le eventuali citazioni testuali sono individuabili attraverso l'esplicito richiamo alla pubblicazione originale.

The candidate declares that the present work is original and has not already been submitted, totally or in part, for the purposes of attaining an academic degree in other Italian or foreign universities. The candidate also declares that all the materials used during the preparation of the thesis have been explicitly indicated in the text and in the section "Bibliographical references" and that any textual citations can be identified through an explicit reference to the original publication.

Firma dello studente

Elena Latta

Table of Contents

Figures

INTRODUCTION

Lean and Industry 4.0 are two different concepts, apparently very distant and difficult to reconcile. Lean has been developed immediately after the World War II and can count on decades of experience. It was originally designed and implemented within the Toyota plants. Even if Lean principles are deeply rooted in the Japanese culture, they have reached different counties all around the world, especially during the 1990s and they have been successfully implemented in the European and American markets. Less than ten years ago, the German government included Industry 4.0 in its programme to build a sustainable competitive advantage for the national manufacturing industry. From that moment on, following the example of Germany, many other countries have developed plans for the technological advancement of their industries, confirming that Industry 4.0 represents the future of manufacturing companies.

Nonetheless, Lean and Industry 4.0 share similar goals such as the reduction of operational complexity and the increase of productivity (BCG, 2017). Lean streamlines the production processes, encourages continuous improvement and involves also shop floor workers in most of the processes. The new approaches proposed by Industry 4.0's technologies enhance speed, efficiency and promote self-managing processes.

Understanding the interplay between Lean and Industry 4.0 is fundamental to make their integration work effectively. They should complement and support each other to overcome some of the drawbacks that they entail. Lean alone sometimes is not sufficient to manage the increasing complexity of markets and operations, while the isolated adoption of advanced technologies can add elements of complexity and rigidity to processes and make them more difficult to handle.

There are not many studies that empirically investigate the conjoint implementation of Lean management and Industry 4.0 in manufacturing companies and also the literature on this topic is scarce (Tortorella *et al.*, 2018).

This is the background in which this work is inserted. It proposes an empirical analysis on the adoption of Lean and Industry 4.0's technologies, to understand if their implementation have a positive impact on the profitability of companies. This purpose is pursued thanks to the data collected through the survey conducted among Italian manufacturing companies from the University of Padua in collaboration with CUOA Business School.

The First chapter provides a theoretical framework both for Lean and Industry 4.0. The section dedicated to Lean tries to follow the evolution of the concept from when it was limited to the shop floor, to its complete deployment as a holistic philosophy. It describes its basic principles,

that guide companies at a strategic level and the most common practices that operationalize them.
The remainder of the chapter tries to define the ever-changing and still under development concept of Industry 4.0. Its basic components provide an idea of its layered structure, even if a more complete picture can be reassembled only after the description of some of its key technologies.
The Second chapter uncovers the origins of the idea of introducing automation technologies in Lean companies. The integration of the two approaches is then suggested starting from the main drawbacks that the isolated implementation of Lean and Industry 4.0 can cause. Two sections present both the literature that argues that Industry 4.0 reinforces Lean manufacturing and the Authors that claim the opposite.
Chapter Three introduces the data used for the empirical analysis proposed by this work. It presents the answers of 454 Italian manufacturing companies aggregated in some descriptive statistics and depicts the main characteristics of the sample. Moreover, it introduces the sample’s breakdown in four categories: the enterprises that implement both Lean and Industry 4.0, the ones that apply only Lean practices, the firms that have Industry 4.0’s technologies, but are not Lean and in the end, the remaining companies that neither implement Lean practices, nor have invested in advanced technologies.
The core analysis of this work is conducted in Chapter Four on the first subset of the sample. The Qualitative Comparative Analysis proposed determines which configurations of bundles of Lean practices and of Industry 4.0’s technologies lead to a higher profitability for companies. The results show three different approaches that enterprises can adopt to enhance their performance: the Lean approach, the Smart manufacturing approach, and the Lean and Smart Product Development mixed approach.
While the first two opposite approaches underline an alternative choice between Lean practices and smart manufacturing technologies, the third approach highlights that for firms that are experiencing the integration of Lean and Industry 4.0 it is fundamental to use the right mix of practices and technologies to have a successful performance.

CHAPTER 1

1.1 Lean definition

Defining Lean is not a simple task, mainly because the term Lean can be used to address a wide range of concepts. Pettersen (2009) uses four possible features of the Lean approach to inspect what Lean can stand for: it can be an Operational or Strategic approach (also defined by the Author as "continuous" or "discrete", p. 132) and can be Practical or Philosophical (respectively "performative" or "ostensive", p. 132). Pettersen (2009), thus, classifies four principal meanings for Lean, recognized through the combination of these dimensions. First of all, Lean can be seen as an Operational Practice that solves isolated events and is defined "Toolbox Lean". Secondly, the Author names the Lean Strategic Practice as the process of "Becoming Lean". Moreover, it recognizes both the Lean Operational Philosophy that aspires to an ideal final state of "Leanness" and the Strategic Philosophy defined "Lean thinking" (Pettersen, 2009, pp.132-133). This complex classification gives an idea about the breadth of the concept of Lean, that ranges from the simple introduction of tools to enhance production, to a long and continuous journey that affects and changes profoundly the culture of the organizations, and that reaches also the partners of the enterprise along its supply chain.

The concept of Lean, was developed in Japan in the 1940s within the Toyota plants and was first described in *The Machine that Changed the World* (Womack *et al.*, 1990). The book analyses the differences between the Japanese production methods and the Western ones, underlying the systematic superior performance obtained by the formers with regards to the mass production systems. Even if mass production can grant lower costs to customers, by exploiting longer production runs, standard designs and running faster and faster large machines, it cannot offer much variety neither to clients, nor to the employees, that in these contexts are often bored by the repetitive operative work.

The Lean approach, instead, aims at providing customers with the products or services exactly when demanded, with higher quality, lower price and shorter response time. These ambitious goals are pursued by placing right-sized machines along the process sequence, developing their ability to self-detect defects and reducing their set up times to allow quick changes and small volume productions. In addition, a feedback system is installed between each stage of the process to send notification of the actual need of material to the previous step (Thangarajoo and Smith, 2015). In *Lean Thinking: Banish Waste and Create Wealth in your Organisation,* (Womack and Jones, 1996) the five basic Lean principles (later described) are clearly explained and enunciated, providing managers with a guide for action to convert their established brownfields in leaner organizations. As the Authors state, by writing the book, their "objective was to send a wake-up message to organizations, managers, employees and investors stuck in the old-fashioned world of mass production" (Womack and Jones, 2003, p.10).

Through an analysis of successful real cases, they present a road map that all the companies can follow to become Lean, because it is suitable for any industry and applicable to every situation. Over time, indeed, Lean methods, originally designed for production, have been successfully implemented and adapted to all the functions within companies such as logistics, distribution, but also finance and human resources. The use of Lean concepts in different industries like retail, constructions, healthcare and their application also for services demonstrate that Lean is a universal approach, versatile and adaptable to contexts different from the automotive sector, for which it was initially designed. To underline the extension of the concept from a functional level to the business level, the Authors has preferred to talk about "Lean thinking", instead of "Lean production" or "manufacturing", suggesting also that Lean is more a philosophy or a mind-set rather than a mere way to organize the operations.

Lean thinking is certainly one of the most powerful weapons to maximize the value created for clients, while eliminating waste in the organization (Womack and Jones, 2003). Taiichi Ohno was the first Toyota executive that systematically recognized and tried to get rid of any kind of waste. The Author defined as *muda* (that means waste in Japanese) any activity that does not add value to the product or service the company is providing and in 1988 proposed his well-known classification of seven types of *muda*: "*defects* in products, *overproduction* of goods, *inventories* of goods awaiting further processing or consumption, unnecessary *processing*, unnecessary *movement* (of people), unnecessary *transport* (of goods) and *waiting* (by employees for process equipment to finish its work or an upstream activity" (Ohno, 1988, pp.19-20). Provided that the ultimate idealistic goal is to create a perfect process for value creation, with no waste at all, the focus of managers should shift from eliminating waste from separate single assets, technologies or vertical divisions, to purifying from end to end the entire value stream. The effects of such an effort are tangible: the companies need less time, space, human effort and capital, they produce at lower costs and with fewer defects and can respond to ever changing customers' demand more quickly, providing a wider variety (Thangarajoo and Smith, 2015). Put simply, they are Lean: create more, with fewer resources.

Moreover, in order to fully embrace a Lean transformation, it is necessary for companies to look at a wider picture and broaden the scope of application of Lean thinking from the company level to the entire supply chain. The supply network of a Lean company and the inter-firm relationships within this chain, should guarantee a smooth flow of goods or services without waste and the sufficient exchange of technology, communication and information in both directions. Usually, the focus of managers is on what happens within the company, so that the relationship with other entities beyond its boundaries is only regulated by the mechanism of purchasing and the subsequent concerns for logistics. A first attempt to give the needed attention to these themes comes from the "Supply chain management". Supply chain management suggests (Stevens, 1989) to add more value than cost at each point of the value chain, balancing some apparently contrasting goals like better customer service, low inventory management and unit costs. But some of the precepts of supply chain management as "vantage point" and "customer superiority" are against the Lean ones (Lamming, 1996). Only by coordinating and aligning all the stages of the value adding process it is possible to have an overall view of the process from raw materials to end customers, thus, a Lean supply.

Lamming (1996), defines Lean supply as "the product of an operating attitude that recognizes the cost associated with any departure from perfect execution of the tasks necessary to provide long-term customer satisfaction, thereby achieving total eradication of those costs" (Lamming, 1996, p.187).

1.1.1 Lean principles

Following and applying the five Lean principles (Womack and Jones, 1996), it is possible to discover and banish waste, thus eliminating one of the first and greatest obstacles for the creation of value. This systemization of Lean thinking into simple and clear principles has become very important over time, because the complexity of products is always increasing while their life cycle is reducing. (Santos *et al.*, 2006)

The principles are:

1. Specify and define *value* from the customers' perspective: the analysis of current customers allow companies to understand what clients regard as value and to get ready to fulfil their demand. Looking at customers to define value is revolutionary since usually firms tend to determine and measure it by business unit, or by looking at internal metrics.
2. Identify the *value stream*: start by listing all the activities needed to create a specific product or service, then determine which are value adding and which are not and eliminate the ones that are identifiable as waste along the value stream. Still organizations need to distinguish the avoidable activities from the unavoidable ones, that should immediately become target for future improvements. When the companies succeed in this, usually the business gains efficiency both in the short and long run, through the reduction of the cost of production and the improvement of the bottom line.
3. Make the value *flow* with no interruptions: all the components of a products should flow in a smooth, constant way from one station to the next one without interruption or with

the minimum time possible. This should prevent inventories from accumulating between the working stages.

4. Let customers *pull:* this is the principle that regulates the pace of production and aligns it with the demand. In fact, no good or service should be produced or assembled until a customer or a downstream stage in the value stream asks for it. Many organizations adopt the opposite *push* logic in manufacturing: they plan the production according to demand forecasts and taking into account also the actual and desired levels of inventory. The problem with this second approach relies in the possibility to have inaccurate predictions, that can cause either the creation of inventories between workstations, or keep some of them waiting idly. Although very successful in solving these synchronization problems, applying a *pull* logic requires a very strong coordination with customers and suppliers to understand their preferences and provide the resources needed in a timely manner to satisfy their requests.
5. Pursue *perfection*: the process of reorganization of flow and elimination of waste is not finished once the first four principles are applied. That moment is just the starting point for their further application. Additional *muda* can be detected at each round of application and the value stream can be continuously improved. Continuous improvement is also itself a management approach that raises the efficiency of many processes and systems, without the need of big capital investments (Zangwill and Kantor 1998). Perfection is not materially reachable but gives direction to the never-ending effort of becoming Lean.

1.1.2 The impacts of Lean implementation

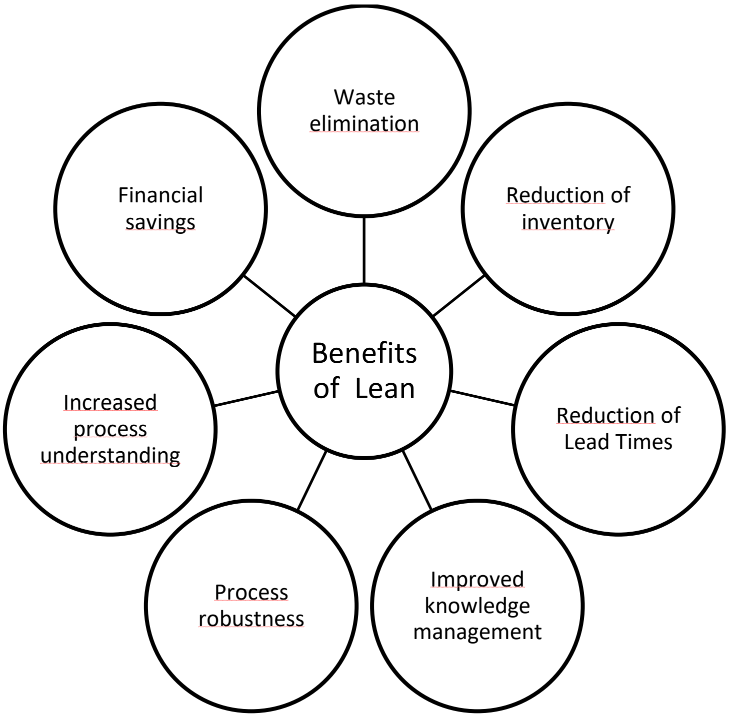
The base concepts on which Lean thinking is based influence strongly the way in which industrial production systems and all the company's processes are organized (Detty and Yingling, 2000).

- *Process stability* requires the attainment of quality standards. To assure high quality products organizations need to monitor all the resources that contribute to deliver value: men, machines, materials.
- *Standardized work* assures that a certain activity is accomplished according to the best operating practices known. The Standard Operating Practices (SOP) should be considered just as a benchmark, not a constraint to further development, exactly as Ford wrote in 1926: "Today's standardization, instead of being a barricade against improvement, is the necessary foundation on which tomorrow's improvement will be based."

- *Level production* (see also *Heijunka* in Lean techniques) and synchronize operations' activity with demand rate. The techniques that generate a smoother production are fast changeovers (see *SMED* in Lean techniques), small lots or mixed-model sequenced production scheduling.
- *Just-in-time (JIT)* is sometimes used as a synonym for Lean manufacturing, and is based on the five lean principles, in particular, JIT requires a continuous flow process layout and a pull logic to keep in-process inventories at the minimum level.
- *Quality at the source* means activating quality checks after each activity to detect immediately, rather than later in the process, possible sources of defects. Some techniques usually enforced are inspection systems with immediate feedback, error-proofing mechanisms (see *Poka-yoke* in Lean techniques) and stringent monitoring and control of factors that cause quality problems.
- *Visual control* (see *Visual control* in Lean techniques) is a very powerful way to communicate information regarding the state of the production process. It is direct, fast and simple, in fact once the signals are known, they can hardly be misinterpreted. Through techniques such as *5S*, inventory displays and *Andon boards* (see *Visual control* in Lean techniques), problems are solved as they occur.
- *Production stop policy* is related with the former point, because anytime there is a problem, the production process is stopped to find a definitive solution, instead of a quick and poor one.
- *Continuous improvement*, as stated above, is a strategy to pursue perfection. Employees should work in teams, contribute their physical and intellectual talents to improve all aspects related to production: safety, productivity, quality and also their work environment. Least but not last, this empowerment of the employees is itself an element that assures discrete, continuous improvement.

The benefits brought by lean implementation (*Figure 1*) are well documented (Melton, 2005): lead times for customers are decreased, manufacturers witness the reduction of inventories, organizations experience an improved knowledge management, the decreased number of errors and therefore reworks and a higher process robustness. In an increasingly competitive environment Lean allows companies to get closer to clients and understand better what they want, exactly when they want it. Furthermore, all the aspects of the business are highly regulated and lean clarity and transparency helps in fulfilling the desire for compliance (Melton, 2005). Moreover, by taking a total-quality approach, Lean firms guarantee that their products and services have a higher level of dependability and reliability compared with the ones of

Figure 1: Principal benefits of Lean implementation.



Source 1: Personal elaboration.

competitors (Hu et al., 2015). The ability of Lean firms to outperform competitors is also attributed (Spear, 2009) to their ability to quickly learn, through the implementation of four rules: *design* the stages in work systems specifying all the details needed for their functioning and prepare a test system to identify issues while operating; *improve* the ability to recognize problems early and gain additional knowledge in the process of solving them; *share knowledge* to put it to a wider use and *develop problem solving capabilities* in all people working, even at lowest hierarchical level. Lean firms that follow these rules with great discipline learn more quickly than firms that are not Lean and can more easily sustain dynamically their competitive advantage.

1.1.3 Lean implementation in SMEs

Lean, that has been recognized as a key improvement concept, can be successfully applied to companies of all sizes, in their efforts to be more competitive, to sustain and possibly enhance their position in the marketplace. (Hu et al., 2015)

According to the European Commission (2015, p.10), "The category of micro, small and medium-sized enterprises consists of enterprises which:

- employ fewer than 250 persons; and
- have either an annual turnover not exceeding EUR 50 million or an annual balance sheet total not exceeding EUR 43 million."

These firms will be thereafter referred to as SMEs: small and medium enterprises, as opposed to LEs: large enterprises.

From the systematic review of literature on the implementation of Lean in SMEs of Hu *et al.* (2015), some interesting results have been found. In general, the Authors report that usually the companies that undergo a Lean transformation and that benefit from it are the Large ones. They are the perfect candidate because they have enough resources and strengths to face the change. Moreover, they have enough negotiating power to influence the whole supply chain and involve all the companies in their effort to become leaner, receiving raw materials and procurements at the right time and in right quantity. Another precondition that encourages Lean application in these big firms is their ability to manipulate, influence and level demand. Nonetheless, usually in SMEs there is a higher degree of communication, with frequent use of workgroups and a greater sense of proximity and close collaboration than in large ones. This is one of the advantages of SMEs that want to implement Lean, that requires a fast and efficient sharing of information among functions and also beyond the organization's boundaries. Also having less infrastructures can be useful in applying Lean principles: infrastructures can cause rigidity and prevent change from taking place. SMEs can thus react with more flexibility to new stimuli, and quickly adapt to new conditions. The smaller dimension allows SMEs to be closer to customers and to produce the right volumes to satisfy their requests, as opposed to the batch production usually run by LEs.

Hu *et al.* (2015) highlight that there is a difference in the type of Lean adopted from SMEs and LEs. In particular, using Pettersen's definitions (2009), SMEs usually implement an "Operational Practice" approach or at most an "Operational Philosophy", appearing to be very focused on the operational consequences of Lean within the organization. Bhasin (2012) confirms this tendency with his study on the implementation of Lean in the UK. The Author finds out that only 20% of small manufacturing companies apply Lean to the whole supply chain, whereas the remaining 80% are still working on Lean with a focus on internal operations. On the other hand, LEs have more frequently a "Strategic Philosophy" attitude towards Lean, looking also at the integration of external partners in the supply chain (Hu *et al.* 2015).

It has also been verified that (Hu *et al.*, 2015), for the implementation of Lean in SMEs, a variety of tools have been used. The most common ones are the mapping practices like Value Stream Mapping (VSM), the use of Kanbans, the five-S (5S) technique for the organization of the workplace, visual management tools, Standardised Work and Total Productive Management (TPM). Some of the techniques that are adopted less frequently by SMEs, because are too complex or expensive, are instead more used in LEs: Kaizen, Level Scheduling, 5 Whys, Small Lot Sizing and Single Minute Exchange of Die (SMED).

1.1.4 Lean practices

For the sake of this analysis, in the following section it is proposed an overview of some of the most common Lean practices implemented by companies.

VSM

Value Stream Mapping is a powerful technique that helps to prioritize the actions to take. It requires two steps of mapping, the first one must show the workplace "as is", at its current state, while the second mapping endeavour should be about how the workplace "should be". The necessity of filling the gap between these two versions of the map, suggests the order and priority of measures to be taken. (Bicheno and Holweg, 2016).

5S

This is a methodology that improves the work environment and teaches how to keep it in an orderly manned without too effort (Santos *et al.*, 2006).

The principles are:

I. *Sort* (*seiri* in Japanese): Necessary things should be differentiated from those that are not.
II. *Set in order* (*seiton* in Japanese): If all the elements are organized and kept at their place everybody can easily find them and use them when needed.
III. *Shine* (*seiso* in Japanese): This principle stresses the necessity to clean the working area.
IV. *Standardized or visual control* (*seiketsu* in Japanese): This fourth step is fundamental in order not to waste the work previously done through the first three principles. Finally, if the work is standardized, it is also simpler to detect deviations from the best practices.
V. *Sustain* (*shitsuke* in Japanese): The newly adopted working procedures need to be enforced until they are translated into new habits.

A3

A3 is a management approach that uses the scientific method as a problem-solving approach. It is a powerful tool because it conducts problem solvers to reach the root cause of the problems, to unveil potential opportunities, encouraging new solutions and ideas. It is also a learning instrument since it helps people to accumulate knowledge, thanks to the transparent problem-solving process. The name of this tool is taken from the size of the paper "A3", that is usually used for the problem-solving technique. In a small piece of paper, anyone should be able to get the key information, well synthesized, in a logical and standardized structure (Tortorella *et al.*, 2019). The popularity of this technique is also related to the fact that it is very cheap, all it is needed to implement it is a pencil and a piece of paper.

Flow layout

Flow layout is the most suitable arrangement of operations to guarantee the Lean principle of flow. Typically, machines are lined up in sequence, according to the process steps required, with parts flowing from machine to machine quickly and smoothly, without any interruption. Flow management is important also for the reduction of the management and coordination costs (Hashmi *et al.*, 2015).

Kanban

Kanban (literally "visible record") is one of the techniques of JIT, "it is a card-based control system to transfer instruction based on logic that nothing will be produced until needed." (Sharma and Singla, 2019, p.56) The Kanban system is one way to implement the *pull* logic in the operations. The system, indeed, is meant to minimize inventories and provide raw materials and goods to the next steps in production, only when required by them.

Visual management

Visual Management is a managerial strategy that facilitates the short-range communication increasing information availability, giving visual and sensorial stimuli and removing possible obstacles from the flow of information. It was originally conceived for improving production management in factories, but the theoretical constitution of VM can be applied by commercial, healthcare, institutional, and educational services. (Tezel *et al.*, 2016)

Standardized work

Standardized work is a tool that is part of the Toyota Production System. It is based on waste elimination and represents an effective way for process improvement. Standardized work is the easiest, safest, and most efficient way to perform an activity. As already mentioned, standardized work should be used by workers just as a basis for future improvement. (Fin *et al.*, 2017)

Kaizen workshops

A kaizen workshop is a kaizen activity that takes place in group, and commonly lasts five days. During these workshops usually a team identifies analyses, implements, tests, and standardizes an improvement in a process.

Poka-yoke

Poka-yoke literally means error-proof, it is a mechanism that prevents mistakes from being made or helps to make them obvious and detectable at a glance. As Pojasek states (1999, p. 91), Poka-yoke "works by taking over repetitive tasks or actions that depend on vigilance or memory, thus freeing workers' time and minds to pursue more creative and value-adding activities."

TPM

TPM comprehends a set of techniques, first tested in Toyota Group in Japan, whose aim is that every machine of a production process is always able to perform its tasks. TPM is different from other maintenance approaches because it requires the participation of all employees: line managers, manufacturing engineers, quality experts, and operators, not only of the maintenance personnel. Employees are involved both in every-day maintenance and improvement projects, sometimes performing also simple repairs. It is the optimal tool to optimize equipment effectiveness, minimize breakdowns and production losses, while empowering employees and extending their skills. (Jain *et al.*, 2018)

Suggestion system

The suggestion system is a procedure established, formalized and controlled by management to actively engage employees. They are involved in carrying out new constructive ideas for improving the products and many other aspects of the company's operations and services such as methods, procedures, materials, equipment or themes related to safety or working conditions. Employees are incentivized to adhere at this program and voluntarily suggest suitable ideas through a system of rewards that is granted to the most active ones. On the other hand, the suggestion system can significantly benefit the organization because it gives employees more sense of belonging, promotes creativity and active thinking, and raises their consciousness thanks to the possibility to benefit immediately from the improvement that they have promoted (Reuter, 1977).

Simultaneous engineering

Simultaneous engineering or Concurrent engineering is a project management approach that helps organizations in developing and launching new products more quickly. Speed is assured through "the integration of research and development, product design, process planning, manufacturing, assembly and marketing into one common activity" (Shenas and Derakhshan, 1994, p.32). Differently from the traditional methods used to design and manufacture new products, simultaneous engineering does not adopt individual specialized groups that work on specific activities but requires only one multi-disciplinary team of experts to perform all tasks (Shenas and Derakhshan, 1994). Additional benefits come from a better prediction of product performance, a quicker response to customers and a time advantage over competitors.

Heijunka

Literally Heijunka means production levelling, smoothing and is a practice that tries to protect firms from variability. The production is scheduled with a repetitive pattern over time, so that production lines manufacture a fixed sequence of products. The goal is of removing peaks or times when machines are underloaded, while keeping at minimum inventories, manpower, capital costs, and production lead time through the value stream. Obviously, in contexts with a high variability in demand and wide product variety, implementing Heijunka becomes really difficult (Huttmeir *et al.*, 2009).

Six Sigma

Six Sigma methodology emphasises improvement and quality control by using rigorous data collecting methods and statistical analysis. This use of mathematical and statistical tools to improve the quality of processes was first introduced by Motorola in 1986. The name Six Sigma derives from the number of standard deviations that represent the distance of a point from the mean in a bell curve. The objective of this approach is to minimize process output variation, gaining cost reduction and improving customer satisfaction (Hu *et al.* 2015). Indeed, the standard quality required is a very tough one and is set to just 3.4 defects per one million opportunities. To apply Six Sigma, a five-step process must be followed to define, measure, analyse, improve, and control often referred to as DMAIC cycle.

SMED

Single Minute Exchange of Die or SMED is a technique for changing over production equipment so that it can manufacture a different part or component, in as little time as possible. SMED refers to the target of reducing changeover times to less than 10 minutes, that means that changeovers last a quantity of time that can be expressed with a single digit. Shigeo Shingo developed this technique after nineteen years of work at Toyota. His key insight about setup reduction was pretty simple, yet very powerful: the set up operations can be distinguished between internal setup operations, which can be done only when a machine is stopped (such as inserting a new die) and external operations, that can be performed while the machine is running (such as transporting the new die to the machine). Once these two have been sorted out, the internal ones should be converted to external operations (Shingo, 1985).

Andon

Andon is one of the most common tools for visual control. It uses a series of alarm lights to signal specific situations to workers. They can indicate that an activity is going wrong or that a material shortage occurred. In an assembly line the Andon system is useful to detect which is the spot in which problems have emerged, so that the supervisor can personally intervene and solve them. (Santos *et al.*, 2006)

1.1.5 Problems with Lean implementation

The implementation of Lean practices is not a quick or simple process, it requires to rethink and reengineer the operations, the way in which companies design their products and finally, the synchronization of the whole supply chain. Not all the companies have the strengths, determination, persistence and patience to achieve a truly Lean thinking (Dettmer, W.H., 2008). The meaningful differences between the traditional manufacturing system and the Lean one, such as on the management of employees, the flow of materials and information, the plant layout and the scheduling and control of production, make the decision to enforce Lean a very difficult one. Firms that historically relied on the oldest methods, indeed, cannot easily predict the benefits they could sense by undergoing a lean transformation (Detty and Yingling, 2000). Melton (2004) records two major reasons among companies resisting Lean implementation. First, the perceived lack of tangible benefits and second the belief that business processes are already efficient. Both reasons seem not so consistent in light of the numerous successful results obtained from the transformed firms, even from companies that were already having a good performance and even in the short term. But as Womack and Jones (2003, p. 95) state "Firms which never start down the path because of a lack of vision obviously fail."

1.2 Industry 4.0

It is agreed (Zhou, Liu, Zhou, 2015) (Paiva Santos, Charrua-Santos, Lima, 2018) (Dorleon, Gervais, 2017) that the concept and term "Industry 4.0" finds its origins in an article published by the German government in 2011, after a discussion about high-tech strategy for 2020 (High Tech Strategy 2020 Action Plan, 2011). When the term appeared again during the industrial fair in Hannover in 2013, it officially gave birth to the German strategy for national industry's development. This strategy is aimed at keeping Germany's advantage in the manufacturing industries where it is already at the forefront, from the automotive, to the electrical and electronic ones. The technological challenges promoted by the German plans quickly started to affect other countries. The European Union, for example, has adopted some of the initiatives related to Industry 4.0 in the H2020 program, its plan for technology and innovation. In the USA the program is named "Industrial Internet", while in China it is "Internet +".

"Industry 4.0" is often referred to as "The fourth industrial revolution". The first three industrial revolutions were driven by new technological changes as the mechanization, electrification and information, while the fourth one is led by intelligent manufacturing. The objective of each of these developmental stages was to improve productivity, in particular, the first industrial revolution, that took place in the middle of the 18th century in England, improved efficiency thanks to the use of hydropower, a wider use of steam power and the development of new machines and tools. The second revolution was disruptive with the great improvements brought from electricity and assembly lines that gave rise to mass production in Europe and USA, during the second half of the 19th century. Electronics and information technologies further increased efficiency in production during the third industrial revolution, in the last years of the 20^{th} century, reaching levels of automation never experienced in the past, in most of the industrialized countries. The attempt of the fourth industrial revolution, that is still going on, is that of unifying the real world of production with the virtual world of data and information (Zhou, Liu, Zhou, 2015). The new manufacturing processes include machines, devices, products and modules that can exchange information, autonomously trigger actions, or activate monitoring and control activities, within a very integrated network.

1.2.1 Definition

The available literature on Industry 4.0 offers a wide range of accurate definitions that capture different aspects of the massive revolution brought by this non-consensual concept.

Khan and Turowski (2016), describe Industry 4.0 as a revolution that has been enabled by the application of state-of-the-art technologies in production processes with the aim to bring new services and values to customers, while benefitting the company itself. Pereira and Romero (2017), instead define Industry 4.0 as a manufacturing paradigm that concentrates on the creation of smart processes and products, thanks to the use of smart machines and conversion of old traditional manufacturing systems in smart factories.

Finally, a more comprehensive definition of Industry 4.0 is given by Zhou, Liu and Zhou (2015) the Authors describe the concept as based on a deep integration of communication and information technologies along with industrial technology. They introduce then one of the base technologies applied in the fourth industrial revolution to accomplish this purpose, that is the Cyber-Physical System (CPS), together with the final result of the transformation that is an intelligent factory, information-led, more customized, green and with a digital manufacturing.

Every definition is neither complete, nor exhausting, because of the complex nature of the concept, but also because it entails predicting future industrial developments and technological trends. It seems important to understand the urgency and need of change in the manufacturing landscape, that is writing a completely new chapter in the manufacturing literature. The fourth industrial revolution, as the previous ones, is the result of the continuous development of new researches, scientific discoveries and the applications of the new findings for economic and industrial purposes.

1.2.2 Purpose

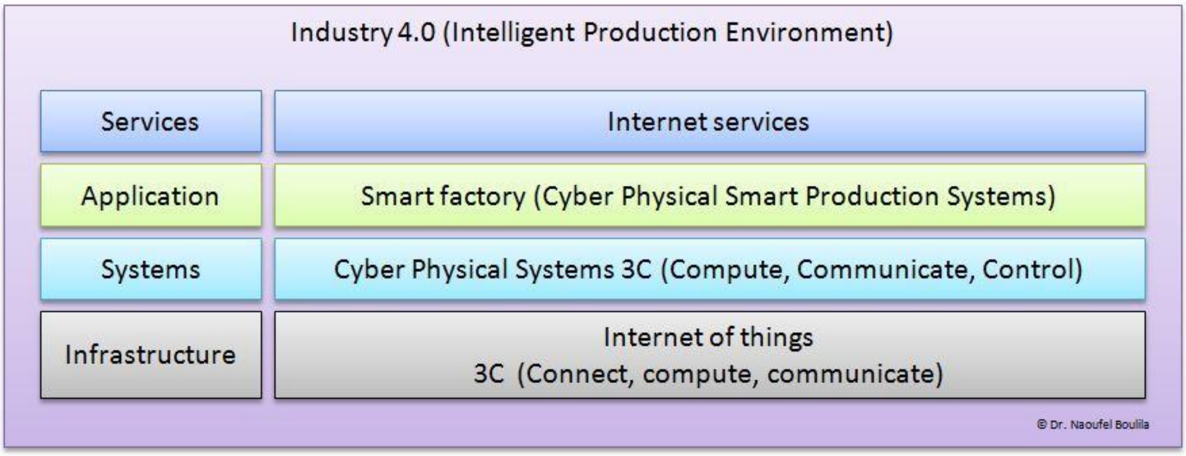
The purpose of Industry 4.0 is not only to enhance production efficiency, it is also that of responding to the demanding conditions of markets, with customers requiring customized products, that cannot be produced in large lots. Moreover, the fourth industrial revolution should prepare companies to cope with new worldwide trends such as green and circular economy. More specifically, the aim of Industry is to create a production model that is extremely flexible, where the products and services offered to customers are digital and personalized, and there is a real time interaction between people, products and devices along the production phases (Zhou, Liu and Zhou, 2015). The aim of Industry 4.0 is therefore the creation of "an open and smart manufacturing platform for industrial-networked information application" (Vaidyaa, Ambadb, Bhoslec 2018, p.234). In order to achieve the ideal levels of efficiency and flexibility, and reduce at the same time energy consumption and cut the costs in the industrial processes, companies should use an integrated framework where they can gather real time information mainly from the production stage, but also from beyond the boundaries of the firm (Paiva Santos, Charrua-Santos, Lima, 2018). The creation of a digital value chain is welcomed also by Oesterreich and Teuteberg (2016), that underlines the positive impact on communication that it can bring if it is implemented together with an increased digitalization and automation at the manufacturing level. The higher degree of information and the rapid communication during all the stages of product development is crucial to enable a better decision-making process. To base the decisions on a continuously updated stream of information ensures a greater accuracy in the response to market changes, reduces wastes such as reworking or defects, allowing to shrink costs, strengthen the relationship with customers and consequently will positively impact on the bottom line (Paiva Santos, Charrua-Santos, Lima, 2018).

1.2.3 Structure and components

Even if the description of the industrial environment and technological advancements that Industry 4.0 promotes, is not always consensual, still there seem to be a common vision on which are the base concepts and key technologies related to the fourth industrial revolution. The new industrial landscape is driven by a higher degree of connectivity, digitalization and integration for the creation of the value adding stream. These fundamental features contribute to the demolition of the boundaries between the physical world and the digital one. To examine more in depth what Industry 4.0 really means, it seems necessary to explore some of its key technologies and concepts. Vaidyaa, Ambadb, and Bhoslec (2018) identify as the four main drivers of Industry 4.0 Internet of Things (IoT), Industrial Internet of Things (IIoT), Cloud based manufacturing and smart manufacturing. Their drivers partially overlap with the four main elements of Industry 4.0 recognized by Dorelon and Gervais (2017) that are: Cyber-Physical Systems (CPS), Internet of Things, Internet of Services (IoS) and Smart Factory. The Authors also enlarge this small list to a broader one, collecting other components of industry 4.0: Big Data, Machine to Machine (M2M) and Cloud or Cloud.

To provide a general picture of the structure of Industry 4.0 and the layers of technology on which it relies, it will be used as a framework, the scheme suggested by Boulila (2019) (*Figure 2*). The Author digs into Industry 4.0, to find at its core, the basic infrastructure of the Internet of Things. On IoT's technologies are built Cyber Physical Systems, that connect the real world to the virtual one. The implementation of CPS for production, give birth to one of its most known applications that is the Smart Factory. It is a highly digitized and connected production environment, characterized by high visibility, connectivity and autonomy. On top of all these layers IoS makes services tradable goods and describes how the infrastructure uses the Internet as a medium for offering and selling them to final customers (Cardoso *et al.*, 2009). IoS completes the revolution of Industry 4.0 by introducing new business models that will change the way in which services are offered and will allow a higher value creation for each stage of the value chain and the corresponding stakeholders (Pereira, Romero, 2017).

Figure 2: Structure of Industry 4.0.



Source 2: Boulila, 2019, p.22.

The following section provides a brief description of the three core concepts and key technology drivers composing Industry 4.0: Smart Factories, Cyber-Physical Systems and Internet of Things.

Smart factory

Put simply, a Smart factory is generally a production plant where Industry 4.0 and its technologies are implemented. It relies on an integrated network in which suppliers, companies and customers are tightly linked. The term "Smart" is adopted very frequently to describe the features of elements related to Industry 4.0. Other alternative synonyms used in the literature are "Intelligent", "Real time" and "Ubiquitous", this last refers to the permeating presence of sensors and digital computing within the factory. Moreover, sometimes "Manufacturing" is used to replace the word "Factory". The concept of Smart factory is not an easy one to define, but several Authors agree to associate it with "independent and autonomous devices that are able to communicate in real-time and cooperate in a smart environment with other smart devices, making decisions and performing actions that are based in the obtained information" (Pereira and Romero, 2017, p.1208). A Smart factory seems to solve some of the challenges faced by the contemporary industry like high variability, advanced customization and the reduction of product life cycles in an increasing dynamic and complex production environment. Smart factories offer flexible production objectives, such as time-to-market requirements, production volume targets and cost-saving strategy (Urbikain *et al.*, 2017). A Smart factory is characterized by that instant and continuous communication between the various workstations and tools of the production and supply chain, that is core to Industry 4.0. The relation between this concept and the fourth industrial revolution is so meaningful that sometimes Industry 4.0 is known as "Factory of the future" (Dorleon, Gervais, 2017), referring to the intelligent production environment built, with fully automated and digitalized processes along the value chain. But it is not sufficient to adjust just the manufacturing processes and the production systems to have a "Factory of the future", it requires also changes in the management style, business models and in the competences of the workforce. For the same reason, Dorelon and Gervais (2017, p. 3) define Industry 4.0 with a holistic view, as a "paradigm shift in production processes and business models, setting a new level of development and management for organizations".

To create a true Smart factory, it is necessary to undergo three types of integration: Horizontal, Vertical and End-to-end integration.

- Horizontal integration involves several resources, processes, IT systems, and information flows present in different stages of the manufacturing process within the smart factory and between other organizations (Pereira and Romero, 2017). It entails an exchange of materials, information and energy both within the company, from inbound logistics, production, to outbound logistics, but also among companies, to create real value networks (Kagermann, Wahlster, Helbig, 2013). Such an integration allows a smooth cooperation between all the stakeholders, a closer collaboration with customers, suppliers and partners and a faster exchange of information in real time.
- Vertical integration concerns the cooperation between different levels of hierarchy within the organization and its divisions, from product development to logistics and sales. The result is a self-organized manufacturing system very flexible and responsive, that can be adapted to different products and services, according to the needs. A personalized custom manufacturing is the alternative to the traditional assembly lines that represent an example of the fixed production processes (Zhou, Liu and Zhou, 2015).

- End-to-end integration provides a solution for integrating the whole value chain through the use of terminals that are already able to put different companies in communication, thanks to the use of CPS technologies. This allows to facilitate and maximize product customization and the reduction of operational costs by filling the gaps between the manufacturing stages and by collecting more easily information on products throughout the value chain (Paiva Santos, Charrua-Santos, Lima, 2018).

A Smart factory is an organization that has reached a good degree of integration at all the three levels. It is also more efficient, safer and more environmentally sustainable thanks to the integration of its production technologies, of all the data and services that it produces and of the information and communication infrastructures in a single digital network.

Sustainability is a key feature of the Smart factories of the future and it should be kept in mind and guaranteed during the implementation of all the technologies related to Industry 4.0 like Internet of Things, Augmented reality devices, Cyber-Physical Systems, and so on (Strozzi *et al.*, 2017).

During their literary review on Smart factories, Strozzi *et al.* (2017) indicate two main aspects that are common to most of the papers analysed, the first one refers to the fundamental support of the governments in the development of new researches and technologies. It is both an institutional and financial aid, strongly wanted by governments to accelerate the accomplishment of the fourth industrial revolution through the planning of a paced agenda. The second common perception in most of the papers is the omnipresence of the smart technologies also outside of the boundaries of the firm. This confirms once more the necessity to broaden the Smart factory concept to the level of the entire supply chain, and to prevent that single companies start individually some initiatives, giving birth to an unsuccessful fragmented implementation. Moreover, the Authors find out some geographical differences in the connotation of the concept of Smart factory, in particular, different world areas demonstrate a different interest focus during their investigations on the concept. The first area is China, and the research interest is on RFID technologies, sensors and multi-agent interactions. It is a logical focus if it is connected with the huge contribution that this area of the world brings to the development of new prototypes and patents in such enabling technologies. The second area is centred in the USA, where the focus is on developing again the manufacturing capabilities of the countries, through this new industrial revolution. The third are is Europe. Here the focus is on giving suggestions on the implementation of Smart factory practices also involving changes in the management behaviour. However, overall the problems related to organizational aspects and the impact of Cloud and digital applications on the organization and its people are not examined in depth, leaving some areas of discussion still opened.

Another interesting trend that emerges from the review of the papers on the topic (Strozzi *et al.*, 2017) is that, instead of engineering new physical machines that take part to the manufacturing process, researches are far more interested in the development of new software, digital and virtual solutions. This can be related in part to the smaller degree of investments required by the non-physical tools, but mainly to the reduced need to change the processes at the shop floor. Finally, as soon as Smart factories become popular in the industry, Cyber risk and security start to be hot topics, raising the awareness on issues that can emerge from an easy integration of information systems and the sharing of data along the value chain.

Cyber-Physical Systems

Cyber-Physical Systems (CPS) are "systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the Internet" (Monostori *et al.*, 2016, p. 621). Generally speaking, CPS are technologies that allow to manage systems that have both physical assets and computational capabilities interconnected. CPS, indeed, are characterised by an accurately engineered physical structure, that is coordinated, monitored and controlled by a computing system, that manages also the communication stream. The interaction between the physical interface and the cyber one is the keystone to understand CPS systems, because these synergies make CPS more than the simple sum of their two natures.

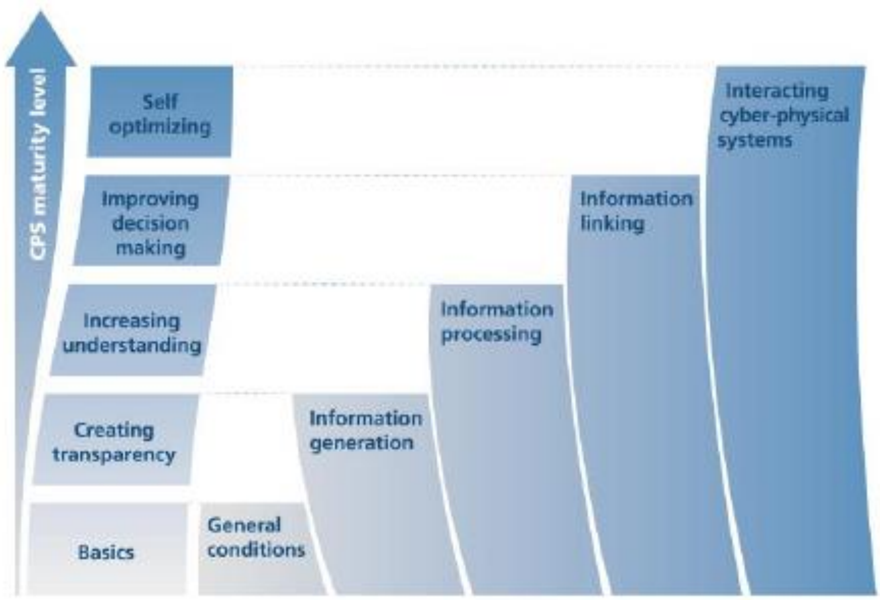
The first time that CPS became a central theme of discussion was at the first National Science Foundation Workshop on Cyber-Physical Systems in 2006, that took place in Texas. It boasted a working group composed by experts from the USA but also from the European Union, that systematically shared their knowledge and experiences of integration of physical processes with computation and data processing (Leitão *et al.*, 2016).

Nowadays, the availability of affordable technologies like sensors, networked computers and machines makes it easier for companies to collect that huge quantity of data known as Big Data. This is the environment in which CPS are growing, and in which high-tech solutions are necessary to exploit the potential of Big Data and to improve the interconnection of systems. It is only through the adoption of CPS that firms can start their transformation into flexible, self-adjusting and self-monitoring Smart factories.

Monostori *et al.*, (2016) describe the technological background of CPS to unveil the central role that they play in the incoming fourth Industrial revolution and the impact that these systems have on manufacturing processes. Computer Science (CS), Advanced Information and Communication Technologies (ICT), and Manufacturing Science and Technology (MST) are at the bases of CPS. The CS, ICT are ever-evolving fields that can strongly bolster the introduction of new production techniques. But it is true also the other way around: the complex nature of production, the need for strongly individualized products, flexible production quantities, and the integration both with customers and suppliers, are granting new challenges that can only be won with the help of disciplines at the forefront as CS, ICT and MST. For this reason, Monostori *et al.* (2016), describe these mutually inspiring developments as a "kind of convergence" between the physical and virtual world.

Monostori *et al.* (2016) offer also the maturity model of CPS that has been formulated by the Laboratory for Machine Tools and Production Engineering of RWTH Aachen University (*Figure 3*).

Figure 3: Maturity model for CPS.



Source 3: Monostori et al., 2016, p.624.

Five stages of maturity are classified as: "setting basics", "creating transparency", "increasing understanding", "improving decision making", and, "self-optimizing". It is during the "information generation" step, that there is the need for real time information from all the activities related to the CPS. The following step of "information processing" activates the mechanism of "information aggregation" to create new knowledge from simple data and information. The next level of "information linking" can only be achieved through a collaborative way of working of the CPS. Finally, the "interacting cyber-physical systems" is only granted through the capabilities of collaborative CPS, like problem solving.

The potential economic impact of CPS is surely big, but it is not easy to measure. CPS are indeed changing the way to create value, through new connected and intelligent products, but also the competitive environment is changing. If possible, competition is even fiercer, with companies facing an increase in productivity and efficiency and confronting also a higher functionality and performance of products. The smartest companies have already understood that having multidisciplinary partnerships with experts of IT, connectivity, cloud computing and new technologies such as sensors, is the only chance of surviving in this kind of arena in which they are fighting and of possibly offsetting competitors (Lee *et al.*, 2015).

Internet of Things

Internet of things is the technological development that is carried out from the new information technologies and the pervasive use of internet. It is applied not only to the industrial field, for promoting economic development and a more efficient production, but also in the daily life, through the creation of true "smart cities" and detailed networks of social relations connoted by a higher degree of intelligence. According to the definition of Pannu and Kay (2019), Internet of Things, or IoT henceforth, "refers to intelligently connected smart devices and systems using embedded technology, software, and sensors to communicate, collect, and exchange data with the user and one another" (Pannu and Kay, 2019, p.322). IoT is, in other words, the technology that enables the interconnection of different types of devices through the internet to exchange data, monitor devices, optimize processes, in order to generate benefits for the economy, the industry and the end user. It is composed of network of sensors, devices, actuators, forming new services and systems. The rapid development of IoT and the insisting demand for new technologies is generating problems and challenges never faced before, such as the need for a stronger collaboration with equipment manufacturers, the nurturing of multiple links along the whole supply chain and sometimes also the coordination with providers of public services, that are usually not ready or flexible enough to develop as quickly as asked. The breakdown of key IoT's key technologies can help to accelerate their adoption in critical areas and guarantee better results.

Liu, Li, Li (2019), identify as key technologies: Sensor Technology, Operating System Technology, Cloud and Edge Computing Technology.

- Sensor Technology: this technology is at the very basis of the IoT concept and is of fundamental importance. Sensors are the interfaces that permit information perception. Their fundamental role is equivalent to the human's five senses. The main producers of such technologies are United States, Japan, and Germany, but also the Asian market is showing an important growing trend, with China leading the investments, mostly public, and guaranteeing an appropriate market share for itself (Liu *et al.*, 2019). The core elements of sensors are realized with sensitive materials and last generation components such as graphene, biomaterials and special ceramics. Having access to these key resources and having an adequate R&D process can guarantee the strategic advantage in the sensors' industry. After the creation of core components, the subsequent step is deploying processes and technologies to integrate different kind of sensors together, miniaturizing them and reducing their energy consumption. Sensors can be applied for a wide variety of applications, such as to keep monitored pressure, light, magnetic forces, temperature, humidity and so on.

- Operating System Technology: it is a software component, precisely, a file system that can be used in different areas like industrial control, aerospace, wearable devices, smart home and others. It contains network protocols and other peripheral modules together with various types of development tools and interfaces. Industrial control, for example, comes from the need to monitor, optimize and schedule production, and is dominated by two basic operating systems: Programmable Logic Controllers (PLC) and Distributed Control Systems (DCS). PLC are embodied in a specialized processor or computer that has all the hardware and software components to do a specific automation task, like running a plant. It manages to process all the inputs from real world through a hardware input interface, and consequently issue commands to various devices and actuators using an output interface. On the contrary, a DCS is not represented by a singular operating item, but it is physically broken into different microprocessors or Functional groups, to ease the implementation and provide the most appropriate level of segregation. The Functional groups are linked to the same interface, organizing the whole control of the plant into small groups, with each group having something similar in common. The evolution of new microprocessors and advanced technologies have blurred the boundaries between these two operating systems, generating also hybrid control technologies, and making the decision of which system to implement a harder one (Nelson and Stauffer, 2008).
- Cloud and Edge Computing Technology: especially in industrial scenarios, the timely acquisition, utilization and distribution of information on a wide spatial basis can improve sensibly the accuracy of predictions about material requirements, scheduling, planning maintenance needed and all the other delicate aspects that manufacturing entails (Monostori et al., 2016). It is easy to understand how quickly the amount of data generated by IoT and sensors will increase gradually together with their diffusion and implementation. This is the only way to fully unlock the potential of real-time intelligence and decision making, but also represents a challenge in terms of high operating costs and of management of complexity. Cloud technologies can help in managing three key necessities of IoT (Liu *et al.*, 2019): computing resources, storage

space and communication bandwidth. The use of virtual servers can guarantee a flexible computing resource for enterprises, that can be expanded when needed by using new cloud hosts. Moreover, the return of data generated from sensors, can be simply stored in virtual databases, but can also be processed and organized in information from artificial intelligence. Communication happens, in this case, when information finally returns to the channel where it is needed. The flexibility of Cloud and Edge computing technology is mostly appreciated for the cost reduction effect that it causes, with services only payed on-demand and always available when needed.

1.2.4 Key technologies

In the following section it will be provided a quick overview of the most important Industry 4.0 technologies.

Advanced robotics

Advance robotics is said to be one of the four "main physical manifestations of the technological Megatrends" (Schwab, 2016, p.19) of the fourth industrial revolution that is taking place in the last years. They are (together with Autonomous vehicles, 3D printing, and New materials) the manifestation of Industry 4.0 easiest to see because of their tangible nature. Elementary Robots can be simply described as a "universal machine for performing mechanical actions" (Galin and Meshcheryakov, 2019, p.1), thanks to their technological evolution, they have become more flexible, mobile, and more intelligent, representing the driving force of automation. Progressively, the range of tasks assigned to robots has expanded, and the introduction of new technologies like sensors and actuators, has given rise to new generations of robots.

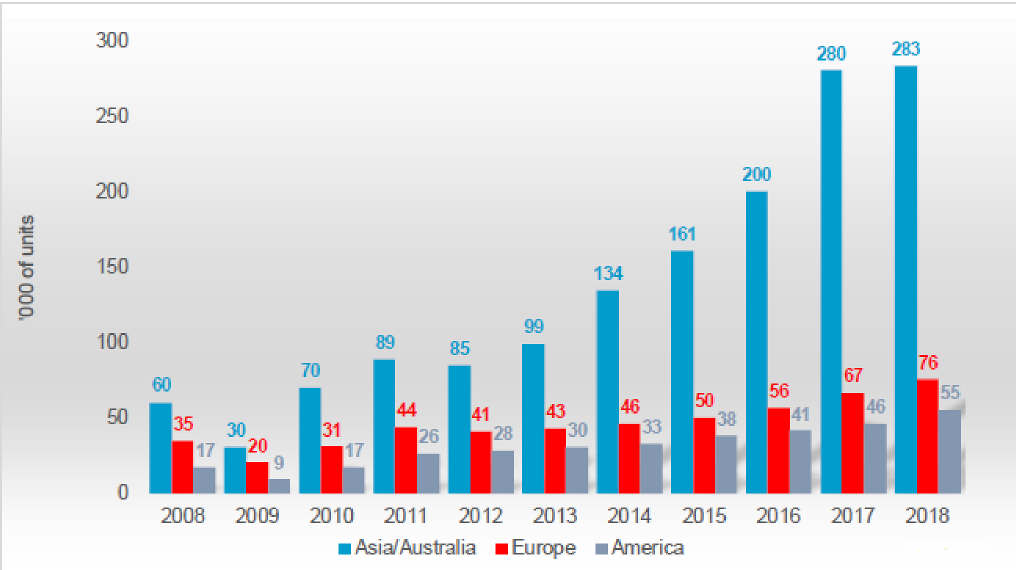
According to Galin and Meshcheryakov (2019), three different directions can be identified in robotics: Industrial robotics, Collaborative robotics and Service robotics.

- Industrial robotics: ISO 8372 (2012) defines Industrial robotics 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". The robots that are covered from this definition must be: "Reprogrammable" that means that they should be designed so that the programmed motions or other auxiliary functions can be changed without physical alteration. "Multipurpose" or capable of being adapted to a different application by the means of a physical alteration, that entails a change in the mechanical system. Moreover, when it comes to describe the motion of the robots in this category, it must be able to move at least in three directions in a linear or rotary mode (IFR, 2019a).

The massive recourse to Industrial robotics and automation, is in line with the roadmap of future development of manufacturing industry, but can be explained also through the numerous benefits that it promises: higher quality and reliability, lower defect rate, reduced cycle time, reduced waste and better floor space utilization (Ghobakhloo, 2018).

Due to the ongoing trend toward automation and technological innovation, since 2010, demand for Industrial robots has grown steadily. Globally speaking, from 2013 to 2018, the annual installations of this category of robots has increased on average 19% each year (CAGR) (IFR, 2019b). The largest market for robots is Asia, where have been installed two out of three robots (67%) deployed in 2018. The second largest market for industrial robot installation is Europe, that has gained alone an annual average growth rate from 2013 to 2018 of 12%. Europe is then followed by America (*Figure 4*). However, considering single countries, China, Japan, the United States, the Republic of Korea, and Germany account alone for 74% of global robot installations (IFR, 2019b).

Figure 4: Annual installations of Industrial robots by region.



Source 4: IFR, 2019b, p.14.

- Collaborative robotics: if the very basic initial idea for using robots was the substitution of people in hard works, and robots and operators were meant to operate separately, today's applications go in a slightly different direction. In particular they support the integration of machine and human interactions, in a collaborative working environment. ISO/TS 15066:2016 (ISO, 2016) describes this idea when states that the objective of collaborative robots is "to combine the repetitive performance of robots with the individual skills and ability of people" (ISO, 2016, p. V). Moreover, it provides an explanation of the operational characteristics of Collaborative robots (Cobots) that differentiate them from traditional robots machines or equipment: “In collaborative robot operations, operators can work in close proximity to the robot system while power to the robot’s actuators is available, and physical contact between an operator and the robot system can occur within a collaborative workspace.” (ISO TS 15066, 2016, p. 2). The collaborative workspace is that part of the operating space where the robot systems and human can perform activities at the same time, while production operations are taking place.

- Service robotics: this category of robots, includes all that robotic complexes that can be used in several fields of human activity and that perform some activities for humans out of the industrial context (Galin and Meshcheryakov, 2019). This testify how robots are increasingly supporting humans both at work and in their private lives.
  The number of service robots that have been sold in the world in 2018 have risen by 61% (IFR, 2019c). The largest fraction of professional service robot’s market (41%) is represented by Autonomous guided vehicles (AGVs) and they are mainly adopted in logistics. The second broader group (39%) of service robots is formed by inspection and maintenance robots. Other examples of Service robots are unmanned aerial vehicles, robotic floor cleaning solutions and powered human exoskeletons.

Additive manufacturing

Additive Manufacturing (AM), also known as 3D printing or three-dimensional printing is a new technology that has opened the field to a completely new production method. Unlike traditional manufacturing, where huge amounts of materials have to be removed to produce the final good, additive manufacturing is based on “processes that add some materials to the previous surface via different deposition techniques that lead to different part quality, density, and geometrical accuracy” (Mehrpouya *et al.*, 2019, p.6). The most accepted definition of Additive Manufacturing is the one of ASTM F42 Committee (ASTM, 2013) that describes AM as “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies” (ASTM, 2013, p.2).
Additive Manufacturing is a perfect response for markets that experience high levels of variability and shifts in demand, and that demand faster deliveries and less dissipation of materials, resources and energy. The advantages granted from AM machines are the fact that they can manufacture products faster, at lower costs and that they require fewer finishing works with respect to the ones needed in the past, thanks to the increasing precision of their output (D'Aveni, 2018). Another central benefit that 3D printing ensures is an unprecedent possibility to customize products. In addition, Additive Manufacturing allows to produce new complex

goods, that cannot be manufactured with subtractive technologies. Moreover, Additive Manufacturing is less capital intensive than the equipment that is traditionally placed in factories' shop floor and can be more flexible for small-batches production. Finally, having multiple small production sites positioned closer to end customers can reduce shipping and transportation costs (D'Aveni, 2018). To sum up, the three main advantages that 3D printing has over traditional manufacturing are: Time saved, Cost reduction and Flexibility (Mehrpouya, 2019).

Additive Manufacturing is revealing increasing capabilities and is moving from marginal applications like prototyping, modelling products and rapid tooling, to a more central role in production, where it competes with conventional manufacturing. This shift is also made possible thanks to the availability of materials and the developed network of suppliers that provide cheaper inputs for a wider range of outputs (Mehrpouya *et al.*, 2019).

It is possible to classify AM processes according to different dimensions. For example, ASTM F42 Committee has also classified them in seven major areas according to their technologies: binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and vat photopolymerization. Guo and Leu (2013) propose a classification in 4 groups according to the different states of materials used: liquid, filament/paste, powder and solid sheet. It is equally important to distinguish the kind of material adopted for 3D printing. Guo and Leo (2013) list four of them: Polymers, Metals, Ceramics and Composites. The last developments of AM technologies have permitted to use a wider variety of materials, suitable to create strong tools and components and that can be applied in fields like aerospace, automotive, biomedical, and energy.

Additive manufacturing is still facing some challenges that hinder its adoption. First of all, the imperfections of the structure of objects, that is caused by the void left between layers and that impacts negatively on its the mechanical performance. Secondly, the still limited list of substances that can be printed and lastly, the small size of the parts that can be produced sets a ceiling to the massive use of AM because, naturally, 3D printers cannot manufacture parts bigger than their build chamber.

Laser Cutting

The use of conventional machining methods has been limited by recent trends as the emergence of advanced materials, the requests for components with complex shape, unusual size and stringent design requirements (Radovanović and Madić, 2011). Laser Beam Machining (LBM) is one of the most spread applications of lasers and an effective method for cutting a wide range of materials. Laser cutting is one of the important applications of LBM and it is intensively applied in the metal working industry. This technology is based on the ability of focused laser beams to precisely cut plates of almost all known materials.

A typical production process with Laser cutting starts from designing parts, nesting these parts on metal sheets, cutting them from the sheets and, if three-dimensional parts are needed, bending them (Dewil *et al.*, 2014). Verlinden *et al.* (2007), explain the procedure of "Nesting", as a method for decreasing the costs for sheet-metal punching and laser cutting. This technique implies combining multiple orders of the same material on a single sheet, so that the amount of material wasted is minimized. To guarantee high productivity and flexibility of the processes, the laser is usually guided by either a Computer Numerical Control machines (CNC) or a five/six-axis industrial robots (Dolgui and Pashkevich, 2009).

Some of the technical advantages of using laser cutting technologies, with respect to other cutting processes are numerous, for example, "a narrow cut, minimal area subjected to heat, a proper cut profile, smooth and flat edges, minimal deformation of a workpiece, the possibility of applying high cutting speed, intricate profile manufacture and fast adaptation to changes in manufacturing programs." (Radovanović and Madić, 2011, p. 35)

Big Data and Cloud Computing

In the era of the fourth industrial revolution, being able to manage the increasing amount of data generated from new technological solutions is a necessary requisite for companies. New challenges are represented from data collection, their storage, processing phase and above all, their analysis. Being able to generate insights and to extract value from data is a precious source of competitive advantage for companies.

One of the most accepted definitions of Big Data is the "three Vs" proposed by Laney in 2001, that even if without explicitly using this name, provides a perfect description of the most important dimensions of Big Data. The three Vs stand for: "Volume", "Velocity" and "Variety", that are the three exponentially increasing features of communication and information through new technologies. Several other Authors expanded this original model, adding more Vs and more features. For example, Schroeck *et al.* (2012) add "Veracity" as a fourth "V", underlying the importance of trusting and being certain about data and the results of their analysis. As the Authors warn, Big Data, today, is a "business priority" (Schroeck *et al.* 2012, p.1) thanks to their ability to affect economy and commerce.

Business Intelligence and Analytics (BI&A) and Big Data are interconnected sectors that have gained popularity and have developed together. BI&A can be described as the "techniques, technologies, systems, practices, methodologies, and applications that analyze critical business data to help an enterprise better understand its business and market and make timely business decisions." (Chen et al. 2012, p.1166). Chen et al. (2012) review also the three main stages of BI&A:

- BI&A 1.0, in the 1990s commonly used analytical techniques founded mainly in statistical methods developed in the 1970s and data mining techniques developed during the 1980s. Moreover, data management and warehousing are considered at the basis of BI&A 1.0.
- BI&A 2.0, instead, began in the 2000s, when new opportunities of analytical research and data collection were offered from Internet and the Web. Several types of new analysis were then possible thanks to web analytics, and thanks to the increasing presence of companies in the web with their sites, products' recommendations and e-commerce.
- BI&A 3.0 has been launched by the diffusion of mobile devices like smartphones, tablets, and other mobile personal devices. The engine of this recent transformation of BI&A is Big Data, that if accurately treated, can offer significant high-impact opportunities. In the industrial field, it is connected with the technologies of industry 4.0 like IoT and the networks of CPS.

An interesting architecture for Big Data Analytics is proposed by Santos *et al.* (2017). They count seven layers:

1. Entities/Applications layer: represented by all Big Data producers and consumers, as for instance customers, suppliers, managers
2. Data Sources layer: some examples are Databases, ERPs, Files, E-Mail, and Sensors.
3. ETL (Extraction. Transformation and Loading) layer: this layer groups the actions necessary for Extraction of data from data sources, Transformation, and Loading of the data into the fourth layer.
4. Data Storage layer: comprehends all the different kinds of data storage systems that can be used in different situations.
5. Raw Data Publisher: it enables data to be downloaded from the available fourth layer by using Web Services.
6. Big Data Analytics: includes components that facilitate the analysis of vast amounts of data. Well known data analysis techniques are Data Visualization and Data Mining.
7. Security, Administration and Monitoring layer: it is fundamental to the other layers for the base functionalities that it provides. Additionally, it ensures the proper functioning of the entire infrastructure.

It is equally important to examine Cloud Computing (CC) because it provides the necessary computation, storage, networking and applications, that can support Big Data applications (Elhoseny, *et al.*, 2018).

Cloud computing is defined in 2008 by Wang and Laszewski as "a set of network enabled services, providing scalable, QoS [Quality of Service] guaranteed, normally personalized, inexpensive computing platforms on demand, which could be accessed in a simple and pervasive way." (Wang and Laszewski, 2008, p.3). In the expression "Cloud Computing", the term "Cloud" refers to the distributed platform for computing that is formed by a group of servers, software, and interfaces, that allows the user to execute a particular task. "Computing" is referred to the fact that users can exploit this cluster whenever they need it, as an on-demand service (Attaran, 2017).

(Mell and Grance, 2011) propose some of the most acknowledged characteristics of Cloud Computing:

- On-demand self-service: Computing resources like server time and network storage can be required and accessed when needed, without the interaction of human with the provider of such services.
- Broad network access: Resources are available over the network and can be accessed through standard mechanisms and various platforms such as mobile phones, tablets and laptops.
- Resource pooling: Resources are put together to serve multiple consumers, with different physical and virtual resources, that can be assigned dynamically and eventually reassigned according to demand. The consumer generally does not know the exact location of the service provider.
- Rapid elasticity: Resources are provisioned and released, sometimes automatically, depending on the demand. This gives to customers a potentially infinite provisioning capability, but an always proportionate real amount of resources.
- Measured service: Resource use is automatically controlled and optimized through Cloud systems. Pay-per-use and charge-per-use are some of measuring techniques adopted.

According to the nature of the service provided, Mell and Grance (2011), categorize three models: Software as a service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS).

In the first case (SaaS), the customer can use the resources needed trough a cloud infrastructure. The infrastructure can be accessed by multiple clients that do not own or control any part of it. In this way, the user is relieved from making heavy investments to own a massive computing infrastructure. In the case of Platform as a Service, the client can tailor some applications or programs according to its needs, in the cloud infrastructure. The user acquires the control only over these personalized tools and not of the entire infrastructure. In the last case, when Infrastructure is used as a Service, the customer gains control over the operating systems, storage, and networks, because he or she can usually run arbitrary software, while still not being proprietary of the underlying infrastructure.

Moreover, different deployment models can be distinguished (Mell and Grance 2011) according to the breadth of use of the infrastructure: it can be a Private cloud, when the access is exclusive for one customer, a Community cloud, if it is opened to a specific community of customers. It is a Public Cloud if the general public can access it. To conclude, a Hybrid cloud is the result of a combination of the other classes that maintain their separate entities, but are tied by common technologies or property.

3D Scanners

A 3D scanner is "A device that analyzes a real-world object or environment to collect data on its shape and possibly its appearance." (Ebrahim, 2014). This information is then used to build a digital and three-dimensional model of the object. As also Anderson (2012) underlines, this device does "reality captures", that speed up the process of obtaining a virtual model of an object. Rather than drawing it manually, the object is put into the scanner and the 3D model is automatically elaborated. The means that the scanner uses to capture the features of the objects are usually lasers or other lights and cameras, while the output is a "point cloud", then turned into a set of geometric figures like polygons intersected and overlapped (Anderson, 2012).

The first 3D scanning technology dates back to the 1960s. These first generation of scanners used lights, cameras and projectors to perform this task and usually took a lot of time and effort to scan objects accurately. The technological leap took place after 1985 when new scanners using white light, lasers and shadowing to capture the surfaces, replaced the old ones. (Ebrahim, 2014).

The 3D models created through scanners are applied in different fields and businesses such as industrial design, reverse engineering, prototyping and quality inspection among others.

Ebrahim (2014) groups scanners in two classes: Contact and Non-contact 3D scanners. The first set of scanners utilize a technology that requires a contact with the object to be scanned. The robotic arm used usually contains a probe that sends the information of its location when it touches the surface. In the second group, at the contrary, the surface of the object is not touched from the machine. The scanning machine relies on some active or passive techniques to obtain information from the object.. Obviously, the second group has the advantage of being able to process also delicate objects.

Augmented reality

Augmented reality (AR) can be defined as an interactive, reality-based environment that takes the capabilities of computers to generate images, sounds, texts and effects to enhance the user's real-world experience through virtual displays. AR is the perfect bridge between the physical world and the digital one, that is becoming part of every day’s life of companies and people. This position in between the virtual and physical reality, distinguishes AR from Virtual Reality, where the real world is completely replaced from the virtual one (Masood and Egger, 2019). In an industrial context, AR can be successfully implemented for design and manufacturing, assembly activities, in training or as a guidance system for operators. Masood and Egger (2019) list the basic components of an AR system: the visualisation technology, a camera, a tracking system, and the user interface.

Four main visualisation technologies are available for AR systems (Masood and Egger, 2019), namely head mounted displays (HMDs), handheld devices (HHDs), static screens, and projectors. The choice of a mobile or stationery visualization depends on which kind of tasks need to be accomplished. The Authors, for example, suggest the adoption of static screens or projectors for assembly applications, to easily display information in the workspace. Head mounted displays (HMDs) is maybe the most interesting field, because they enable operators to move and at the same time receive information hands-free, speeding up operations. Daling *et al.* (2019) state that there are many studies that reveal that the use of HMD to train employees on the job can increase quality and efficiency of processes. Moreover, these AR technologies promise the minimization of the errors committed in processes, and that they will enhance the communication with employees in charge of maintenance. Overall, the market for AR is still very dynamic and only in its first stages. Both big companies and small start-ups are introducing these technologies that can help their operators to expand their capabilities at increasingly cheaper prices (Davydov and Riabovol, 2019).

CHAPTER 2

2.1 Lean and Industry 4.0

It is recognized that Lean is the manufacturing paradigm that, in the last years, has changed most the production schemes inherited from the past, and it will not stop spreading until companies have changed their mindsets. The several improvements that Lean has brought to manufacturing companies include the reduction of waste and consequently of production costs, the strengthening of flow, the enhancement of quality, the reduction of lead times, an improved responsiveness and the increased flexibility. Moreover, Continuous Improvement is the central concept with which Lean transforms companies in learning entities. Despite all the improvements experienced by Lean companies, not all the firms engaged in a Lean transformation journey have managed to fully implement the Japanese philosophy. Several industries, especially some SMEs, have tried in vain or obtaining only a partial success. Often, one of the causes of failure in Lean implementation is the scarce degree of personalization and adaptation of Lean techniques, tools and principles to the context where they are meant to operate. Too often, they are taken as universal concepts and applied unchanged to every situation. Other possible causes are the lack of fit with the environment or the powerlessness of the basic Lean manufacturing methods that cannot secure the required operational standards. The main problem faced when becoming Lean, however, usually resides in the initial phases of implementation, when companies are not strong enough to sustain their Lean project and to manage the turmoil and disarray that their novelty bring (Buer *et al.*, 2018).

Industry 4.0, instead, is a new technological paradigm that is taking root in industrial contexts and in information and communication fields, and that is bringing an unstoppable change in the way in which companies produce and people exchange information with the surrounding environment. Companies, thanks to the new technologies like IoT and CPS, become Smart Factories, and all the activities, people and supply chain entities are connected in virtual and physical standardized networks, based on the internet standards. The fourth industrial revolution allows firms to overcome the mass production manufacturing approach and to embrace mass customization at more accessible costs. New low-cost technologies are indeed integrated not only in production machines, but also within products and help operators in accomplishing their tasks. Not all companies, especially the small ones, can still afford the investments that Industry 4.0’s implementation entails, even if incremental technological developments are decreasing their impact (Sanders *et al.* 2016).

In many cases, the implementation of both Lean and Industry 4.0 individually is not sufficient to cope with the rapid expansion of world markets and the intense competition that characterizes this environment. No company that remains unchanged over time can survive to the strong pressure of competitors. The creation of a sound competitive advantage, although fundamental, is a very tough matter, that requires companies to cope with the emerging information technologies, to continually innovate and introduce new ways to improve process quality. To address the weaknesses that both Lean and Industry 4.0 bring, it is interesting and significant to explore the solutions offered by the implementation of the two practices together (Pavlović *et al.*, 2018).

2.1.1 Lean Automation

The very first attempts to integrate Automation technologies and Lean Manufacturing took place in the 1990s and their results were named Lean Automation (Kolberg and Zühlkeet, 2015). The advent of Computer Integrated Manufacturing (CIM), opened up to speculations on the features of the factories of the future. The visionary view of machines that operate autonomously, without the need of the intervention of human operators, even if seemed an infeasible idea at that time, gave birth to the communion between automation technologies and robots and the Lean Manufacturing archetype (Sanders *et al.*, 2016). The concept of Lean Automation gradually gained popularity, whit the intent to create simple automation solutions that can be appropriate for the low level of complexity required by Lean production environments (Buer *et al.*, 2018). But the era of CIM was doomed to fail precisely due to the overly complex requirements of the first underdeveloped automations technologies. In the following decade, Lean Automation has fallen into oblivion both in the academic and scientific fields as well as its industrial applications. Conversely, nowadays the new push of Industry 4.0 is awakening Lean Automation and its potential and widening the scope of solutions to combine Automation and Lean. Industry 4.0, that can be considered a developed form of CIM, opens the doors to new areas of application for Lean Automation (Kolberg and Zühlkeet, 2015).

In order to guarantee a complete review of the arguments in the debate of integration between Lean and Industry 4.0, it will be followed a framework proposed by Buer *et al.* The framework presents four relationships to investigate: Industry 4.0 supports Lean manufacturing, Lean manufacturing supports Industry 4.0., Performance implications of an Industry 4.0 and Lean manufacturing integration, and the Effects of environmental factors on an Industry 4.0 and Lean manufacturing integration. The first three relations will be discussed more in detail in the following sections.

2.1.2 Industry 4.0 supports Lean manufacturing

Horbal *et al.*, (2008) are among that Authors that argue that Lean production is showing its limits in front of a market demand that is characterized by high levels of variance and variety, and that requires a production decoupled from market demand, and that cannot sustain the optimal and smooth level of capacity utilization. In addition, to produce individual unique items, as sought from mass customization, the fixed cycle times and sequences of production of Lean are not sustainable. A reorganization of buffers, production processes and Kanban cards or bins, would require a useless effort and a waste of time and resources. Since Lean manufacturing was born in the automotive sector, it can successfully be translated in sectors where the production methods and standards are similar, but it does not usually fit well in non-repetitive production environments (Horbal *et al.*, 2008). Not to mention the fact that, Lean manufacturing, for evident historical reasons, does not take into account the new future-oriented technologies.

Even if Lean, in reality, is not as doomed as these Authors suggest, still Industry 4.0 technologies can help to overcome some of the drawbacks that it entails and to match future requirements. The introduction of Industry 4.0 technologies in Lean contexts seems a natural update of original Lean principles, when thinking about Ono's definition of "Autonomation" (Ohno, 1988). The Author describes Autonomation (Jidoka in Japanese) as an "Intelligent automation". It requires that all the processes that were traditionally accomplished manually, are automatized, including all the phases, until inspection. Human intervention is required, for example, only when a defect has been identified, but on a normal basis, the machine should stop automatically when a problem occurs. This principle should prevent other defects from running down the line undisturbed, and on the other hand relieves workers from the task to continuously check the processes and inspect products. If Autonomation has played a fundamental part in Lean manufacturing from the very beginning, Industry 4.0 can be looked at as its natural evolution.

Rüttimann and Stöckli (2016), demonstrate that Lean and Industry 4.0 are not incompatible and define Industry 4.0 as "an extension to Lean outbound logistics, integrating upstream and downstream logistics exploiting the web potentiality as well as reconsider Lean flow" (Rüttimann and Stöckli, 2016, p. 498). The Authors confirm that Industry 4.0 does not make Lean obsolete, on the contrary, they are sure about some benefits that it can bring, like increasing Lean Production flexibility, whereas are more cautious about stating that it makes Lean processes smoother, faster, more stable and more accurate.

Sanders *et al.* (2016) paint a vivid picture of how Industry 4.0 can solve some problems related with lean implementation. In particular, they group the ten dimensions of Lean manufacturing proposed by Saha and Ward in 2007, in four broad categories and try to demonstrate that they can be attained through Industry 4.0 technologies.

- The first category contains the "Supply factors", that take care of the process of integration with suppliers. Sasha and Ward dimensions included are: "Supplier feedback", "Just in time delivery by suppliers" and "Supplier development". To build a good relationship with suppliers it is fundamental to share timely information about the products that they provide to manufacturers. When this transfer of information does not work efficiently, the whole supply chain loses its synchronization, and the possible sources of waste multiply. Some compatibility issues between the technologies of suppliers and manufacturers may arise, but new software and hardware components are accurately designed in order to provide compatible interfaces and to use standardized communication forms. Industry 4.0 has introduced simple technologies like smartphones and tablets connected to the internet, to allow cloud computing and mobile computing. Moreover, some more sophisticated solutions like collaborative manufacturing and development environments are proposed to facilitate integration and collaboration with suppliers. To ensure in-time deliveries, that are fundamental to reduce the levels of inventory storage of goods, Industry 4.0 is a valid ally. Wireless tracking technologies are available and allow tagged goods to be virtually followed and monitored along their paths. Finally, the manufacturing company, together with its suppliers should create one big virtual organization in order to change together throughout the Lean transformation. This technological network should encourage the exchange of tangible and intangible assets and resources, information and data.
- The second category focuses on the central "Customer factor". As long as satisfied customers are the key to success, they should be indulged. In particular, they should be involved from the first steps of manufacturing, in order to customize as much as possible their products. Some Industry 4.0 technologies, like B2C applications and manufacturing execution systems, can help customers to follow their products and understand which level of completion they have achieved, and whether it is still possible to modify their requirements. Moreover, Big data management technologies solve the complex calculations that are necessary to aggregate the information about customers and develop useful market researches to sort them into homogeneous categories. In the end, Smart products are able to convey interesting data to manufacturers also after their purchase and depict a more detailed scenario of their utilization.
- "Process Factors" form the third category. They are "Pull production", "Continuous flow" and "Setup time reduction". The use of e-kanban systems can substitute the

traditional manual Kanban, by using sensors that trigger the replenishment loop of empty bins. But they represent also a source of advancement, since the charging level and other kanban's parameters can be remotely changed. Batches of materials and semi-products can then be tracked through Radio Frequency Identification (RFID) tags. This kind of technology uses a wireless contact-free system to let radio-frequency electromagnetic fields transfer data by the means of a tag attached to an object (Nicoletti, 2013). RFID is also precious for the reduction of errors in inventory management, that can lead to capacity shortage or unnecessarily high levels of buffers, thanks to its ability to communicate real-time information. This assures that materials, semi-finished products and goods flow without pointless stoppages along all the stages. The benefits of having networked enterprises entail also the possibility to integrate the scheduling and planning of production with other subcontractors. Having subcontractors means having an assurance against capacity shortage and obtain assistance and resources, if needed. Another ability that Industry 4.0 technologies have is to reduce changeover times obtaining the fast levels required by mass customization. Together with other plug and play systems, the same precious RFID technology, enables machines to have learning and self-optimizing behaviours. As soon as the machine is charged with the parts of the products to work, they start to communicate, trough tags loaded within the workpiece. The machine rapidly executes the instructions captured from the components.

- The fourth and last category is "Control and Human factors". It encompasses "TPM", "Statistical process control" and "Employee involvement" all dimensions that concern quality controls and take into account also the work environment. Smart factories manage breakdown episodes differently from traditional companies, reducing the impact of machine stoppages and damages. The interconnected machines are self-aware and can sense the possibility of an incoming breakdown. Once the machine has stopped, it sends notification to engineers and maintenance personnel about the kind of problem it is facing, and the possible causes. The automation of this phase ensures the reduction of the time needed to intervene and fix it. Three Industry 4.0 technologies make production get closer to error-free processes. They are again RFID, IoT and Advanced Analytics. The Radio Frequency Identification solves the problem of high variance of the activities to be performed and of the ignorance of operators about the details of the process by allowing the communication between the work-piece and the machine. IoT guarantees a deeper integration of different value adding steps thanks to the combination of data collected from different machines. Finally, Advance Analytics with its predicting capabilities is able to find patterns and foresee future trends, using business intelligence tools and statistical methods. For what concerns the centrality of the role that employees play in Lean contexts, future-oriented technologies are not in contrast with it. Empowerment and greater involvement of workers is obtained by automating the repetitive and least rewarding activities and leaving to them just the diversified and stimulating tasks. Suggestions and feedback then are sent from workers directly through their smart devices on a real time basis. Employees' relation with the technologies of Industry 4.0 can be positive, encouraging companies to invest on them and be confident that people will be happier and work more efficiently.

Thanks to all these positive examples Sanders *et al.* (2106) support the idea that Industry 4.0 solves most of the obstacles that companies can face while implementing Lean, and possibly, make them even stronger to face future threats. Wagner *et al.* (2017) demonstrate the same concept, through an empirical study on an IT-system built to support a lean JIT production process within an automotive company. The research shows that "Industry 4.0 applications can stabilize and support lean principles" (Wagner *et al.*, 2017, p.130). The Authors provides also a useful tool to design and build Industry 4.0 and Lean integrated applications. It is a matrix that describes the impact of Industry 4.0 technologies on Lean established practices and can be used in the first phases of automation, as a roadmap to choose the most suitable investments to reinforce specific Lean manufacturing features. In the end, Bauer *et al.* (2019) describe the contribution of Industry 4.0's technologies stating that "certain instruments can enrich lean processes" (Bauer *et al.*, 2019, p. 503).

2.1.3 Lean manufacturing supports Industry 4.0.

Kolberg and Zühlkeet (2015) propose a slightly different perspective from which to consider Lean and Industry 4.0's technologies integration. They argue that it is less risky to implement the complexity of Industry's 4.0 technologies in Lean companies, because their production processes are more standardized, simplified and reduced to the essential. In this sense, Lean is a required precondition to foster the introduction of new technological solutions. The Authors strongly believe that Industry 4.0 can easily integrate in Lean environments, and even bring benefits to Lean production, because Industry 4.0 solutions, even if very expensive, can succeed where the cost-saving and very simple solutions of lean cannot ensure the required level of performance.

The consulting firm Staufen AG (2016) confirms that Lean management and Industry 4.0 complement one another, but that Lean production continues to lead the way. As long as Toyota

continues to be a point of reference for the other manufacturing companies, Lean will continue to be a fascinating topic.
Wang *et al.* (2016) introduce us to the "Made in China 2025" plan, that is one of the plans for the industrial and technological development that were approved by the governments of different countries, following the example of the German one. This plan's focus is on the digital, intelligent and networked manufacturing. However, the Authors provide a brief description of the state of the art of production in China, depicting disordered factories, with very rudimental technologies and the majority of the products manufactured manually. They suggest that companies focus on process improvement and reorganization, before implementing Industry 4.0's intelligent technologies, to eliminate the huge amount of waste that they produce. Lean manufacturing is strongly recommended as a solution to make production more controllable and to be able to monitor and model it as needed. As Wang *et al.* (2016, p.443) state, "Lean production is the basis of the intelligent manufacturing in the current situation of the manufacture in China." On the other hand, they recognize that in the end, the level of leanness that smart factories achieve, is higher than the one of traditional companies. It is after these reasoning that the Authors propose their "Lean Intelligent Production System" in order to fully realize the "Made in China 2025" plan.
Talking about China, Staufen AG (2016) is of the same opinion, and states that "Automation and smart manufacturing are still based on a stable and flowing process as well as on continuous improvement. For this reason, it is important for Chinese companies to find their way back to the basics and design effective and efficient processes, despite the new technologies in place" (Staufen AG, 2016, p.23). The consulting firm is sure that Lean management will help the Chinese companies to overcome their challenges.
The points of view of Wang *et al.* (2016) and Staufen AG (2016) are perfectly in line with what Bill Gates stated about the employment of technologies: "The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency" (cited in Krishnan, 2013, p.45). This quotation highlights once more how convenient it is, for companies that want to upgrade their technological structure, to apply Lean techniques in the first place. In the same direction goes also Nicoletti's research (2013), when states that "Automating a process not streamlined is counterproductive" (Nicoletti, 2013, p.285). Furlan (edited by, 2018) reports that the mere adoption of technologies can introduce elements of complexity and variability in the processes and make them harder to control. The warning is that of not digitizing wastes. Lean manufacturing solves also these problems that the application of technologies alone can cause, such as the level of flexibility that sometimes is threatened by

overinvestments in automation. Furthermore, Nicoletti (2013) calls into question the ability of automation technologies alone to improve performance and recommends companies to connect them with process optimization techniques, and to keep them as flexible as possible. Kamble *et al.* (2019) recognize that "the successful implementation of LMP [Lean Management Practices] enables the organisations to be prepared for initiating the implementation process for I4 T [Industry's 4.0 technologies]" (Kamble *et al.*, 2019, p. 13).

Mayr *et al.* (2018), sum up the main insights from that part of the literature that sees Lean as a prerequisite for the successful introduction of Industry 4.0 solutions. First of all, standardized, transparent, and reproducible processes are the necessary basis for introducing Industry 4.0. Secondly, decision makers should have the competences, borrowed from Lean management, to identify and avoid waste and concentrate on value for the customers. Thirdly and finally, the efficient and economic use of Industry 4.0 technologies can be achieved only by using Lean to reduce product and process complexity.

2.1.4 Performance implications of Industry 4.0 and Lean manufacturing integration.

A discrete amount of literature studies the impacts of Industry 4.0 and Lean manufacturing integration on operating performance. It emerges that (Buer *et al.*, 2018) the main features of businesses that are impacted are: costs, flexibility, quality of products and of processes, inventory levels and reliability. It has already been mentioned Nicoletti's opinion about the impact that the integration of Lean and Industry 4.0 technologies has on processes' flexibility. Other benefits that the Author recognizes are the reduction of cycle time brought by Lean thinking, together with the balance of work in progress that assures a continuous flow. A streamlined process is then the ideal candidate for automation. The result is an agile and lean company that can easily respond to market requirements. Also Ma *et al.* (2017) recognize the flexibility enhancements brought by the combined application of Lean and 4.0 technologies. They demonstrate not only that Lean Automation, created through the use of Cyber-Physical Systems, is able to gain higher level of flexibility, but also that it is a cost efficient and effective solution, that guarantees that global economic conditions are shrunk. Wagner *et al.* (2017), apply the technologies of Industry 4.0 suggested from their impact matrix on a JIT production process. They manage to measure the positive impact that the implementation of a big data architecture that keeps track of material consumption has brought to the reduction of warehouses' dimensions and the elimination of the stocks at the shop floor. Moreover, they reveal a higher level of reliability and traceability of processes. Jayaram (2016), proposes his "Lean Six Sigma Approach for Global Supply Chain Management using Industry 4.0 and IIoT". He couples Lean and Six sigma as two quality control methods, used to improve efficiency and quality of processes, through the elimination of unnecessary activities and defects. But it also recognizes that "Lean six sigma and Industry 4.0 are complement to each other" (Jayaram, 2016, p.92) and that when they are applied together, the global supply chain "is fully autonomous, free from defects and has an ideal process flow" (Jayaram, 2016, p.92). The Author highlights the gains in quality that the integrated approach grants, together with the possibility to reduce costs and increase the value of the goods delivered to final customers.

Kamble *et al.* (2019) measure the impact of Lean and Industry 4.0 on companies' Sustainable Organizational Performance (SOP) instead of on their operative performance. Triple Bottom Line (TBL) is one of the best measures for evaluating the sustainable performance of an organisation. The TBL refers to the three dimensions on which enterprises perform, in order to satisfy the different needs of their stakeholders. The three dimensions are: economic, environmental, and social. The effects of the isolated implementation of Lean management are easily measured on all the three sustainability dimensions. Industry 4.0 too has been proved to have a positive effect on the SOP. The empirical study of Kamble et al. (2019) manages to study the combined effects of Industry 4.0's technologies and Lean management practices on Sustainable Organizational Performance. The findings reveal that Industry 4.0 has a positive and direct influence on Lean practices and that these Lean practices have a significant mediating role on the relationship between Industry 4.0 and SOP.

CHAPTER 3

3.1 Survey

The precious collaboration of the Department of Economics and Management of the University of Padua and the CUOA Business School has given rise to an inquiry on Italian manufacturing firms. In particular, a survey has been sent to almost 15.000 Italian manufacturing firms located in Central and Northern Italy to investigate the diffusion of practices related to Lean Management and to the adoption of technologies that can be ascribed to Industry 4.0. The answers received have then been cleaned, eliminating incomplete or fake data, and codified into a database in Excel.

This database has been created over time, from September 2017, to July 2019 with four mailing sessions in which companies have been massively contacted.

The criteria used in the selection of the companies to contact have been:

- Geographical area: each mailing session has targeted different geographical areas. So far, the chosen regions have been Veneto, Emilia Romagna, Piedmont, Lombardy, Friuli-Venezia-Giulia and Tuscany.
- Sector of economic activity: the companies selected are manufacturing companies, that belong to ATECO 2007 classification Codes from 10 to 32. ATECO classification is a type of codification of economic activities designed and adopted from "Istituto nazionale di statistica italiano" (ISTAT) to measure the most important economic metric at a national level.
- Number of employees: companies with less than ten employees have been excluded from the contacts.
- Operating status: companies in liquidation have been excluded from the contacts.

The cleaned and final database contains information about 454 respondent companies.

The whole survey has been reported, in its English translation, in the *Annex*. It is structured in two main sections: the first part includes some general and information about companies, whereas the second one explores the principal techniques and solutions that they adopt, mostly concerning Lean Management and Industry 4.0.

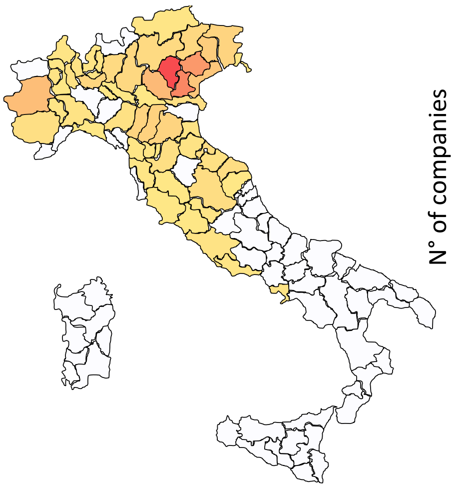
3.2 Composition of the database

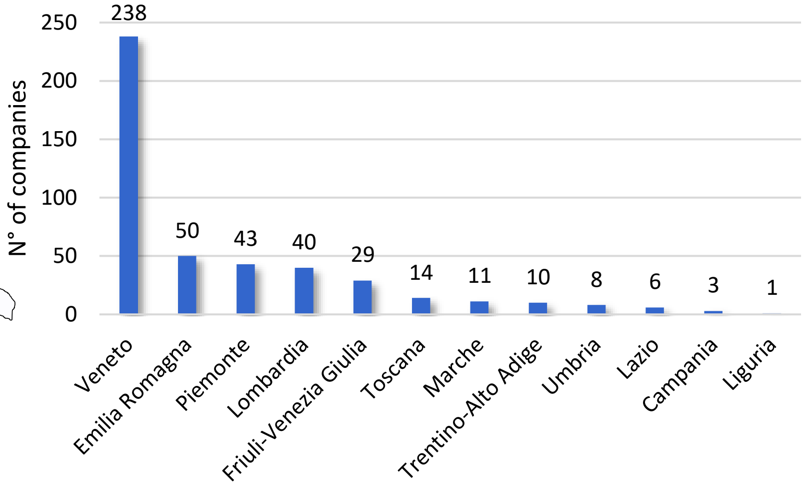
The data analysed in the following chapters come mainly from 454 firms that replied to the survey. Further information about their financial and economic performance have been added, retrieving it from AIDA database ("Analisi Informatizzata delle Aziende Italiane") by Bureau Van Dijk, that stores metrics about more than 200 thousand Italian Limited Companies.

3.3 Section 1 of the survey

Geographical distribution of respondents

Figure 5:Geographical distribution of respondents at provincial and regional level $[n = 453]$





Source 5: Personal elaboration.

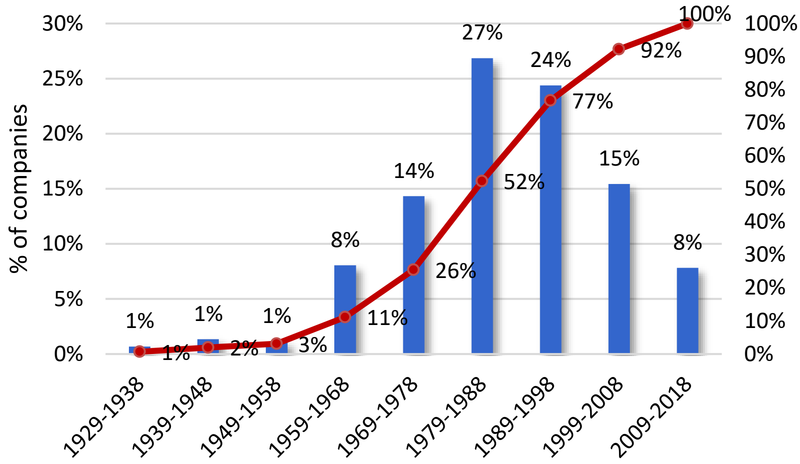
Figure 5 represents the geographical distribution of companies that replied to the survey. It is evident that almost all the companies that replied belong to regions that have been selected for the mailing sessions. The majority of the companies (53%) are from Veneto region, and in particular from the provinces of Vicenza (19%), Padua (12%), Treviso (9%) and Verona (6%). The most active province out of Veneto is Turin (5%). These results are not surprising, if it is taken into consideration first of all the territorial proximity of both the University of Padua, and the CUOA Business School, with the companies that replied. It is equally fundamental the feeling of trust that both the promoters of the survey have built during the past years with companies.

In the future, it will be interesting to expand the geographical area of origin of respondents also to the southern regions and the islands, in order to have a sample that better represents the Italian manufacturing landscape. However, the distribution of manufacturing firms in Italy is not homogeneous, and the areas questioned with the survey are the more intensely populated from these companies. In particular, according to ISTAT[1], in the north-west of Italy there are 30% of all the manufacturing companies, with Lombardy that accounts alone for 20% of the sample. The north-east is the second area more populated, counting 24% of the companies and Veneto region that contains 11% of the enterprises. In the centre of Italy are grouped 21% of the Italian manufacturing companies. The south of the peninsula is the least populated area, with only 18% of firms.

[1] I.Stat, Dataset: Enterprises and persons employed – C. Manufacturing companies, downloaded on 6-10-2019

Year of foundation and age of the companies

Figure 6: Year of foundation of companies. [$n = 447$]

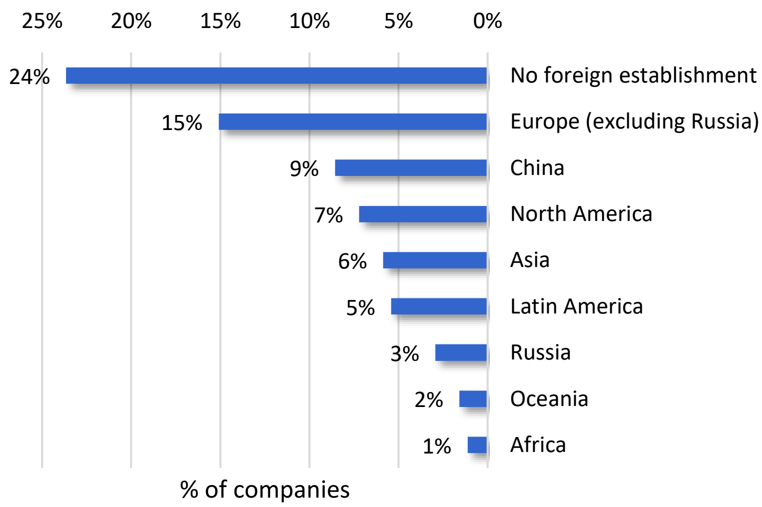


Source 6: Personal elaboration.

Figure 6 depicts the distribution of companies according to their year of foundation. 14% of them are born in the 70s, when the economy of Italian manufacturing was led by Fiat and the old industrial triangle formed by Milan, Turin and Genoa. Another 27% of the companies are born in the 80s, when the north-east area of the peninsula has started to gain its important position in the economy of the Country. Slightly less companies (24%) were born in the 90s, in a changing technological environment open to foreign markets and connections with companies beyond the borders (Bricco, 2018). The average age of firms is of 32 years.

Foreign establishments and Export

Figure 7: Foreign establishments. [$n = 444$]

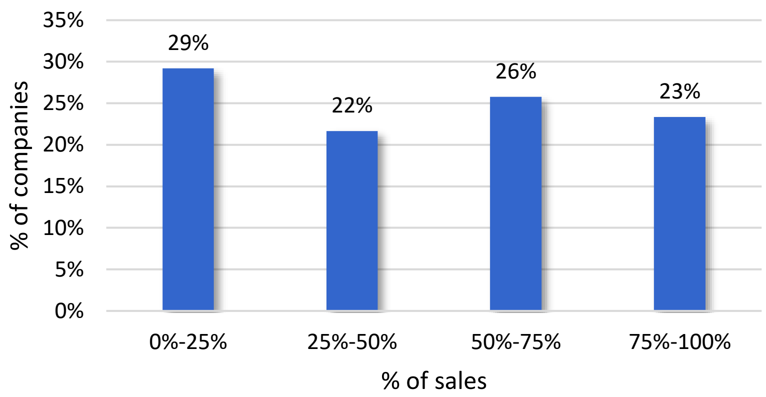


Source 7: Personal elaboration

Almost 67% of the companies in the sample have a foreign establishment (*Figure 7*). Most of the them (15%) have a plant or factory within Europe. An interesting data is that 9% of the selected manufacturing companies have chosen China to set up their foreign branches. An analysis of the evolution of the relationship of Italian firms with China (Corò and Volpe, 2013), confirms that the Asian region, and in particular China, are one of the most attractive territory for Italian companies' foreign investments. This trend has not stopped neither during the recent years of the financial and economic crisis. In the 2007-2010 period, the most critical in Italy, the presence of Italian branches abroad has seen an increase of 10%, with an expansion for the industrial sector of 18% of the turnover. These data are stunning, if compared with the ones of Italian industrial production that in the same period was facing a decrease of 20% from the pre-crisis levels.

It is demonstrated (Corò and Volpe, 2013) that both exporters and companies with a presence in foreign countries are able to gain better productivity and performance results, up to a certain threshold of offshoring. For these reasons it is interesting to consider also the data about companies' export.

Figure 8: Percentage of export on sales. $[n = 411]$

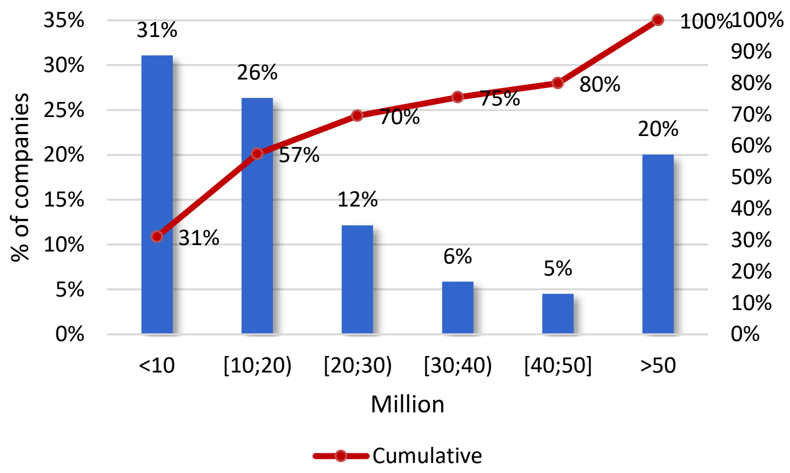


Source 8: Personal elaboration.

The percentage that represent the share of export on total sales of 2018 (*Figure 8*) is smoothly distributed over the four categories, with half of the companies that realize a significant share (more than 50%) of the turnover of 2018 abroad. However, the geographical distribution of the biggest exporters in Italy has changed over time, following the same path of the industrial development. While in the 80s the north-west of Italy produced half of the total national export, and the north-east represented just one fourth of it, 2017's data show an increase up to 32.7% (Bricco, 2018). The export is still growing in 2018 in all the Italian areas, even if at a slower pace than 2017's (ISTAT, 2019). The principal markets in which the companies of the sample export are Europe, in particular in Germany, France and UK, but also USA and Russia.

Size according to revenues

Figure 9: Revenues of 2017. [$n = 444$]

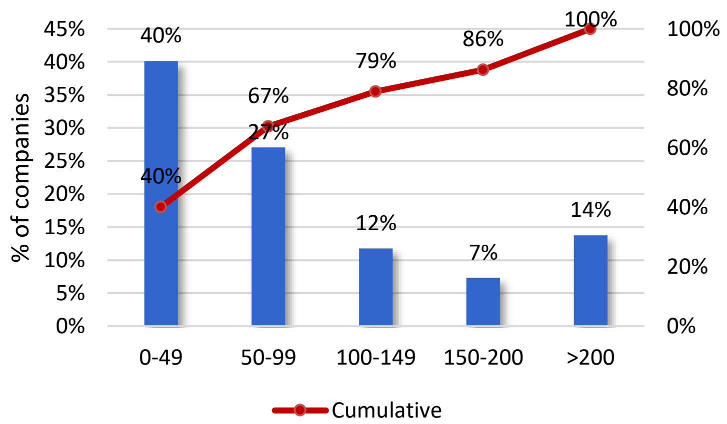


Source 9: Personal elaboration.

More than half of the companies (57%) that answered the survey has a turnover that is below 20 million, and 31% below 10 million. Another 23% of the companies are distributed between 20 and 50 million of revenues and the remaining 20% produce more that 50 million of sales. It can be concluded that, according to the European Commission's turnover requisite (2015), 80% of the companies surveyed are SMEs.

Employees and workforce

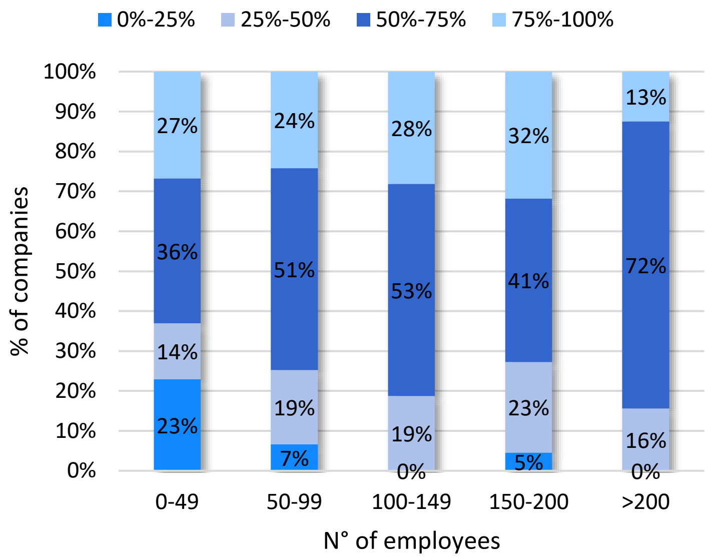
Figure 10: Number of employees. [$n = 451$]



Source 10: Persona elaboration.

According to the European Commission's employees' requisite (2015), Almost all the companies are in the category of SMEs. Only 11% of the companies indeed, have more than 250 employees. The companies that employ less than 50 employees are 40% of the sample (*Figure 10*), whereas another 27% has more than 50 but less than 100 employees. The median number of employees is 65.

Figure 11: Percentage of labourers. [$n = 334$]



Source 11: Personal elaboration.

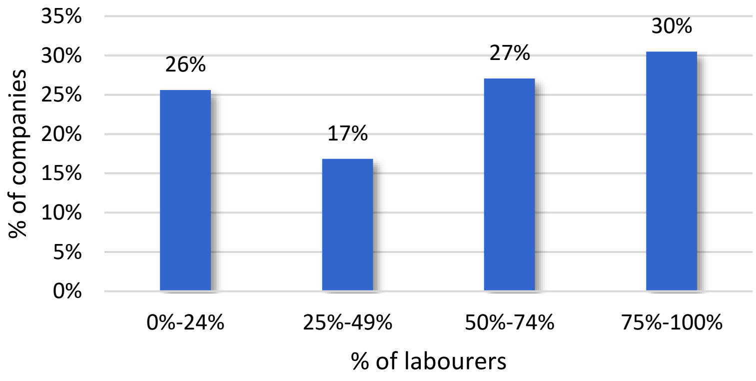
The percentage of labourers on total employees (*Figure 11*) is between 50% and 75% for almost half of the companies in each category of dimension. In general, the bigger the companies, the larger the share of labourers hired. It is interesting to notice as, among the smallest companies (0-49 employees) a larger number of enterprises (23%) have few labourers, precisely, less that one fourth of the employees. Overall, the value that represents the median share of labourers is 60%. It is in line with the mean share of labourers at a national level (INPS[2]), that in 2017 is 55%.

A core theme for employees is Job rotation. It can be defined as a periodical and systematic movement of employees from one task to another (Mahalakshmi and Uthayasuriyan, 2015). It requires that employees are shifted from one job to another, where each activity requires different responsibilities and skills. Job rotation can be addressesd with other names, that can describe some of its features: rotational assignments, transfers, job changes, lateral moves, cross training and redeployment. The importance of job rotation is recognized by several studies, applied in different situations and countries all around the world. It is a useful tool to train employees, so that they can substitute other employees and can provide the enterprise with a more flexible workforce. Having a reserve of trained employees to use in case of need, represents a key resource that can provide a competitive advantage for companies. At a personal level, it is recognized that (Fægri *et al.*, 2010) job rotation improves the common understanding of the job and the problem-solving ability. Moreover, it builds a higher degree of team efficiency among workers and make it easier for them to access promotion opportunities, once

[2] INPS, Database: Lavoratori dependent nel mese, downloaded on 7-10-2019

they have completed the whole program. The main benefit that can be attributed to this practice, is the enhancement of job involvement and interest among employees, that end up being also more productive. In this way, it is convenient to implement such programs both for employees, and for employers, that can experience a positive effect on the performance of the workforce.

Figure 12: Percentage of labourers involved in job rotation. $[n = 410]$

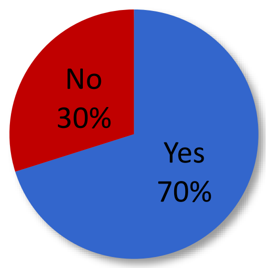


Source 12: Personal elaboration.

From the sample analysed (*Figure 12*), we can verify that 30% of the companies involve a very high percentage (between 75% and 100%) of labourers in job rotation, but also another 27% a slightly lower share (between 50% and 75%). The fact that job rotation is applied to labourers, is positive, since these workers usually have very repetitive and demotivating tasks.

Family Businesses

Figure 13: Companies that are Family businesses. $[n = 442]$

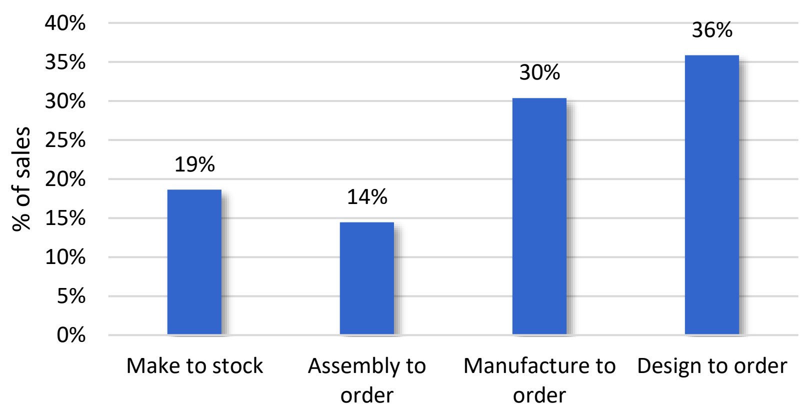


Source 13: Personal elaboration.

The importance of Family businesses in the economic framework of Italy is undeniable. Most of them were born in the 70s and now, it is time for the third generation to lead them. In the sample, 70% of the companies are Family Businesses (*Figure 13*). It is interesting to highlight some of the characteristics that differentiate them from the managerial firms (Vescovi, 2018). First and foremost, the ownership of the company is of the members of the family, that cover also the most important roles within it. Usually, the management is given to the second or following generations. Another common characteristic is that most of the times they belong to the category of SMEs. The decision mechanisms and their outcomes depend deeply from the ownership structure of the business, but also from the culture and traditions of the companies and the competencies and capabilities of the family members. Together with the economic objectives, these companies pursue different goals such as maintaining a good level harmony within the family and the preservation of the value of the company in the long term, pursued through conservative choices.

Manufacturing approach

Figure 14: Average percentage of sales from each Manufacturing approach. $[n = 423]$



Source 14: Personal elaboration.

Manufacturing companies can vary a lot also according to their Manufacturing approach. This is the way in which they organize production and respond to customers' demand. In *Figure 14*, from left to right, four approaches are proposed, that offer an increasing possibility of customization of the products.

- Make to Stock (or MTS) is a production strategy that is traditionally used by businesses that build enough inventory to match the predicted consumers' demand. The level of stock replenishment is set according to the forecast of how many products will be ordered by customers. This is an efficient way of organizing production only for businesses where forecasts of demands are extremely accurate. Moreover, generally, the changes in production level, that should be adjusted during the year according to demand, are very expensive.
- Assembly to Order (or ATO), is an alternative to MTO, where products ordered by customers are quickly assembled and are customizable only to a certain extent. The idea is that the basic components of the product are already manufactured and ready to be assembled once an order is received. It is an intelligent intermediate solution between

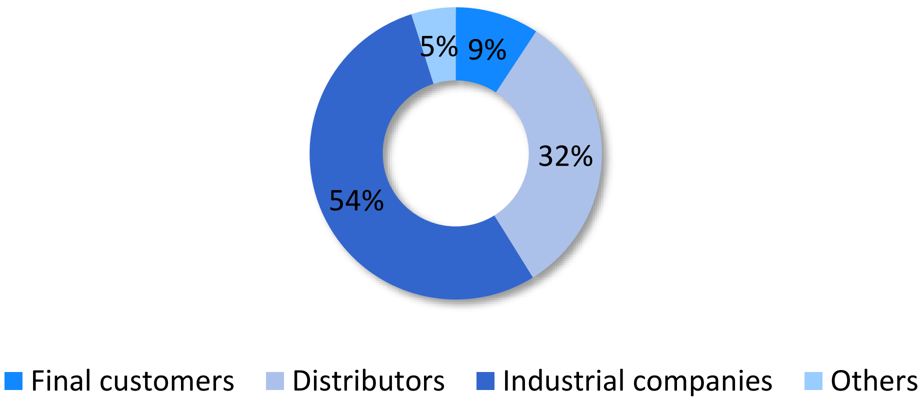
MTS and MTO, that unifies the pros of a quick delivery of the products to the final customer, with the possibility to partially customize products.

- Manufacture to Order (also known as made to order or MTO), is a business production strategy that allows consumers to customize to their specification the products that they are going to purchase. In the manufacturing process related to MTO, the production of an item begins only after an order is received. It embodies today's mass customization.
- Finally, the highest degree of customization is reached from Design to Order (or DTO) production strategy, in which production starts only after the design phase, where all the requirements of the customers have been satisfied in a co-creation phase.

The sample shows that on average, 36% of the turnover of companies comes from the DTO, whereas 30% comes from a MTO approach. The high values of these two business solutions suggest that the production is more and more customized, because the demand requires so. And it is thanks to recent progresses of manufacturing and information technologies that companies can fulfil more easily customers' requirements (Battini *et al.*, 2009).

Distribution channels

Figure 15: Average revenues per distribution channel. $[n = 403]$



Source 15: Personal elaboration.

The decision of which Distribution channels to adopt is a fundamental step in creating an ideal marketing mix, together with the creation of the product itself, its pricing strategy and all the promotion activities to launch it. Distribution channels can be defined as the path that products follow, from production to when they reach the hand of the final consumer (Kotler and Keller, 2011). They are represented by interdependent organizations that have the common goal of making products and services available for consumption. The dynamic markets require companies to structure more and more complex channel strategies, that can mix the use of different channels.

- Direct sales take place when the manufacturing company interacts directly with final customers and delivers the produced goods to them, without the help of other intermediaries, representing the shortest type of distribution channel. Thanks to direct distribution, companies can create a strong relationship with final customers and sense quickly and vividly the possible changes in their requirements. On the other hand, companies must be able to manage a good communication and marketing activity.

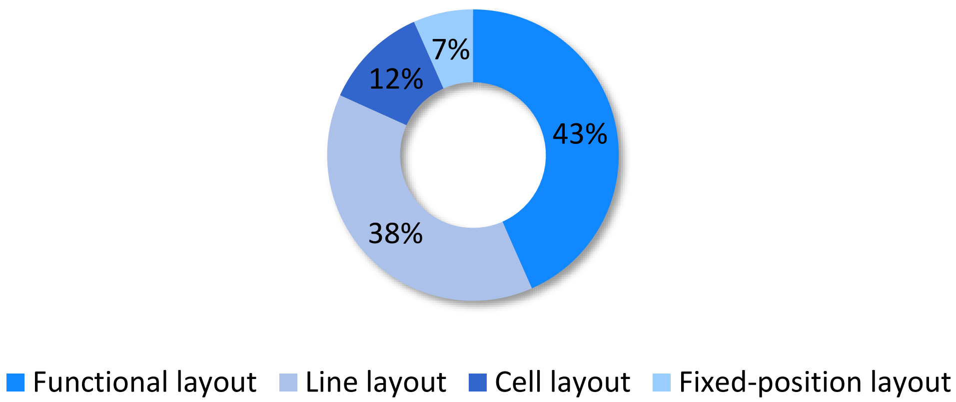
- Often companies decide to delegate part of their tasks to intermediaries like Brokers and Distributors, that are channel members that help them in bringing the products or services to the market.
- The supply chain can usually involve wholesalers or retailers. This is the case of Business to Business transactions (B2B), that require professional interaction between companies, typically in the form of manufacturing firms that purchase raw materials or components from suppliers.

Designing the appropriate distribution strategy is very delicate task and should take into consideration companies' requirements about the speed of delivery of their products and the expectations of customers on their purchasing experience. Moreover, all the members of the channels should be in line with the strategies and objectives of the whole organization (Dal Farra *et al*., 2019).

The average sales that come from Direct sales (Sales to final customers) account in the sample for 9% (*Figure 15*) while a greater percentage (32%) of turnover comes from distributors. But more than half of the sales (54%) of the companies interviewed come from industrial companies (B2B). Taking into account that they are all manufacturing companies, it is no surprise that a great part of their business is to sell to other industrial companies.

Layout adopted

Figure 16: Layout adopted. [$n = 438$]



Source 16: Personal elaboration.

To define the Layout of the operations it is necessary to decide "how the transforming resources are positioned relative to each other, how its various tasks are allocated to these transforming resources and the general appearance of the transforming resources" (Slack *et al*., 2016, p.217).

The Layout in the end dictates "the pattern and nature of how transformed resources progress through the operation or process." (Slack *et al.*, 2016, p.217). The principal four layout types are: Functional, Line, Cell and Fixed position.

- The functional layout, also called Process layout is a configuration that groups together all the operations that have a similar nature. The purpose of this layout is to manufacture products that require several different processing requirements. In functional layouts, the goods flow along the operations, from an activity to another, according to their manufacturing needs. The flow paths of materials from an area to another differs from product to product. The major advantage of Functional layout is flexibility, that is granted to the company through the possibility to handle a great variety of processing requirements.
- Line layout, or Product layout, is a way to arrange operations that requires that machines, resources and auxiliary services are arranged sequentially, according to the processing route of the goods. Ideally, the whole process should be arranged in a straight line, that can be totally dedicated to one single version of a product. The advantages of such a layout include the realization of a smoother flow, smaller in-process stocks, the reduction in throughput time and work-in-process.
- Cell layout is an arrangement of operations in which machines and all the transforming resources are grouped together because they are necessary for the processing of a family of similar items. This physical organization is the cell, and the operators within it are trained to use all the machines of the equipment and have the responsibility for the finished output. This type of layout rationalizes the complexity of operations and allows factories to produce in small batches, offering a higher degree of flexibility. Moreover, employees are more motivated because they have a higher level of training, variety of works and responsibility.
- Finally, in Fixed-position layout it is not the item that needs to be processed that moves, but it remains in a fixed position for all the time required for its manufacturing. This counterintuitive disposition is generally required from the nature of the product itself that is too big or fragile to move. On the other hand, this layout requires that all the machines and tools necessary can be transported and shifted when needed, to perform their job on the spot. Sometimes, fixed-position layout can entail problems with storage space caused from the little room left within the working area, but it still represents the most efficient solution or the only one available.

The sample shows (*Figure 16*) a predominance of the first two layout types described, with respectively 43% of the companies that adopt a Functional layout and 38% Line layout. Only

12% adopt a Cell layout, and 7% Fixed-position layout because the conditions that require its use are rarer.

Classification of Economic activities

The manufacturing companies of the sample belong to the twenty-one selected ATECO Codes: 10, 11, from 13 to 18 and from 20 to 32. As already mentioned, ATECO 2007 is an Italian classification of economic activities developed by ISTAT and adopted since 2008. It is a 6-digit code that defines in detail the nature of the activities of companies. This classification is the national version of the European nomenclature, Nace Rev. 2.

Figure 17: ATECO 2-digit classification. [$n = 448$]

Sectors of Economic activity	% of companies
Manufacture of machinery and equipment n.e.c.	23%
Manufacture of fabricated metal products, except machinery and equipment	19%
Manufacture of electrical equipment	8%
Manufacture of rubber and plastic products	7%
Manufacture of furniture	5%
Manufacture of food products	5%
Manufacture of chemicals and chemical products	4%
Other manufacturing	4%
Manufacture of other non-metallic mineral products	3%
Manufacture of basic metals	3%
Manufacture of textiles	2%
Manufacture of beverages	2%
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	2%
Manufacture of paper and paper products	2%
Printing and reproduction of recorded media	2%
Manufacture of computer, electronic and optical products	2%
Manufacture of basic pharmaceutical products and pharmaceutical preparations	1%
Manufacture of wearing apparel	1%
Manufacture of leather and related products	1%
Manufacture of motor vehicles, trailers and semi-trailers	1%
Manufacture of other transport equipment	1%

Source 17: Personal elaboration.

In *Figure 17*, it is evident the predominance in the sample of companies of the first two sectors: Manufacturing of machinery and equipment, 23% and Manufacturing of fabricated metal products, except machinery and equipment, 19%. These data confirm an important presence of heavy industries in the sample. This kind of industry usually is capital intensive, requiring large and expensive machines and tools, and sells to other industries, rather than to final customers and it is in line with the data already discussed in *Figure 14*. The rest of the sample is way more fragmented, with sectors that group less than 10% of the companies.

A further analysis of the twelve most common sectors at the 6-digit level is also offered in *Figure 18*. Machining is still the most common sector in the sample (30 companies).

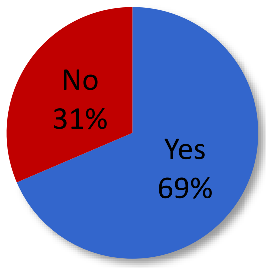
Figure 18: ATECO 6-digit calssification, most common sectors. $[n = 126]$

Sector of Economic activity	N° of companies
Machining	30
Manufacture of non-domestic cooling and ventilation equipment	13
Manufacture of plastic packing goods	13
Manufacture of metal structures and parts of structures	10
Manufacture of machinery for food, beverage and tobacco processing	9
Manufacture of other plastic products	8
Forging, pressing, stamping and roll-forming of metal; powder metallurgy	8
Manufacture of domestic appliances	7
Manufacture of other machine tools	7
Printing and service activities related to printing	7
Manufacture of other fabricated metal products n.e.c.	7
Manufacture of electric motors, generators and transformers	7

Source 18: Personal elaboration.

Adoption of Industry 4.0

Figure 19: Companies adopting Industry 4.0 technologies. $[n = 299]$

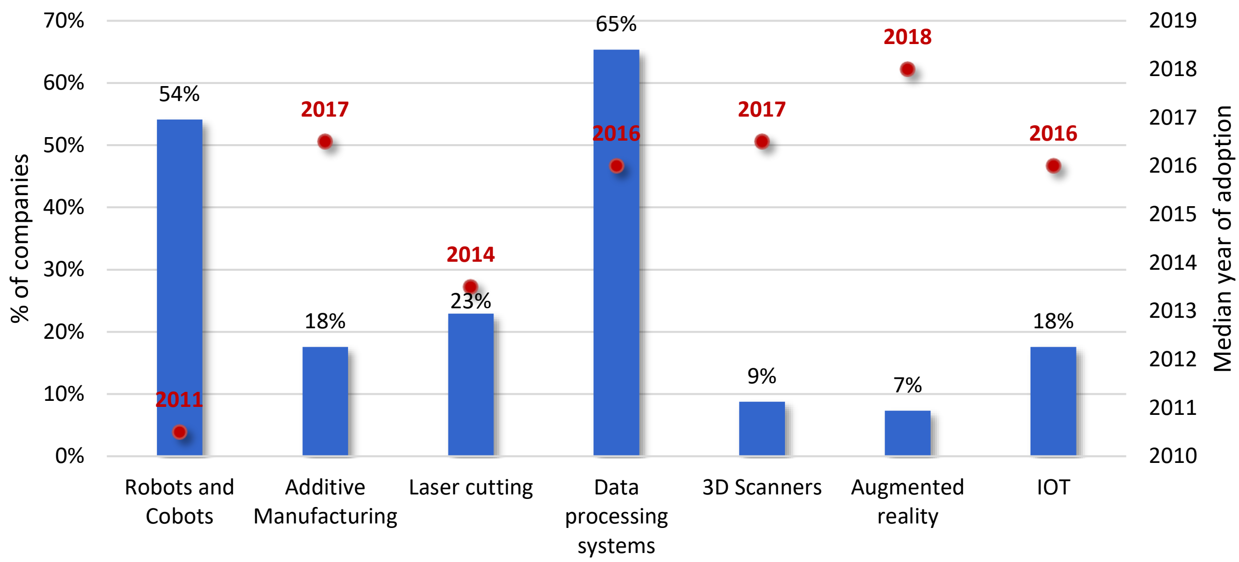


Source 19: Personal elaboration.

Only 31% of the respondent companies, equivalent to 95 firms, do not apply any Industry 4.0's technology. In Italy the Government issued at the beginning of 2017 the "Piano Nazionale Impresa 4.0", a plan to incentivize Industry 4.0 and the related investments, allocating 18 billion euros for the years 2017-2020 (Deloitte, 2019a). Italy has approximately 5,400 high-tech manufacturing companies (Deloitte, 2019b), positioning itself among the first four most technologic countries in Europe, together with Germany, the UK and Poland. Deloitte's (2019a) research highlights a positive attitude of Italian managers toward industry 4.0, even if they are still not certain about which strategies and solutions to adopt. In particular, it is spread a general distrust towards the efforts that Italy has made so far in this field. In this climate halfway between hope and uncertainty, however, Italy is investing a lot in research and development. Italy's top R&D spending enterprises boast an average annual expenditure of €185.4 million, that is higher than the EU average of €165.8 million (Deloitte, 2019b).

Technologies of Industry 4.0

Figure 20: Industry 4.0's technologies adopted. [$n = 205$]



Source 20: Personal elaboration.

Figure 19 contains some fundamental information about the principal Industry 4.0's technologies implemented from the companies of the sample and already described in the first chapter. The bar graph represents the percentage of companies that adopt that specific technology, whereas in red it is showed the median year of their adoption.

- Advanced robotic (Robots and Cobots): 54% of the companies in the sample adopt robotic in their shop floors. Italian statistics show that the robotic intensity is of 185 robots per 10,000 manufacturing employees (Deloitte, 2019b). This places Italy in the global top ten, ahead of Spain, France and the UK. The Italian country is also in the seventh place worldwide, and in the second in Europe, for the production of robots, with an annual average of production of 6,500 units. The median year of adoption of this technology is 2011 and reveals that this is the oldest one and that maybe some of the firms in sample have adopted at first traditional old generation robots.
- Additive manufacturing: Known also as 3D printing, is a technology that is adopted from 18% of respondents. In 2018, 4% of EU enterprises employed 3D printing (EUROSTAT, 2109). Finland is the heaviest user of Additive manufacturer, with a 7% of enterprises using it, whereas in Italy, like Austria and France among others, this share is 4%. The overall European percentage of adoption rises to 13% if computed only for large enterprises, against the 4% of SMEs. The high percentage registered in the sample under analysis, can be partially explained because it contains only manufacturing firms. Manufacturing is the sector where this technology is most used also in EU (9%)

(EUROSTAT, 2019). AM is a technology that has been introduced recently from companies, whit 2017 as the median year of adoption.

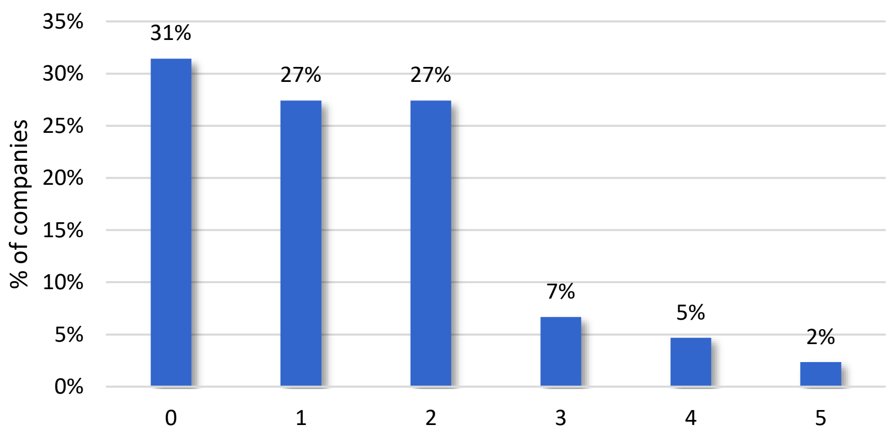
- Laser cutting: this technology is slightly more common among companies (23%) and is not one of the most recent to be introduced, since the median year of adoption is 2014.
- Data processing system: this broad category contains both Cloud Computing (CC) and Big Data, and it is the most implemented technology among the respondents. 65% of these enterprises use a system to elaborate the data collected from the shop floor. EUROSTAT (2018) reports that Cloud computing has been implemented from 26% of EU enterprises in 2018. According to the research, these companies use CC mostly for their e-mail systems and storing files in electronic form, but 55 % of them use also advanced cloud services like software applications for financial and accounting, customer relationship management or other business applications. The European countries record very different percentage of adoption of CC, with countries like Finland, Sweden, Denmark, and Belgium that recorded at least 40 % of enterprises used cloud computing. According to the classification described in chapter one, in 2018, more firms used Public cloud servers (18 %) than Private cloud servers (11 %) (EUROSTAT, 2018).

  Big data analysis has been used by 12% of companies in EU in 2018, with a significant difference between large enterprises 33% and SMEs 12% (EUROSTAT, 2019). Italy has an average adoption of Big Data around 6%. The sources of data at a European level are different: in SMEs prevailed the use of geolocation data from mobile devices and data from social media, whereas large enterprises mainly used data from the enterprise's own smart devices or sensors and other sources. Moreover, data analysis can be both performed by own employees (90% of enterprises) or by an external service provider (75 %). The preference of using internal people to analyse data is not present among SMEs, where slightly more enterprises rely on external service providers (42%) rather than on their own employees (40%).

  The high percentage of adoption of data processing systems showed by the sample under analysis can reveal that the respondents have taken into consideration other traditional types of data processing systems such as ERP or MRP when answering this question of the survey. Nevertheless, the median year of adoption is 2016, showing a recent trend of implementation of these technologies. This is in line with the data in EU, where a significant increase (+7%) in the adoption of CC was registered from 2014 to 2018. (EUROSTAT, 2019)

- 3D scanner: this technology is implemented by 9% of the companies in the sample. This is a recent introduction for these enterprises, that show as median year 2017.
- Augmented reality: this technology is adopted by few companies (7%), mostly because it is a very recent application for manufacturing, especially used for training employees and quality control. The median year of adoption is 2018.
- Internet of Things: this technology is adopted by 18% of companies in the sample and the median year of adoption is, as for data processing systems, 2016. The rising use of IoT in Italy is testified by the value of the IoT's market in 2017, that reached €3.5 billion. A value that was 32 per cent higher than in 2016 (Deloitte, 2019b). The Innovation Group (2017), reports the results of a survey conducted in 295 companies adopting IoT technologies, on the most common results expected from the implementation of this technology. 43% of the respondents expect "More efficiency within operations management", 30% instead wishes for the "Usage of the generated data to provide new services", another 20% hope for the creation of "New joint partnerships and go-to market strategies". Only 2% expect a "Reduction of the average production costs" while "Other" results are hoped for from 4% of the enterprises interviewed.

Figure 21: Number of Industry 4.0's technologies adopted. $[n = 299]$



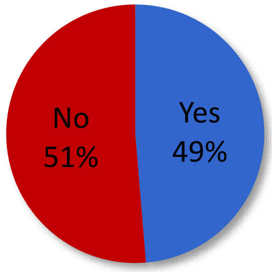
Source 21: Personal elaboration.

Among the firms answering to these questions about Industry 4.0, 31% of them do not implement any of its technologies. The majority of the companies, precisely 54% of them, adopt one or two technologies that can be ascribed to Industry 4.0. Only a residual 14% adopt a higher number of technologies, between 3 and 5. This suggests that only a small portion of enterprises can be considered heavy adopters of the new technologies, while it is quite common to have one or two of the most known applications of Industry 4.0.

3.4 Section 2 of the survey

Lean implementation

Figure 22: Companies implementing Lean techniques. $[n = 454]$



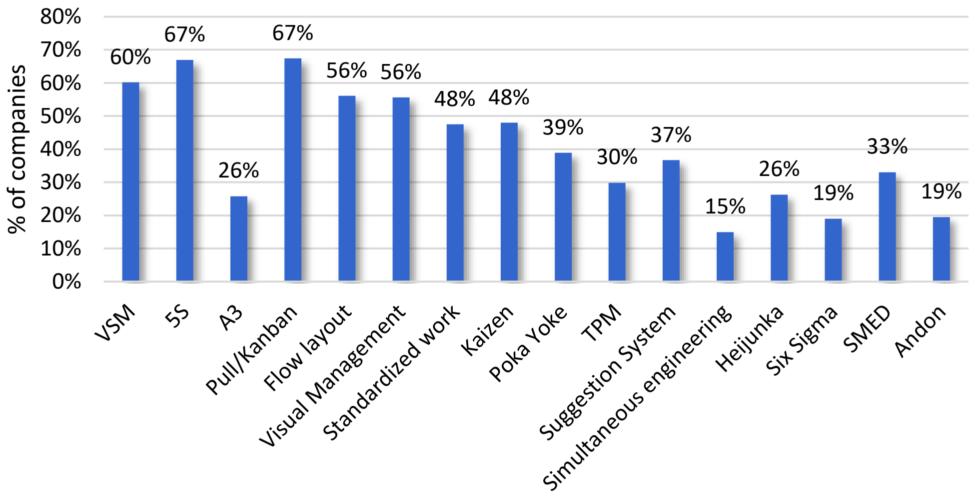
Source 22: Personal elaboration.

The sample of companies is almost equally distributed (*Figure 22*), when it comes to talk about Lean implementation. Almost half of the companies (49%), apply some Lean techniques, whereas the remaining 51% is not Lean at all. Camuffo (2012), remembers that companies like Snia Viscosa and Fiat started to experiment their own versions of quality management and Toyota Production Systems respectively in the 70s and 90s. The Author defines that period as the first “lean wave” in Italy. It affected the largest industrial groups and the subsidiaries of multinational companies present in the Country such as Electrolux-Zanussi, Pirelli, SKF among others. Thanks to these early adopters, Lean practices became more popular, even if they didn’t really change the structure of the industrial sector. Lean has gained again strength and popularity in the second half of the last decade, when it has affected the SMEs and has provided to them a new source of competitive advantage in a tough environment like the globalized markets. The Professor, thanks to the 2011 survey “Made in leanitaly: how Italian firms are undertaking lean transformations to survive and thrive”, observes that the companies touched from the first two waves of Lean implementation, especially SMEs, have taken Lean seriously and are trying to promote structural changes within their industry sectors, gaining also encouraging results. He concludes listing the most damaging factors for future deployment of Lean companies: first of all, sometimes the size of enterprises is too small to allow the right amount of investment to be committed to Lean implementation. In the second place, Italian unions are not always supportive of Lean implementation, sometimes impeding its application. Lastly, the unique structure that Italian clusters present, makes it harder to gain fast improvements, because it requires the involvement of all the interconnected companies within the same complex supply chain in the process of Lean transformation (Camuffo, 2012).

In the sample, the median Year of adoption of Lean is 2013, confirming the renewed interest of companies for the Japanese manufacturing principles.

Implementation of Lean practices

Figure 23: Lean practices adopted. [$n = 221$]



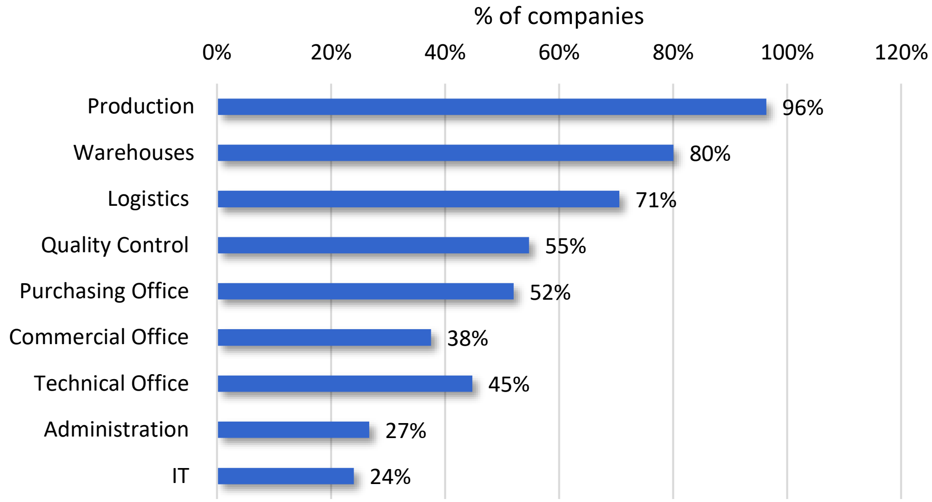
Source 23: Personal elaboration.

Figure 23 shows which of the Lean practices already described in the first chapter are adopted from the Lean companies of the sample. The most applied are 5S and Pull-Kanban, that have been enforced by 67% of the companies. Then follow Value stream mapping (60%), flow layout and Visual Management, both adopted by 56% of the enterprises, and Standardized work and Kaizen (48%). The remaining techniques are Poka Yoke (39%), Suggestion system (37%), SMED (33%), Heijunka and A3 (26%), Six sigma and Andon (19%) and in the last place, Simultaneous engineering (15%). These results are consistent with another survey conducted among Lean companies in Italy by Portioli-Staudacher and Tantardini (2007). The Authors reported that 5S, Kanban Value Stream Mapping and SMED, are the most commonly implemented techniques. Whereas very few Lean implementers started six sigma and TPM.

Most of the practices above mentioned can be grouped in the category of Hard Lean practices. According to the division of Bortolotti *et al*. (2015) and Buer et al. (2018), Lean practices can be divided in two groups: Hard and Soft. The first cluster is formed by technical and analytical tools, whereas in the second, there are practices that concern more people and relations (Bortolotti *et al*., 2015). These Authors propose as Hard Lean: Andon, Heijunka, Kanban, One piece flow, Poka Yoke, Single-minute exchange of die (SMED), Standardised work, Total productive maintenance (TPM), Value stream mapping (VSM), Statistical process control, Takted production, Just-in-time deliveries by suppliers Man-machine separation, Waste reduction. Soft Lean practices are instead: 5S, Kaizen, People and teamwork, Small group problem solving, Training employees, Top management leadership for quality, Supplier partnership, Customer involvement. Even if the literature (Shah and Ward, 2007) recognizes the importance of the adoption of Soft Lean practices, often companies seem more concerned with the extensive use of Hard practices, not providing to the other group an appropriate level of attention. Bortolotti *et al*. (2015) suggest that Hard practices, even if very important and necessary for becoming Lean, are not sufficient for companies to differentiate successful Lean enterprises. The outcome is different if also Soft practices are taken into consideration.

The companies in the sample show a high interest in both Hard and Soft Lean practices, with 5S and Kaizen as representative of the second group.

Figure 24: Areas of implementation of Lean. $[n = 221]$



Source 24: Personal elaboration.

Almost all the Lean companies (96%) that participated to the survey apply Lean to Production (*Figure 24*). It represents the area in which Lean was originally developed, and the starting point for each company to apply the waste reduction and process improvement theories. The other most affected areas are Warehouses and Logistics, reorganized with Lean practices respectively by 80% and 71% of the companies. Stocks and Warehouses are sensibly reduced through the implementation of Lean five principles. Logistics represents another core function to involve in the Lean transformation process to embrace the logic of Just-in-time and to adopt the supply chain perspective and see the internal production processes as a part of a unique value stream from suppliers to the end customer (Langstrand, 2009). Quality Control is another essential function for Lean since “Lean manufacturing is a philosophy to provide better quality of products with lower cost and on time with lesser efforts” (Modi, D.B., Heman, 2014 p.339). For this reason, 55% of the companies apply Lean techniques in it. Also Purchasing offices and Technical offices are often involved in Lean projects, respectively by 52% and 45% of the companies. Commercial offices are involved by 38% of the companies, Administration by 27% and IT by 24%. These are less common areas of application of Lean, but it is not to be forgotten that Lean thinking requires the involvement of the entire organization, starting from the shop floor, invading all the vital functions, and reaching the board room, involving also suppliers, partners and customers in the same journey toward Leanness (Mathaisel and Comm, 2000).

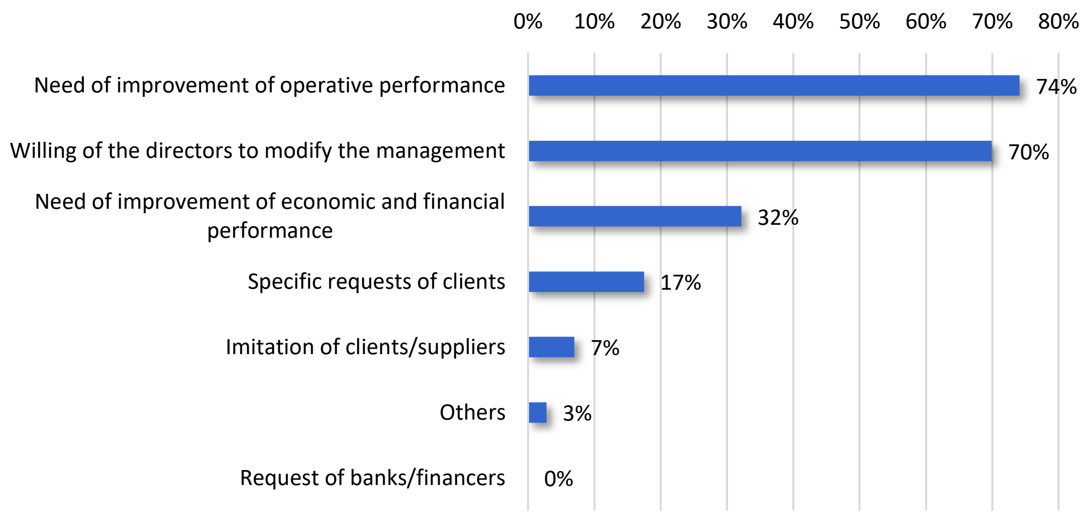
Figure 25: Distribution of Lean practices. [$n = 3558$]

	Production	Warehouse	Logistics	Quality Control	Purchasing Office	Commercial Office	Technical Office	Administration	IT	
VSM	3%	2%	2%	1%	1%	1%	1%	0%	0%	11%
5S	4%	2%	2%	1%	1%	1%	1%	0%	0%	12%
A3	1%	1%	1%	1%	0%	0%	1%	0%	0%	5%
Pull/Kanban	3%	3%	2%	0%	1%	0%	0%	0%	0%	10%
Flow layout	3%	1%	1%	0%	0%	0%	0%	0%	0%	7%
Visual Management	3%	2%	1%	1%	1%	1%	1%	0%	0%	10%
Standardized work	3%	1%	1%	1%	1%	1%	1%	0%	0%	9%
Kaizen	3%	1%	1%	1%	1%	0%	1%	0%	0%	9%
Poka Yoke	2%	1%	1%	1%	0%	0%	0%	0%	0%	5%
TPM	2%	0%	0%	0%	0%	0%	0%	0%	0%	3%
Suggestion System	2%	1%	1%	1%	1%	1%	1%	0%	0%	8%
Symultaneous engineering	1%	0%	0%	0%	0%	0%	1%	0%	0%	2%
Heijunka	2%	0%	0%	0%	0%	0%	0%	0%	0%	2%
Six Sigma	1%	0%	0%	1%	0%	0%	0%	0%	0%	2%
SMED	2%	0%	0%	0%	0%	0%	0%	0%	0%	2%
Andon	1%	0%	0%	0%	0%	0%	0%	0%	0%	2%
	36%	16%	14%	10%	7%	5%	7%	3%	3%	3558

Source 25: Personal elaboration.

In *Figure 25* the combined distribution of Lean practices and their areas of implementation is shown. The most common mix is the application of 5s in production (4% of the total practices).

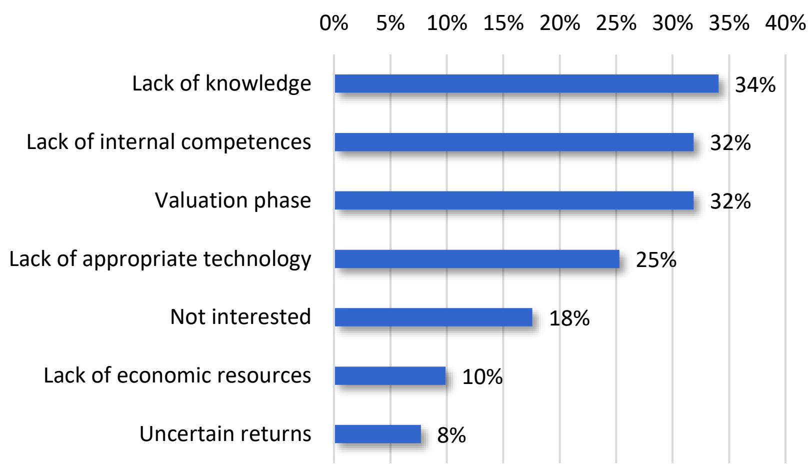
Figure 26: Reasons for applying Lean. [$n = 143$]



Source 26: Personal elaboration.

Among the motivations proposed (*Figure 26*), the preferred reasons that convinced Lean companies to undergo their transformation are related to the urgency of improvement of operative performance for 74% of the respondents. Slightly less (70%) underline a willingness of directors to change the logic of management of the companies. The improvement of economic and financial performance is sensed too as one of the motivations for applying Lean by 32% of respondents. The residual answers were less popular: companies that are Lean for a specific request of clients are just 17% of respondents, underlying as supply chains are still far from being a synchronized and efficient set of activities from start to end. Falah *et al.* (2009) list the main motivations found in the literature behind Lean adoption. It is mostly explained from an internal desired of companies, that is in line with their internal objectives. Other reasons are the increase of customers' satisfaction, the reduction of the time to market of products and the improvement of quality of goods, services and of the processes. Some other factors are the reduction of costs and the increase of efficiency and housekeeping capabilities.

Figure 27: Reasons refraining companies from applying Lean. [$n = 91$]

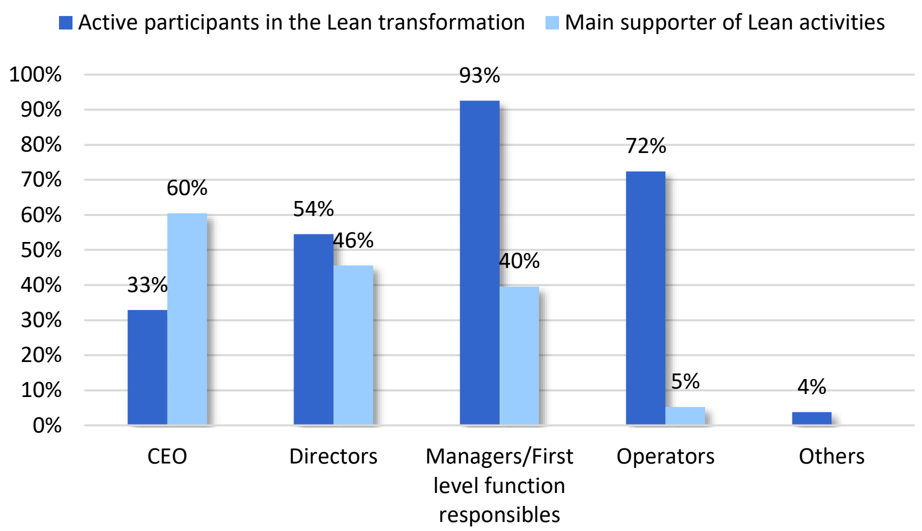


Source 27: Personal elaboration.

Analysing the reasons that hold back companies from becoming Lean (*Figure 27*), it is surprising to see that more than one fourth of respondents still declare that do not know enough about the topic. The awareness about Lean philosophy is still scarce in Italy. Even if Lean concepts have been developed a long time ago and started spreading from the 90s all around the world, some regions in the world or some industry's sectors have not yet known Lean and its benefits (Abu *et al.*, 2016). The level of Lean awareness inside a Lean company, instead, is one of the preliminary requirements for implementing Lean awareness (Salem *et al.*, 2016). Other reasons that were indicated from the respondents of the survey were: Lack of internal competencies, 32%. It is encouraging that 32% of non-Lean respondents are currently considering the introduction of Lean in their enterprises. On the other hand, 18% of companies are not interested in Lean. One fourth of respondents claim that the cause of their non implementation is determined by the lack of appropriate technologies, while 10% lack economic resources. The uncertainty of the returns is the least chosen motivation for not applying Lean. Abu *et al.* (2019) list also the barriers to lean implementation found in the literature. The most common are consistent with the results that have been obtained from the database: lack of Lean understanding in general, and more specifically lack of technical knowledge about Lean methods and lack of understanding about its benefits. Then also the resistance to change of companies and people, the financial constraints and shortage of Lean consultants and trainers. Furthermore, cultural difference in the workplace is another important obstacle.

People affected by Lean implementation

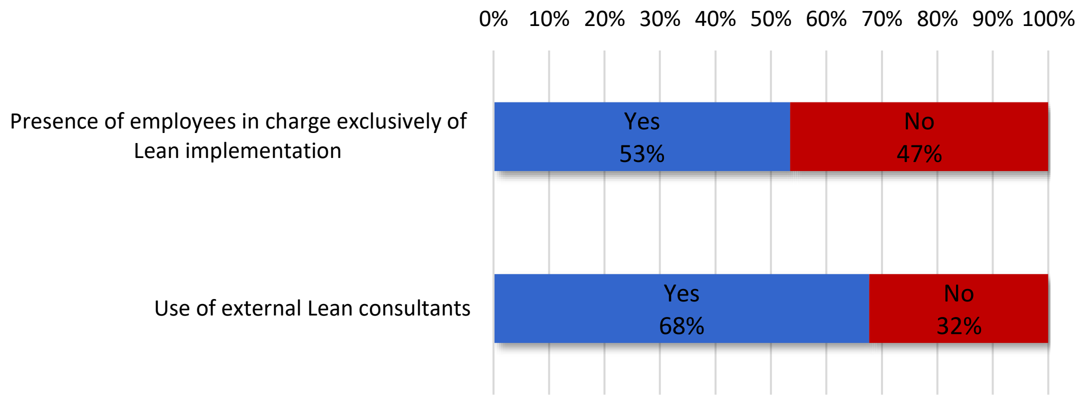
Figure 28: Key roles in Lean implementation. $[n = 134]$



Source 28: Personal elaboration.

The involvement of people in Lean transformation's journeys is essential for the success of the process, together with having a common focus on continuous improvement (Bortolotti et al., 2015). *Figure 28* reports the results of two questions addressed to Lean companies. The first one asks who the main active participants in the Lean transformation are, that means for example, identify those who take part to the kaizen workshops. The second asks companies to recognize the main supporters and promoters of Lean activities. It is easy to notice that the answers are distributed symmetrically for the first three categories. In particular, the CEOs are most frequently (60%) the main promoters of Lean activities, followed by Directors and Managers (46% and 40%). But considering the Active participants, these positions rank with the opposite logic: the lower the hierarchical level, down to the First level function responsibles, the higher the level of involvement. The highest value is reached by First level function responsibles, that are involved for 93% of the companies. They are followed by a significant 72% of respondents that have Operators that participate actively in the Lean transformation.

Figure 29: Other internal or external people involved in Lean implementation. $[n^a = 217; n^b = 217]$[3]



Source 29: Personal elaboration.

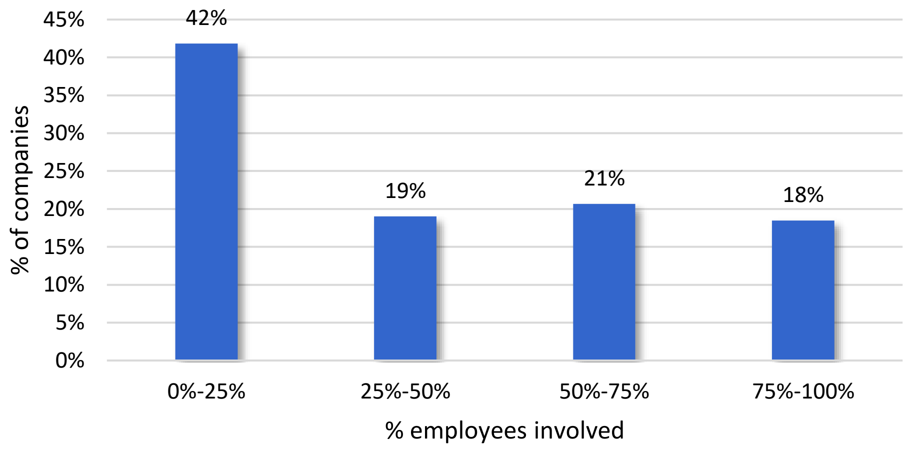
The survey then digs into the other people involved in Lean transformation (*Figure 29*). In 53% of the companies there are employees specialized in Lean implementation such as Kaizen Promotion Officers (KPO) or Lean internal consultants and navigators. The use of external Lean consultants is a common practice for 68% of the Lean companies interviewed. Whether to make use of internal specialized employees or external consultants for implementing Lean, is a thorny issue. Lean is living a transformation from the Hard Lean of the origins developed in the automotive sectors, to the Soft Lean of Lean thinking and Lean philosophy, that has more to do with the organizational culture and HR management, than with the practical tools useful to reduce waste. Holmemoa *et al.* (2018) advise managers to consider carefully the use of external consultants during the Lean implementation. As Lean has changed over time, so should have done also consultancy. Hard Lean requires consultants that convey decontextualized knowledge, as experts that give their prescriptions on which tools and techniques to use to become Leaner. Soft Lean, instead, is contextualized, local adapted and continuously learning. This new approach challenges the old type of consultant and requires a "process consultant". This softening of Lean has not coincided with a decrease in the demand for Lean consultancy. The Authors do not think that external consultants are completely useless for Lean implementation. For example, especially in the first phases of the implementation, they can be invited as experienced members of teams to promote learning and innovation. Nevertheless, it seems that "an outside expert cannot easily install a soft, participation-oriented form of lean"

[3] n^a is referred to the number of respondents to "Presence of employees in charge exclusively of Lean implementation"
n^b is referred to the number of respondents to "Use of external Lean consultants"

(Holmemoa *et al.*, 2018, p.148). Soft Lean is more easily developed internally, especially if supported by a significant commitment and effort from line managers.

The above-mentioned shift of Lean from Hard to Soft is reemphasizing the human centricity of Lean philosophy. Marin-Garcia and Bonavia (2015) support the idea that a successful Lean implementation depends not only on using the right practices, tools and techniques, but at least equally depends on a change in the mindset of employees and on their involvement in Lean activities. Other authors have recently put greater attention on the social aspects of Lean like employees' involvement. Among others, Anand *et al.* (2009) state that the participation of employees is essential to promote Continuous improvement and that it can be achieved giving to employees adequate training and motivation. Some other Authors propose even that employee involvement is an antecedent to Lean management practices (Cua *et al.*, 2001), and that it has an indirect effect on the performance of companies.

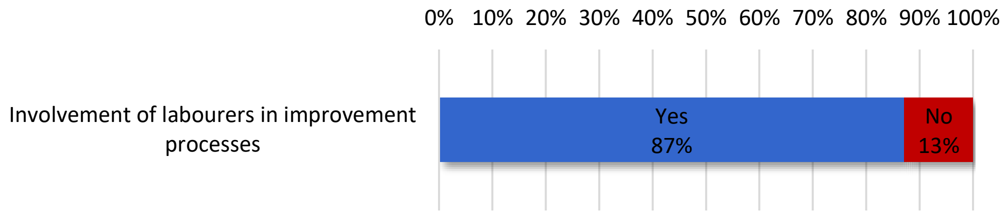
Figure 30: Percentage of employees involved in Lean projects. [$n = 184$]



Source 30: Personal elaboration.

The percentage of employees involved in Lean projects in the sample (*Figure 30*), is in a very low range, between 0 and 25%, for 42% of Lean companies interviewed. 19% of the enterprises involve a slightly higher percentage of them (between 25% and 50%). The total amount of companies that involve more than 50% of their employees is 39%, and only 18% involve almost all their workforce. These results underline the necessity for companies to engage more their employees in the transformation process so that Lean principles and techniques can be implemented more efficiently and have a positive impact on performance.

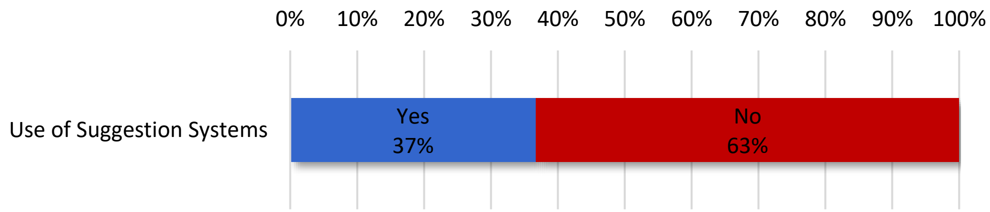
Figure 31: Involvement of labourers in improvement processes. $[n = 210]$



Source 31: Personal elaboration.

Another aspect under investigation with the survey is the involvement of labourers in the improvement process. A very high percentage of companies (87%) involve their labourers in the Lean continuous improvement (*Figure 31*). It has been experienced (Conti *et al.*, 2006) that continuous improvement projects are supported from workers. This is mainly because these projects usually enhance the quality of products, bringing an impact on the motivation of labourers. In particular high quality can provide workers with a sense of pride and a feeling of job security especially in processes that require a low levels of job control like the ones regulated by Standard Operating Procedures (SOP). Moreover, Lean implementation avoids frustrations such as searching for parts and tools or trying to assemble poorly-fitting parts, thanks to high reliability of Lean designs.

Figure 32: Use of suggestion systems. $[n = 207]$

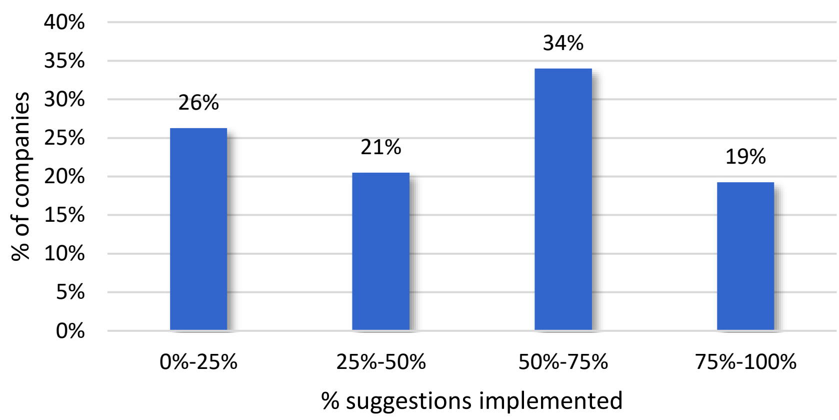


Source 32: Personal elaboration.

The use of suggestion systems (*Figure 32*) is a practice that is accepted only by 37% of the Lean companies in the sample. Having this kind of system means that companies turn to their employees and labourers for new ideas and suggestions. The use of suggestion systems in Lean is rooted in the past of Japan, as this technique dates back to the 18-th Century.

Today it is one of the Human Resource Management practices most implemented and that have the greatest positive effects on productivity. While companies become more efficient, they also give to employees and labourers the opportunity to feel important when their ideas are known or implemented. It is demonstrated that (Marksberry *et al.*, 2014) if employees focus on the needs related to their job, they will feel more motivated to participate. Even better if the participation is related to an incentive or reward. One of the most common effects obtained from people that share their suggestions is that they feel involved in decision making. The suggestion program in Lean contexts is not considered a way to replace the management in solving problems, but rather a process to shed a light on problems that are usually not visible to the management, but familiar to workers.

Figure 33: Percentage of suggestions implemented. $[n = 156]$

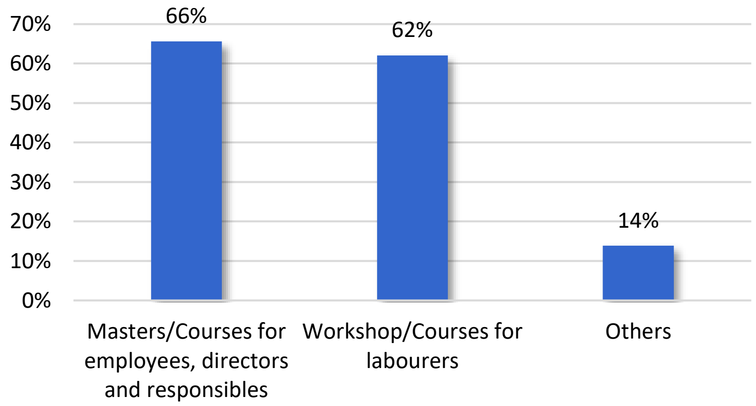


Source 33: Personal elaboration.

As the studies suggest, employees can feel motivated if they see their ideas accepted and used as incremental steps to improve processes. In the sample of companies interviewed, the percentage of suggestions implemented (*Figure 33*) is quite high. Most of the companies (53%) implement more than half of the suggestions given (between 50% and 100%), demonstrating a true commitment to this problem-solving system. As a benchmark, Liker and Hoseus (2008), give the number of suggestions generated by Toyota's suggestion program. They are more than 90,000 suggestions per year, and the percentage of them that are implemented is more than 90%. For the companies that answered a percentage between 0% and 50% (that are 47% of the sample), the comparison with Toyota is still very ambitious.

Type of training

Figure 34: Type of training chosen. $[n = 195]$

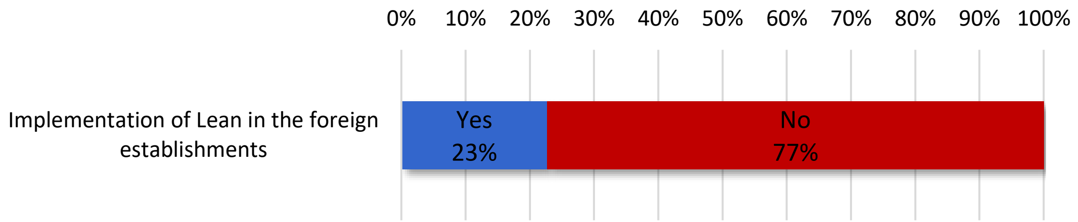


Source 34: Personal elaboration.

Lean management is characterized by continuous training and learning processes, and the development of the knowledge of human capital in Lean companies is of high importance. It is true that often the success of organizations depends on the competences that the employees have in order to perform their tasks. In addition, Lean managers are usually recognized by the level of qualification that they have (Kabst *et al.*, 1996). Moreover, all employees should be included in the training activities even those at the lower level of the hierarchy, that usually have less priority. Everyone in the company, indeed, is fundamental for the "leaning process". *Figure 34* shows the training methods chosen by the respondent companies. It is possible to understand that both employees, directors, responsibles and labourers have been involved in courses or workshops as training activities. It seems that the hierarchical level of trainees does not matter as 66% of companies have engaged in courses for higher level of employees, against a slightly lower 62% of enterprises that has trained labourers from the shop floor. Other types of training have been chosen by 14% of respondents.

Lean in the foreign establishments

Figure 35: Implementation of Lean in foreign establishment. [$n = 181$]

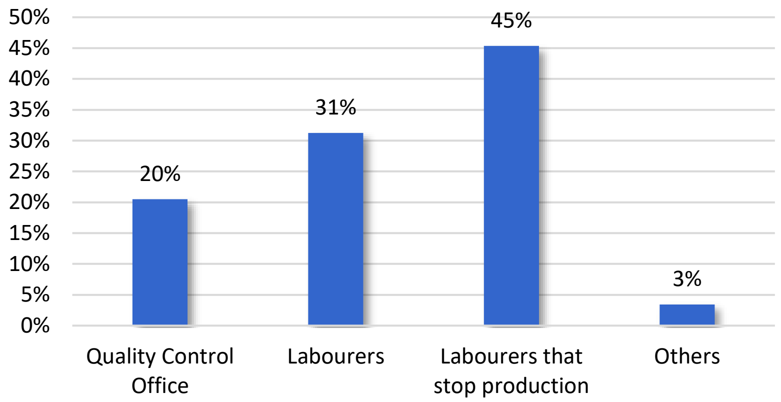


Source 35: Personal elaboration.

The choice to implement Lean in the subsidiaries or in the plants that companies have abroad is not a common one, pursued by less than one fourth of the companies (23%) (*Figure 35*). Lean implementation, like any other initiative to improve productivity, is often related with difficulties also in the home country. Being in an international and intercultural context is even worse and adds obstacles in the path to success. Göhner *et al.* (2017) list all the barriers and challenges faced when implementing Lean management in subsidiaries of companies in Brazil. The most significative are: Lack of skills and technical knowledge of Lean management, Lack of human/financial/technical resources, Lack of communication or engagement throughout the organization, Lack of team-based culture or culture of trust, and cultural differences. In particular cultural differences inhibit "intra-firm communication, negotiation and product standardization, which all lead to misunderstandings between employees and management, as well as between the organization and its suppliers, customers and partners," (Göhner *et al.* 2017, p. 103).

Detection of errors and abnormalities

Figure 36: Responsibles of detection of errors and abnormalities. $[n = 205]$

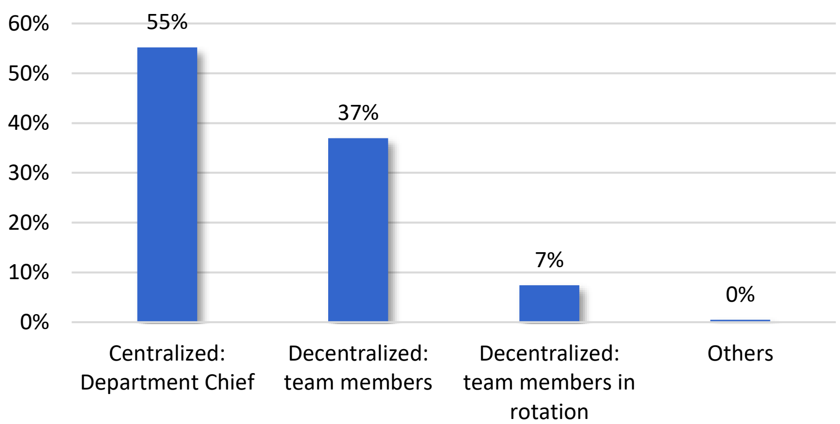


Source 36: Personal elaboration.

The different approaches to quality control are depicted in *Figure 36*. In the first case, Quality control office is for 20% of the companies the responsible for the detection of errors and abnormalities in the production process. For 31% of respondents Labourers are the ones that have this task, but they cannot take any countermeasure because they do not have any authority. A large part of the sample (45%) has invested Labourers in controlling the quality of products and processes and has also given them the authority to intervene with the needed corrective actions and stop the production process if needed.

Responsibility and supervision activities

Figure 37: Approach to responsibility and supervision activities. $[n = 203]$



Source 37:Personal elaboration.

More than half of the companies in the sample (55%) declare to have a centralized responsibility approach (*Figure 37*), where department chiefs are in charge of supervision and control activities. The rest of the sample is divided in two different types of decentralized approaches.

In the first case, that is the case of 37% of the respondents, within work teams there are one or more team members that perform control and supervision activities. In the second case, the supervision activities are performed by some team members chosen according to a rotation system.

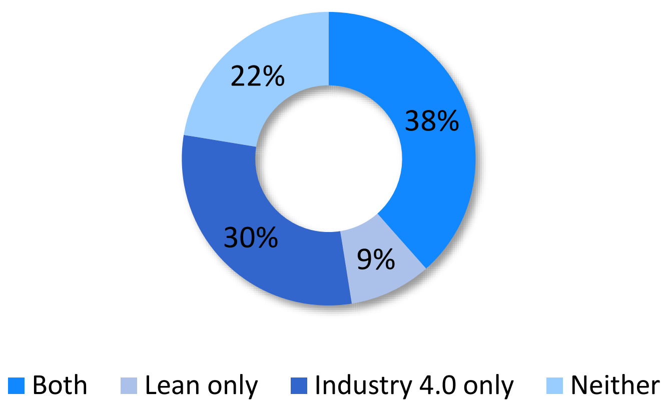
The paper of Delbridge *et al.*, (2000) explores the roles and responsibilities of shop floor operators, front-line managers and specialist functions such as engineers and other personnel. The Authors focus on three main aspects. First of all, Production responsibility, that entails quality inspections, reworks and all the technical aspects of the day-to-day activities. In the second place, Management responsibility, that is the extent to which typical responsibilities usually given to the management are assigned to the group. For example, the degree of responsibility that the group has for monitoring quality performance. Finally, Innovation and improvement, that are related to the participation of workers to problem solving and process-improvement activities. The findings of this work show that the production responsibility for shop floor operators is very limited and usually labourers are not upskilled for tasks like maintenance, but only have control on routine quality tasks. These technical tasks are domain of specialists that are outside the production teams but play a fundamental role in quality inspection. In addition, there is not a high degree of decision-making autonomy, that means that management responsibility is not effectively allocated to workers, and that teams are not self-managing. These results are a bit counter-intuitive for Lean contexts, where there should be more autonomy especially on shop floor's control activities and decisions, but they are in line with the data collected through the survey. As already noted, among the companies in the sample the centralized approach is still the most popular one, and even if firms adopt a decentralized approach, authority is still a prerogative of few selected people. For what regards front-line managers, indeed, they usually are team leaders in work teams. These work teams, even if can be described as self-managed, have still a hierarchical and centralized structure of responsibility. More expected (in line with what discussed before) and reassuring results show an increase of responsibility for labourers in problem solving and process improvement.

3.5 Breakdown of the sample

In the following section, a series of additional analysis on the data from the survey will be presented. One of the objectives of this work is to investigate the theme of Lean implementation and Industry 4.0 technologies' adoption within companies. To understand the motivations behind the choices of companies, it is important to know better their profiles and try to identify common features and behaviours. Some of the analysis already performed in the preceding section for the whole sample, will be here proposed broken down into four groups of companies.

Sample's categories

Figure 38: Breakdown of the sample. [$n = 299$]



Source 38: Personal elaboration.

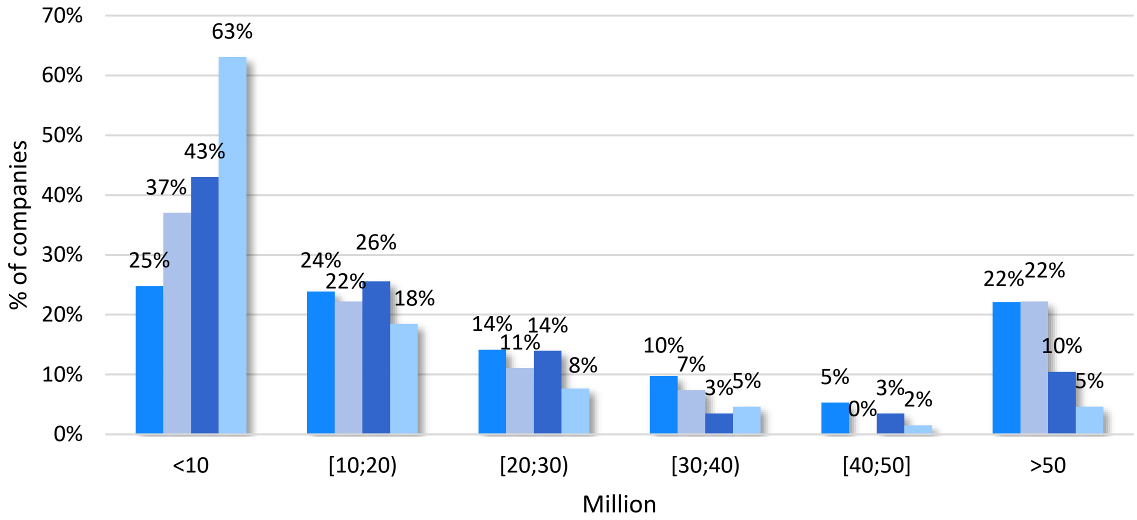
The first group (38% of the sample) (*Figure 38*) contains all the firms that have adopted Lean techniques and that are also Industries 4.0 (Both). The second (9% of the sample) refers to all the Lean enterprises that have not adopted Industry 4.0's technologies (Lean only). The third category (30% of the sample) groups all the companies that have Industry 4.0's technologies but are not Lean (Industry 4.0 only). The last group (22% of the sample) is formed by the remaining companies that have declared that are not Lean and that do not implement any Industry 4.0's technology. Among the 454 companies that returned the questionnaire, 155 did not answer the question related to Industry 4.0 implementation and are excluded from the sample because they cannot be correctly classified in these four groups.

Size according to revenues and sample's categories

The most outstanding finding of *Figure 39* is that many of the companies that are not Lean and do not apply Industry 4.0's technologies, are also very small in terms of revenues. Exactly 63% of them have less than 10 million revenues, that is a much higher share of companies compared to the average of the whole sample (31%). This is a result that can partially explain why they do not use such techniques and technologies. They can feel no need for a Lean transformation or the implementation of advanced technologies, since their businesses are not as complex as the ones of bigger enterprises. As Antony (2008) affirms, for example, in SMEs there is no evidence of problems related to management activities, such as support and commitment, and these enterprises are for their nature more agile.

On the other hand, the companies might not have enough resources to invest in new future-oriented technologies or training activities. Albliwi *et al.* (2014) report that the most common critical failure factor for Lean and Six sigma projects among small and medium enterprises is

Figure 39: Revenues of 2017. $[n^b = 115;\ n^{Lo} = 27;\ n^{Io} = 90;\ n^n = 67]$ [4]

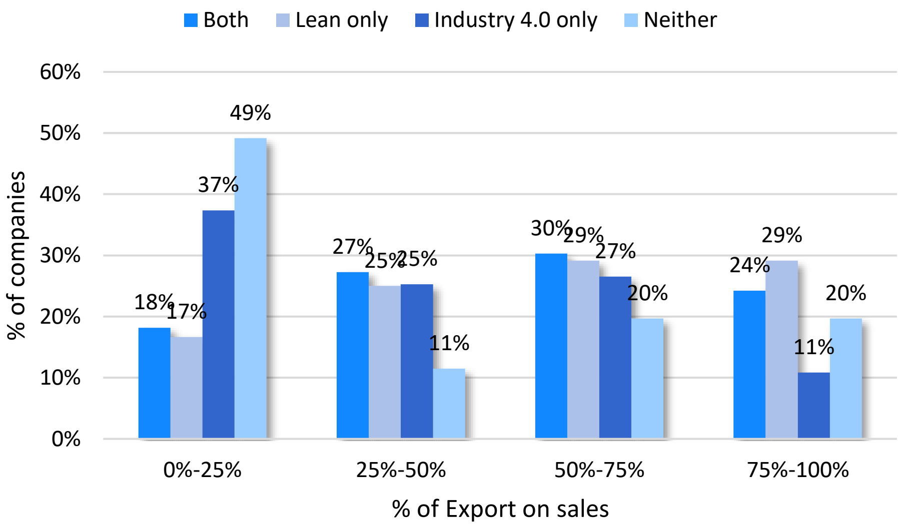


Source 39: Personal elaboration.

the lack of financial and physical resources, together with a lack of understanding of how to start a Lean transformation and poor organizational capabilities. The suggestion that the Authors give to managers is to be sure to have all the necessary resources before to start deploying transformation projects, even if this reasoning is not to be taken as a rule, and this is proven by the presence of small size companies that are Lean and technologically advanced.

Export according to sample's categories

Figure 40: Percentage of export on sales. $[n^b = 99;\ n^{Lo} = 24;\ n^{Io} = 83;\ n^n = 61]$



Source 40: Personal elaboration.

[4] n^b is referred to the number of firms that implement both Lean and Industry 4.0
n^{Lo} is referred to the number of firms that implement only Lean, but do not adopt Industry 4.0 technologies
n^{Io} is referred to the number of firms that adopt Industry 4.0 technologies but are not Lean
n^n is referred to the number of firms that neither implement Lean, nor Industry 4.0 technologies.

The smoothness of the distribution of companies of the whole sample over the different ranges of export is not maintained when analysing the four different groups of companies in *Figure 40*. Almost half (49%) of the companies that are neither Lean nor implement Industry 4.0's technologies have very small shares of export, for a value between 0% and 25% of the turnover of 2018. The openness to markets different from the one of the home countries can be mediated also by the dimension of companies. As we have highlighted in the previous section, this group of companies is the one that shows smaller sizes according to revenues. Generally speaking, the smaller the business, the bigger the barriers to export can seem. In particular, World Trade Organization (2016) reports that the participation of small and medium enterprises in trade is weak, with direct exports that represent just 7.6% of total sales in the manufacturing sector. It is a small percentage if compared with the 14.1 % of large manufacturing enterprises.

On the contrary, 58% of Lean companies and 54% of Lean enterprises that adopt also Advanced technologies have more than half of the sales of 2018 that is generated from sales in foreign markets. These companies are, not by chance also bigger in terms of revenues (*Figure 39*).

Figure 41: Average revenues and export on revenues. [5]

	Both	Lean only	Industry 4.0 only	Neither
Revenues (in millions)	57,6	37,8	21,2	16,4
Export on revenues	52%	55%	36%	36%

Source 41: Personal elaboration.

To sum up the data that we have seen in detail in *Figure 39* and *Figure 40*, it is proposed in *Figure 41* an overview of the same variables, Revenues 2017 and Export. On average, the companies that implement both Lean and Industry 4.0 have higher revenues that the other groups of companies. The companies that are Lean but do not apply Industry 4.0's technologies, instead are the ones that have a greater percentage of export on turnover.

Employees and workforce according to sample's categories

The same reasoning behind export distribution can be easily repeated for the number of people employed from the companies of the sample. The small dimension of the companies that do not adopt neither Lean nor Industry 4.0 is evident (*Figure 42*) since the average number of employees is 47 (68% of this group of companies have less than 50 employees). It is possible to note, at the contrary, that the companies that implement both Lean and Industry 4.0

[5] Number of companies for revenues [$n^b = 115$; $n^{Lo} = 27$; $n^{Io} = 90$; $n^n = 67$]
Number of companies for export [$n^b = 99$; $n^{Lo} = 24$; $n^{Io} = 83$; $n^n = 61$]

Figure 42: Average employees, labourers on employees and labourers involved in job rotation.[6]

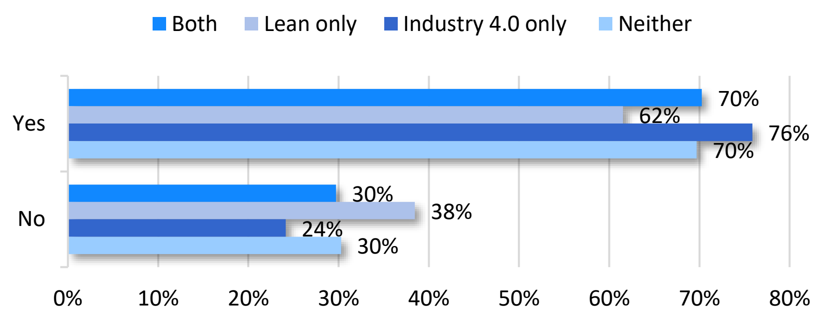
	Both	Lean only	Industry 4.0 only	Neither
Employees	179	107	68	47
Labourers	61%	49%	54%	57%
Job rotation	59%	57%	52%	50%

Source 42: Personal elaboration.

technologies are big companies, that employ on average 179 people (23% of them have more than 200 employees). On average it seems also that the companies that apply only Lean have more employees than the enterprises that use only advanced technologies. The percentage of employees represented by labourers is slightly higher for companies in the first group (61%) and appears to be lower in the companies with only Lean. Among these few workers, by the way, a big share (57%) is involved in job rotation. The percentage is higher only in the case of companies that are Lean and implement also Industry 4.0 technologies. On average only half of the labourers of companies that do not implement neither Lean nor Industry 4.0 is involved in job rotation.

Family businesses according to sample's categories

Figure 43: Family businesses. $[n^b = 111;\ n^{Lo} = 26;\ n^{Io} = 87;\ n^n = 66]$



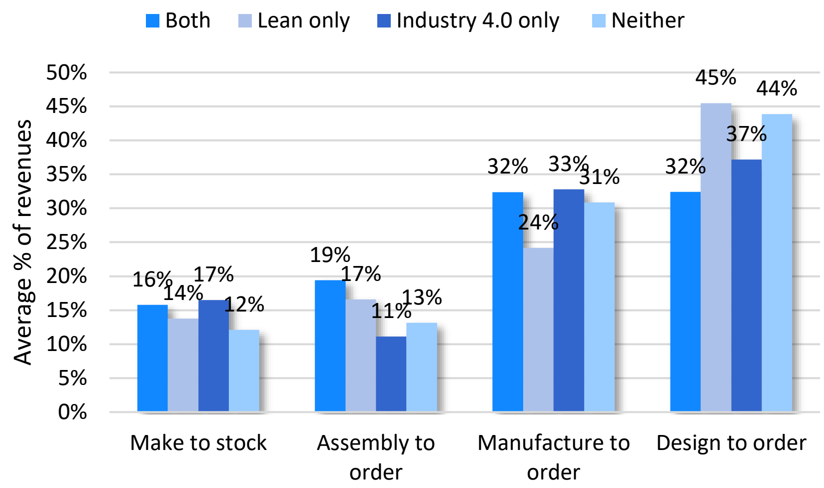
Source 43: Personal elaboration.

All the four groups of companies in the sample are predominantly family businesses (*Figure 43*), confirming the composition of the Italian economic framework described before. In particular 76% of companies that implement Industry 4.0 technologies are family businesses. The highest share of companies that are not family businesses (38%) is among companies that adopt only Lean.

[6]Number of companies for employees $[n^b = 115;\ n^{Lo} = 27;\ n^{Io} = 89;\ n^n = 66]$
Number of companies for labourers $[n^b = 106;\ n^{Lo} = 25;\ n^{Io} = 88;\ n^n = 66]$
Number of companies for employees involved in job rotation $[n^b = 103;\ n^{Lo} = 25;\ n^{Io} = 87;\ n^n = 65]$

Manufacturing approach according to sample's categories

Figure 44: Average percentage of sales from each manufacturing approach.
$[n^b = 114;\ n^{Lo} = 27;\ n^{Io} = 89;\ n^n = 65]$

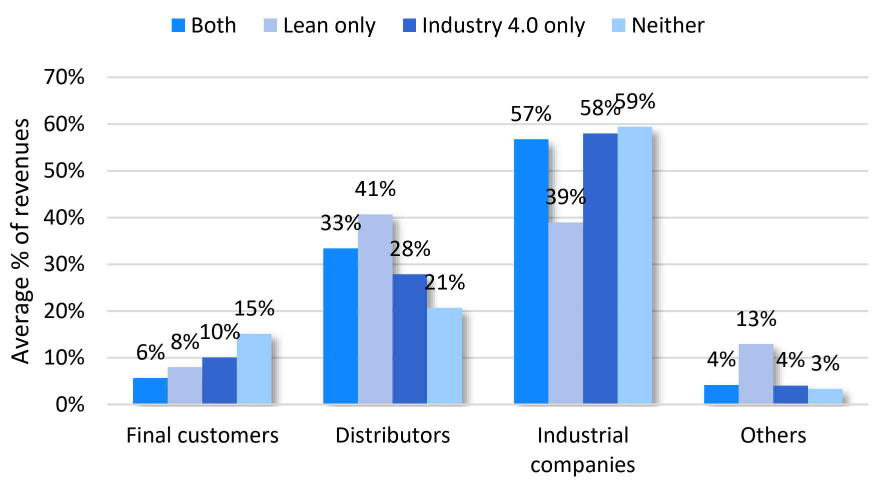


Source 44: Personal elaboration.

From *Figure 44* it is possible to note that the distribution of the sales of the companies in the four groups is almost uniform within the same manufacturing approach, but overall is heavily weighted in favour of the Design to order approach. In particular Lean companies that are not Industries 4.0 have 45% of revenues that come from this approach, similarly to companies that do not adopt neither Lean nor Industry 4.0.

Distribution channels according to sample's categories

Figure 45: Average revenues per distribution channel.
$[n^b = 100;\ n^{Lo} = 24;\ n^{Io} = 84;\ n^n = 65]$



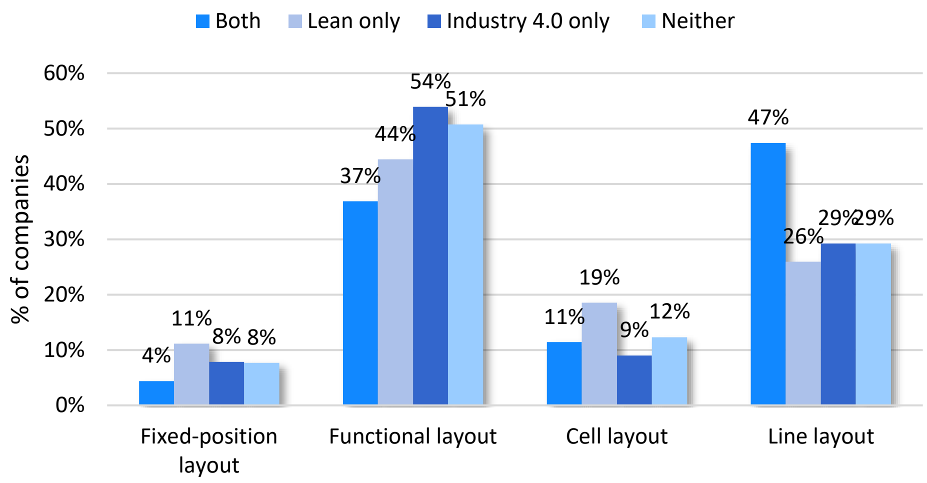
Source 45: Personal elboration.

Figure 45 shows that the four groups of companies have slightly different shares of turnover that come from different distribution channels. For example, companies that apply only Lean prefer to sell through distributors (41% of their revenues come from this distribution channel).

While all the other partitions of the sample have higher percentage of turnover gained from selling to other Industrial companies.

Layout adopted according to sample's categories

Figure 46: Layout adopted. $[n^b = 114;\ n^{Lo} = 27;\ n^{Io} = 89;\ n^n = 65]$



Source 46: Personal elaboration.

It is interesting to notice in *Figure 46* that companies that adopt both Lean and Industry 4.0 technologies prefer Line layout, with 47% of the companies that have reorganized their production processes according to this layout. In most of the cases, the most common layout is the functional one, while the cell layout is chosen more frequently (19% of the companies) by firms that adopt only Lean techniques.

Performance according to sample's categories[7]

Figure 47: Financial performance. $[n^b = 155;\ n^{Lo} = 27;\ n^{Io} = 90;\ n^n = 67]$

	Both	Lean only	Industry 4.0 only	Neither
*Equity multipier[8]	2,82	2,86	2,42	3,67
D/E ratio	1,86	1,29	1,13	1,93
Long-term debt	0,17	0,17	0,15	0,15
Short-term debt	0,83	0,83	0,85	0,85

Source 47: Personal elaboration.

[7] The data shown in this section are computed as the mean of the median values of the years from 2015 to 2017. The values of all the performance measures have been tested with ANOVA to see whether any statistical difference exists between the groups. The measures for which there is a significant difference between the groups have been indicated with a *.
[8] This leverage index is calculated as Total Assets/Total Equity.

The financial indexes in *Figure 47* give a picture of the level of debt used as a source of capital by the companies of the sample, and of their ability to repay their financial obligations.
The best results for the first three indexes are reported from the companies that Implement exclusively Industry 4.0's technologies. The lowest level of short-term debt instead, is recorded by the group of Lean companies that do not adopt advanced technologies and by the group of companies that implement both.

Figure 48: Profitability indicators. $[n^b = 155;\ n^{Lo} = 27;\ n^{Io} = 90;\ n^n = 67]$

	Both	Lean only	Industry 4.0 only	Neither
EBITDA margin	8,48	6,75	9,76	6,90
ROA	4,56	4,70	4,74	3,84
ROI	6,14	2,99	4,16	5,36
*ROS	4,36	3,67	5,41	3,48
ROE	8,37	6,98	8,00	6,87

Source 48: Personal elaboration.

Figure 48 sums up the most important profitability ratios of the companies interviewed. They assess the ability of these enterprises to generate earnings and value for shareholders. That companies that adopt Industry 4.0, but that are not Lean show the best results for EBITDA margin, ROA and ROS. Very good results for ROI and ROE are obtained from the companies that implement both Lean and Industry 4.0, suggesting that their combination can be a positive driver for profitability.

Figure 49: Operative performance indicators. $[n^b = 155;\ n^{Lo} = 27;\ n^{Io} = 90;\ n^n = 67]$

	Both	Lean only	Industry 4.0 only	Neither
Average days of inventory	51	65	42	42

Source 49: Personal elaboration.

The operative measure in *Figure 49* indicates the average period of time in days that goods and materials spend stocked as inventory. Unexpectedly, the highest value is recorded by companies that adopt only Lean, while the best groups are the one of companies that implement only future-oriented technologies and the one composed by the firms that are not Lean and do not have Industry 4.0 technologies.

Figure 50: Measures of productivity. $[n^b = 155;\ n^{Lo} = 27;\ n^{Io} = 90;\ n^n = 67]$

	Both	Lean only	Industry 4.0 only	Neither
Value added per employee	67.668	69.477	71.217	57.210
Revenues per employee	226.988	230.110	220.970	215.390

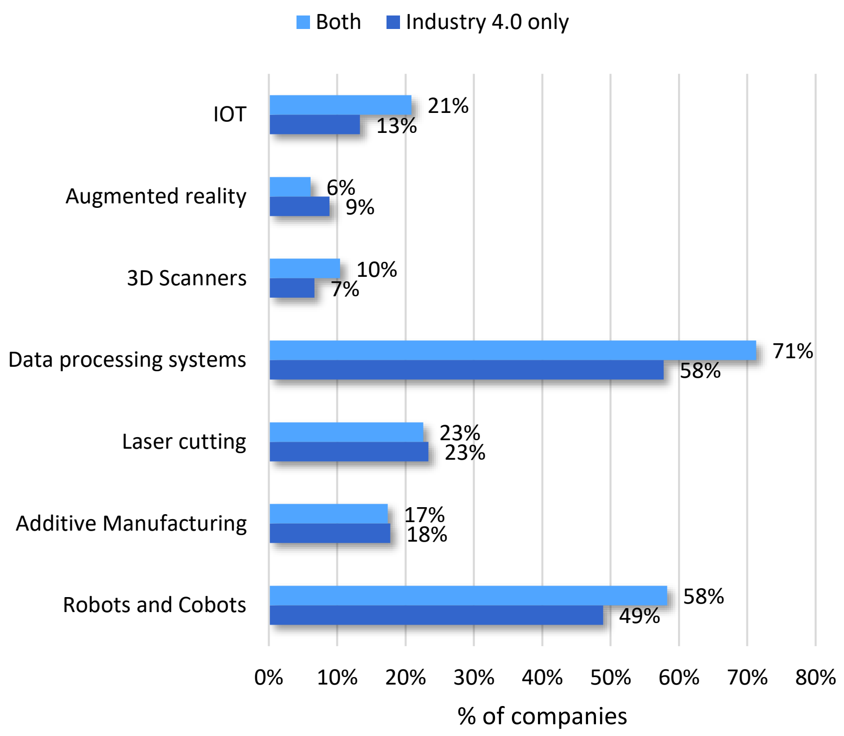
Source 50: Personal elaboration.

The measures of productivity presented in *Figure 50* assess the efficiency of companies and of their production process. Once again, the best result for the first measure (Value added per employee) is the one of the third group of companies, that implement only Industry 4.0's technologies. The companies that adopt only Lean practices, instead, are the ones that have the highest levels of revenues per employee.

3.6 Information from companies that adopt both Lean and Industry 4.0's technologies

Adoption of industry 4.0's technologies according to sample's categories

Figure 51: Industry 4.0 technologies adopted. $[n^b = 155;\ n^{Io} = 27]$

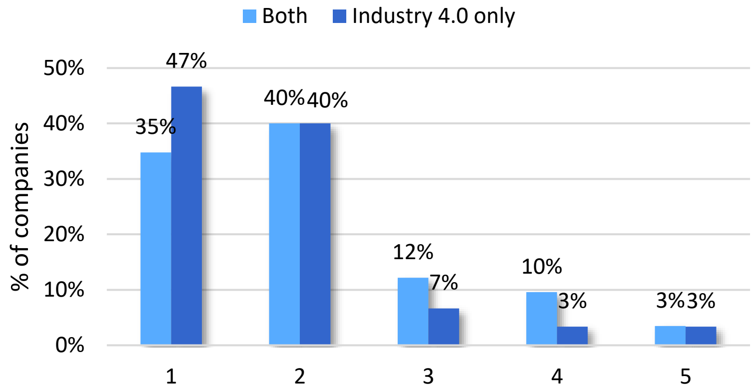


Source 51: Personal elaboration.

Figure 51 displays which technologies of Industry 4.0 have been adopted from the respondents. It seems that enterprises that adopt both Lean and Industry 4.0 implement in larger proportion

Data processing systems (71%), Robots (58%) and IoT technologies (21%), in comparison with companies that are not Lean.

Figure 52: Number of Industry 4.0 technologies adopted. $[n^b = 155;\ n^{Io} = 90]$

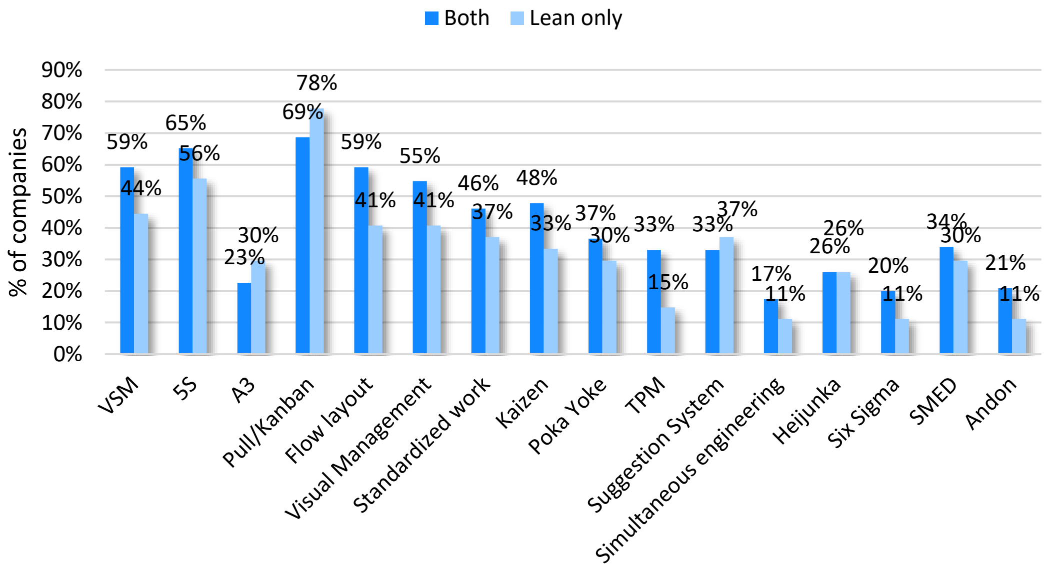


Source 52: Personal elaboration.

It is interesting to see how the number of Industry 4.0's technologies implemented changes if we consider the companies that implement only Industry 4.0, or if we look at the ones that have adopted also Lean practices. *Figure 52* suggests that in general all the companies adopt less than five advanced technologies, and most of them adopt one or two of them (75% of companies that implement both and 87% of enterprises that are not Lean). But it seems also that companies that implement sophisticated technologies and Lean together adopt a number of technologies higher than the group of companies that adopt only Industry 4.0. The average number of technologies per company for the first group (Both) is 2.1, while for the second group (Industry 4.0 only) is 1.8.

Adoption of Lean practices according to sample's categories

Figure 53: Lean practices adopted. $[n^b = 155;\ n^{Lo} = 27]$

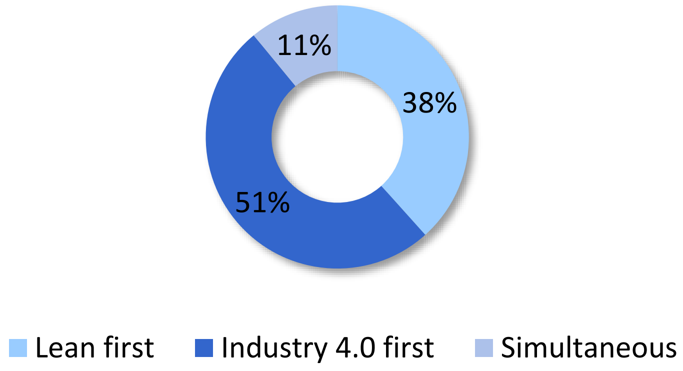


Source 53: Personal elaboration.

Figure 53 reveals that most of Lean practices listed are implemented by a higher percentage of companies within the group of the ones that adopt both Lean and Industry 4.0 technologies in comparison with companies that adopt only Lean. This logic is inverted only for the adoption of Suggestion systems, Pull/Kanban and A3.

Order in which Lean and Industry 4.0 are adopted

Figure 54: Companies that implement first Lean, Industry 4.0 or both simultaneously. $[n = 73]$



Source 54: Personal elaboration.

There is not a clear rule on which should be the first step to move, whether to implement Lean first and then automate the processes with Industry 4.0 technologies or to equip companies with future-oriented technologies first. Albeit from an historic perspective Lean came first, and the most advanced technologies have been developed only recently, each year thousands of new companies are established, and very different paths of growth are designed for each of them. In the sample being examined, most of the companies (51%) that adopt both Lean and Industry 4.0 have implemented Industry 4.0 technologies first (*Figure 47*). Lean instead is implemented first by 38% of the respondents and only 11% of the companies have started the simultaneous implementation of the two.

Figure 55: Profitability indicators. $[n^{Lf} = 28;\ n^{If} = 37;\ n^{S} = 8]$[9]

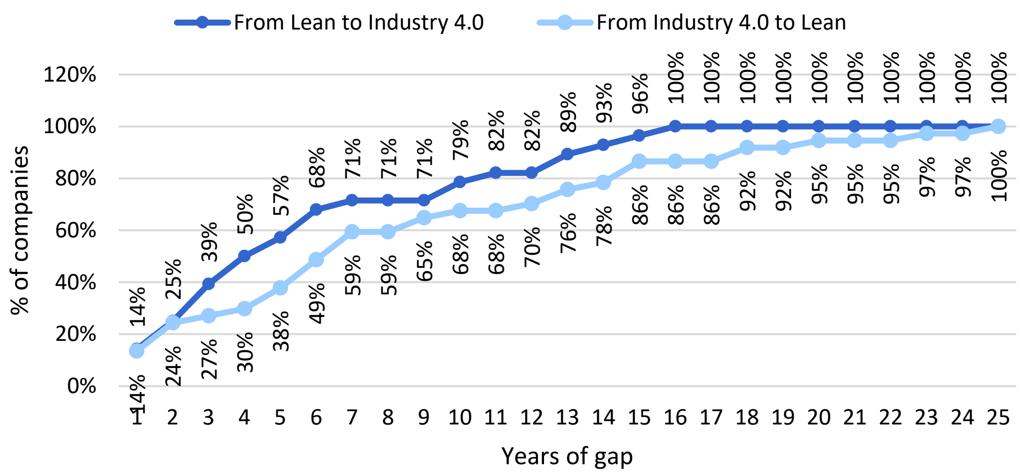
	Lean first	Industry 4.0 first	Simultaneous
EBITDA margin	8,17	9,25	5,94
ROA	4,33	4,37	3,00
ROI	6,32	6,58	1,99
ROS	4,35	4,03	2,61
ROE	6,99	7,10	7,84

Source 55: Personal elaboration.

[9] n^{Lf} is referred to the number of firms that implement first Lean and then Industry 4.0
n^{If} is referred to the number of firms that implement first Industry 4.0 and then Lean
n^{Lf} is referred to the number of firms that implement Lean and Industry 4.0 Simultaneously

The profitability indicators in *Figure 56* show that the companies that implement Industry 4.0 first are the ones that have higher EBITDA margin, ROA and ROI. The best ROS is the one of the companies that implement Lean first, while the enterprises that implement both simultaneously have the highest ROE.

Figure 56: Cumulative years of gap between implementations. [$n^{Lf} = 28$; $n^{If} = 37$]



Source 56: Personal elaboration.

An analysis of the time elapsed between the adoption of Lean and Industry 4.0 in the companies of the sample (*Figure 55*) shows that the transition from Lean to Industry 4.0 is quicker than the opposite shift. From the cumulative representation it is possible to see that after 16 years from the adoption of Lean practices, all the companies have already implemented Industry 4.0 technologies. The companies that started from an investment in new technologies, instead, took 25 years to complete their passage to Lean. This can imply that Lean prepares the basis for a faster and more efficient implementation of Industry 4.0 technologies, while the opposite journey can be harder and may take more time.

CHAPTER 4

4.1 Purpose

The purpose of this work, and in particular of the analysis that is proposed in this chapter, is to determine whether there are some combinations of Lean practices and Industry 4.0's technologies that can assure an outstanding performance to companies that adopt them. Such results can be a great stimulus for companies' investments on new technologies and a further good reason to embrace a Lean transformation. Moreover, there is a lack of researches that empirically study the relationship between a successful lean implementation and the adoption of Industry 4.0 in manufacturing companies (Tortorella and Fettermann, 2018). To achieve this purpose, it will be used a Qualitative Comparative Analysis or QCA. This kind of analysis has been used in the past to study different aspects related to Lean management and the introduction of Industry 4.0 technologies, separately.

Some examples of QCA studies related to Lean are Galeazzo and Furlan (2018), that examine the presence of different configurations of Lean bundles able to ensure a successful financial performance to companies. The Authors find that Lean bundles always need to be complemented with other lean bundles, since none of them can explain the good financial performance of firms alone. Hallavo *et al.* (2018) study Lean in a longitudinal context, through the use of QCAs over time. They prove that the holistic application of Lean bundles is effective, and this success is also related to aspects such as the status, ownership and phase of the business cycle in which companies are. Moreover, the Authors encourages researchers to use more QCA in their studies, suggesting it especially with small samples. Examples of the use of QCA to investigate Industry 4.0 technologies include Moors and Rogiest (2018), that focus on the deployment of Big Data analytics. In particular they concentrate on aspects like leadership, culture and decision making that combined together can guarantee a successful implementation of the technology and an increase firms' efficiency and reliability. Jenson *et al.* (2016) test innovation systems in general, through the use of a QCA. Innovation systems try to identify the necessary environments and interactions for achieving a meaningful innovation. The QCA approach is proved to be useful also to construct theories of innovation, as well as for testing them. There is not an ample literature about the use of Qualitative Comparative Analysis to study the joint implementation of Lean and Industry 4.0. For this reason, this work offers a new approach to understand the logic behind the successful integration of Lean and future oriented technologies. An important decision to take, is also which performance indicators to use to judge the impact of Lean bundles and Industry 4.0's technologies.

While within the Lean framework, past researches have confirmed the positive impact of the Japanese practices on operational performance (Galeazzo and Furlan, 2018), the study of financial ratios have led to mixed findings. While some Authors have reported a positive impact of operational innovations such as Lean and Industry 4.0 technologies on financial performance, others have found no relationships at all (Klingenberg *et al.*, 2013). Klingenberg and Geurts (2009) partially explain these contrasting results stating that JIT does not affect profitability directly, but it reduces inventories, decreasing the costs of carrying them. The problem is the scarce ability of the traditional financial ratios to accurately measure inventory costs. They conclude that "the "pure" inventory financial ratios are useful in the analysis of JIT, since the profitability ratios can be influenced by other factors, unrelated to the impact of JIT on the firms' operations." (Klingenberg and Geurts, 2009, p.429).
In some of the studies of the impact of IT innovation on business performance, there are contrasting results. Some of them state that new technologies have a positive impact on business performance (Kim and Choi, 2018), while others deny their ability to increase financial growth. This work tries to study the impacts of the joint implementation of some groups of Lean practices and Industry 4.0's technologies on two of the most important profitability indicators: EBITDA margin and ROA. The first measure represents the operating profits of the companies in percentage of sales and allow for a comparison with the other companies in the same industry. The second gives an idea of how much a company is efficient in the use of its assets and in producing earnings. This measure too is recommended for comparisons with the performance of other companies or to monitor a firm's Return on Assets over time.

4.2 Qualitative Comparative Analysis (QCA)

The Qualitative Comparative Analysis (QCA) is a technique of qualitative, holistic comparison developed by Ragin (1987). It is a technique to analyse dichotomous social data and determine which logical conclusions are supported by a data set thanks to the use of the Boolean algebra. QCA can be applied to the study of few cases or hundreds, indistinctly. It was initially designed for social and political sciences' studies, but now it is applied in many more fields such as business, entrepreneurship, innovation management among others.
The Author, stepping back from traditional statistic approaches, tried to mix different aspects of qualitative and quantitative social science methods, giving a meaningful contribution to the field of comparative social research (Vancea, 2007). Ragins' (1987) qualitative comparative method is case-oriented (as opposed to variable-oriented) and historical (as opposed to abstractly causal), meaning that it is influenced by complexity and historical specificity and is suited to study well-defined actual outcomes and generate new schemes from them, rather than

being abstractly causal and vague. QCA preserves some other positive features of case-oriented techniques such as their characteristic of being holistic, that is they consider cases as whole entities and not as a collection of variables (Ragin, 1987). In addition, the QCA tries to overcome the main drawbacks of both case-oriented and variable-oriented quantitative approaches. The first ones usually, can be applied only to a limited range of cases, while the second ones instead, entail the acceptance of important simplifying assumptions.

The advantages of QCA over traditional methods, recognized by Galeazzo and Furlan (2018) are three:

1. Conjunctural causation: the causes are not viewed and studied as isolated, but always together with the other attributes, because sometimes the outcome stems only from the combination of them.
2. Equifinality: alternative configurations of attributes can lead to the same outcome. This is opposed to the traditional concept of Unifinality that tries to discover the only combination of causes that can produce the outcome.
3. Asymmetrical relations: proving that a combination of causal conditions entails a certain outcome, is not equivalent to state that the absence of that outcome is justified by the lack of that conditions.

The simplest version of the QCA is also referred to as Crisp-Set QCA (csQCA) and will be further explained in the next sections and used for the analysis of the database. It exists also an advanced version of this technique that is the Fuzzy-Set QCA (fsQCA), later developed from Ragin in 2008. The main difference between these two is that the data of the fsQCA are no more dichotomous. The cases are associated with a score of membership to the set of attributes that ranges in the interval between 0 and 1. This allows for a more nuanced analysis and helps to obtain richer results.

4.2.1 Basic concepts

Boolean algebra is at the basis of the QCA and is the algebra of logic and of sets. Some of the aspects of Boolean algebra, although quite simple, are fundamental (Ragin, 2007) for the analysis. One of these is that data, as already mentioned, must be binary. They typically represent the presence (1) or absence (0) of a certain condition, under which an outcome is obtained. Together with the causal conditions, also the outcome must be binary.

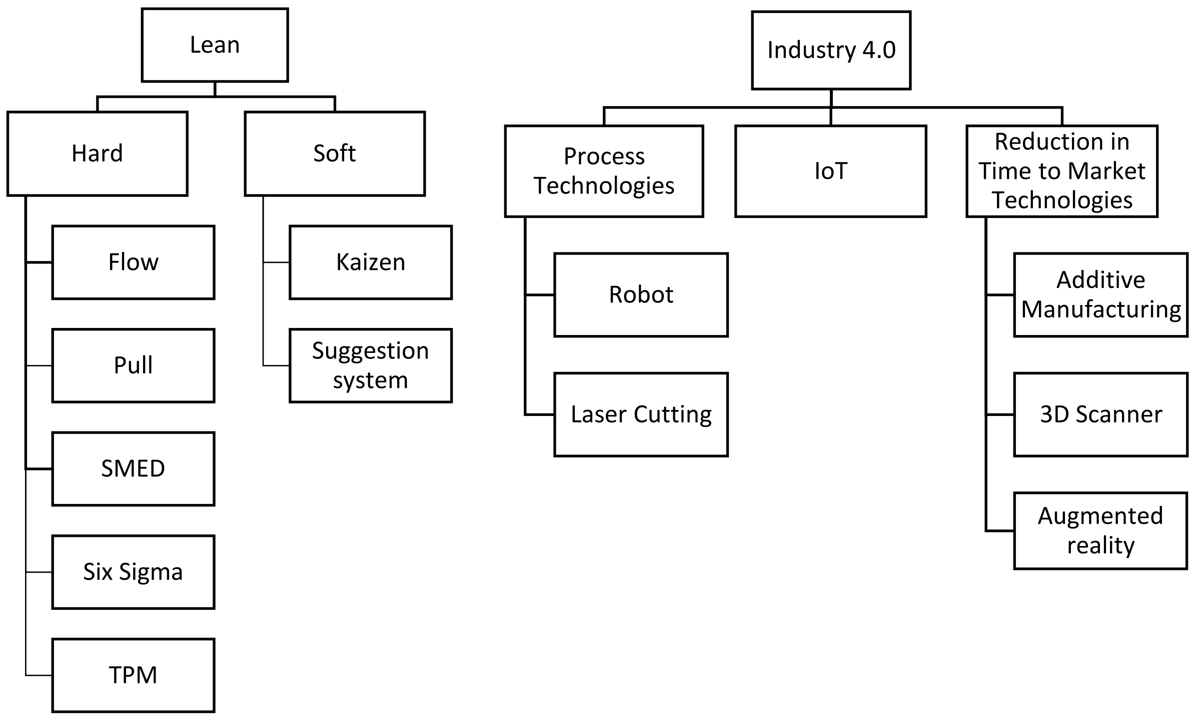
To typical representation used by the QCA to display evidences is the Truth table. This is a matrix that sorts data according to all the possible combinations of values of the causal conditions. Each one of these combinations is reported as one row of the table. Moreover, for each row it is assigned a value for the outcome, according to the output suggested from the cases in the database that have that specific combination of attributes. The result is a series of rows that do not represent a single case, but all the cases that share the same combination of input values.

In order to minimize the number of rows and simplify and make more readable the table, there are straightforward rules to follow. For example, if two rows differ in only one causal condition but still share the same outcome, then that distinguishing causal condition can be considered irrelevant. Once it is removed a simpler, combined expression is created. This logic is applied until no further reduction of expressions or number of rows is possible. Moreover, the frequency associated to each row, that means, the number of cases that present that combination in the sample, can be set, in order to take into consideration only the sequences that are most common. For example, for the sake of the analysis conducted in this chapter, the minimum level of frequency required for each row is 2.

4.2.2 Bundles' composition

To conduct this Qualitative Comparative Analysis, it will be necessary to choose some variables as causal conditions in order to test their contribution to the final outcome. In particular two bundles of Lean practices and three combinations of technologies will be tested as conditions for the outcome to be true.

Figure 57: Bundles' composition.



Source 57: Personal elaboration.

Figure 57 shows the composition of these bundles. To study Lean techniques, it has been adopted the division of practices proposed by Bortolotti *et al.* (2015). As already explained in chapter three, the Authors group Hard practices and Soft ones. The first ones are a group of technical and analytical tools, whereas in the second cluster, there are practices that concern more people and relations. Among the practices inspected with the survey, five (Flow, Pull, SMED, Six Sigma and TPM) correspond to the Hard ones of Bortolotti *et al.* (2015), while two can be associated with the features of Soft practices (Kaizen and Suggestion System).

According to the number of Hard and Soft practices adopted from companies, a membership or non-membership label has been assigned to firms, for these bundles. In particular, for Hard practices, it has been set a cut-off level of three, meaning that, if companies have zero, one or two Hard practices, still they have a non-membership score of 0, while if they implement three, four or all five practices, they gain a membership score of 1 for that bundle. For Soft practices a similar reasoning has been applied, so that companies that adopt at least one, or at maximum two practices, have a membership score equal to 1 and 0 otherwise. The choice of the bundles and conditions for Industry 4.0 follows Tortorella and Fettermann's study (2018) on Brazilian firms. The Authors divide the technologies of Industry 4.0 in three groups. The first one, named Process Technologies (PT), contains all the technologies strictly related to production operations, like Robots and Laser cutting. The second attribute is not a bundle, but a single condition, and is represented by IoT. This technology can be associated both to production processes and products. The third cluster gathers the technologies able to produce a Reduction in Time to Market (TTM), such as Additive Manufacturing, 3d Scanners and Augmented reality. As long as a company adopts one specific technology, it gains a membership score of 1 for that specific attribute, otherwise a 0.

4.2.3 Database preparation

The database analysed is only a portion of the initial one. In particular, it contains the data of 114 companies that implement both Lean practices and Industry 4.0 technologies. One company has been removed because it was not possible to retrieve its economic and financial data from AIDA. As already explained, the information regarding the implementation of Lean techniques and Industry 4.0's technologies (here causal conditions) has been codified on a binary basis. The outcome variables' binary codification has required a comparison with the ROA and EBITDA margin of all the companies within the same ATECO sector at the national level. The data about all the Italian enterprises have been downloaded from AIDA database.

The values of the performance indicators for each single company of the database have been computed averaging the ROA's values for the years 2015, 2016 and 2017. For example, to obtain the ROA's value for company i:

$$ROA_i = \frac{ROA_{2015} + ROA_{2016} + ROA_{2017}}{3}.$$

On the other hand, it has been computed a benchmark value for the same performance indicators for each of the twenty-one 2-digit ATECO sectors involved in the survey. For each year from 2015 to 2017, it has been identified the median value among the companies of that sector, and in the end, these tree values have been averaged. For example, to obtain the ROA of the ATECO sector j:

$$ROA_{ATECO_j} = \frac{Median\ ROA_{2015} + Median\ ROA_{2016} + Median\ ROA_{2017}}{3}.$$

Subsequently for each company i, its performance indicators computed as in the first formula, have been compared with the ones of the ATECO sector to which it belongs, that are computed as in the second formula. If the performance indicator of the company is higher than the average value of the sector, the outcome of that company is associated with a 1 (successful performance), otherwise a 0. This indicates whether that enterprise has a performance that is higher or lower than the one of its competitors.

4.2.4 Data analysis

The analysis will be conducted using the fsQCA 3.0 software. The software reorganizes the data of the database according to Boolean logic and Truth table's simplification mechanisms and proposes three kinds of final results (Complex, Intermediate and Parsimonious solutions). The difference among the solutions automatically proposed relies in the different use of Counterfactual analysis. Counterfactual analysis becomes useful when the sample size is not very large and when the phenomenon that is under analysis occurs with a limited range of cases, showing a limited diversity. One way to substitute absent combinations is through the imagination of counterfactual cases and the reconstruction of their hypothetical outcomes through theoretical and substantive knowledge (Ragin, 2007). Thanks to the Truth tables and the logic behind their construction and reduction, QCA makes this process of taking into account counterfactual cases explicit and systematic. Counterfactuals are of two types: Easy or Difficult. Easy counterfactuals are created thanks to theoretical bases and past knowledge that help to predict outcomes. Difficult counterfactuals, instead, do not use any theory to assign an outcome to the combinations of causal variables. Now it is possible to understand that the solutions proposed by the fsQCA software are:

- Complex, if they do not use counterfactuals at all.

- Parsimonious, if they use both Easy and Difficult counterfactuals. They represent the simpler solution, without any evaluation of its plausibility (Muñoz, 2015).
- Intermediate, if they use only Easy counterfactuals.

The suggested solutions on which to focus are the Intermediate and Parsimonious (Galeazzo and Furlan, 2018). They provide Core and Peripheral causal conditions for the output.

- Core conditions (present in both parsimonious and intermediate solutions) are fundamental for the outcome to be true, that means that they show a strong causal relationship with it.
- Peripheral conditions (present only in the intermediate solution), instead, are also known as "contributing" because they are not essential for the outcome, but just help in supporting it.

To evaluate these solutions, it is important to introduce the concepts of Consistency and Coverage. The fsQCA software returns the values of these two parameters both for all the configurations considered together and for each configuration taken individually.

- Consistency can be defined as the "degree to which instances of an outcome agree in displaying the causal condition" (Ragin, 2008, p. 44). In other words, it represents the share of instances characterised by that set of conditions that show also the outcome in question. It is estimated as a ratio between the number of cases present in a determined configuration that exhibit the outcome, and the number of cases of the same configuration that do not show the outcome (Muñoz, 2015).
- Coverage "assesses the empirical relevance of the configuration associated with the outcome" (Galeazzo and Furlan, 2018), that means that keeps into consideration the degree to which a combination accounts for instances of an outcome.

  If there are multiple configurations sufficient for the outcome, two different measures help in assessing their empirical relevance. They are Raw coverage and Unique coverage. Raw coverage explains how much these different configurations overlap, while the Unique coverage highlights the relative contribution of each singular configuration to the shared outcome.

To conclude, it is fundamental to discern the search for Necessary and Sufficient conditions.

- Necessary conditions are the ones that must be present for the outcome to occur.
- Sufficient conditions. A condition can be defined Sufficient "if by itself it can produce a certain outcome" (Ragin, 1987, p.99).

Looking at Sufficient and Necessary conditions together, it is possible to combine them and have a condition that is both Necessary and Sufficient, if it is the only and singular one to produce an outcome; Sufficient, but not Necessary, if it can produce the outcome, but it is not the only one that has this ability; Necessary but not Sufficient if it can produce the outcome only in combination with other causes, but is present in all such combinations; or finally, neither Sufficient nor Necessary, if it only appears in some of the combinations that cause the outcome (Ragin, 2017). In this work, first of all, single conditions have been analysed for Necessity: if any of them has a consistency level higher than 0.9 (used also in Galeazzo *et al.*, 2018), than it has been considered as Necessary for the outcome. Then Sufficient conditions and their combinations have been searched.

4.3 Results

As suggested by Ragin (2017), first off all, each single condition or combination (the bundles of Lean techniques and Industry 4.0's technologies) has been tested for Necessity. None of the conditions has resulted as Necessary, that means that their consistency levels are lower than 0.9. In particular, their values range between 0.24 and 0.68. This means that the financial success of firms is not necessarily caused by the Lean practices or Industry 4.0's technologies indicated in the bundles, and that there are firms that perform better than the others within their sector, even without implementing them. Albeit there are not Necessary conditions, the analysis has highlighted the presence of Sufficient combinations of conditions.

Figure 58: Results of the QCA for Sufficiency.

	High ROA			High EBITDA Margin		
Configuration	C1	C2	C3	C4	C5	C6
HARD	●	●	⊗	●		⊗
SOFT	•	•		•	●	
PT	⊗		•		⊗	●
IoT	⊗	⊗	●	⊗	⊗	●
TTM		●	⊗	●	●	
Consistency	1	1	1	1	0.83	1
Raw coverage	0.06	0.05	0.08	0.04	0.07	0.10
Unique Coverage	0.05	0.03	0.08	0.03	0.06	0.10
Overall solution consistency		1			0.93	
Overall solution coverage		0.17			0.19	

Source 58: Personal elaboration.

The results of the QCA for Sufficiency are reported in *Figure 58*, according to the most common notation used in the literature. The figure should be read in the following way: the causal conditions are reported in the rows. The columns, instead, represent the different combinations of practices and technologies that lead to the outcome of interest. The black dots represent the presence of the condition within the combination, while the white dots with a cross, represent the absence of that condition from the combination. If there is neither a black, nor a white dot, it means that that condition is indifferent to the outcome, its presence or absence is not symptomatic for the outcome to be true. Moreover, big dots reproduce Core conditions, while smaller dots stand for Peripheral ones. The last rows include the values of Consistency, Row coverage ad Unique coverage for each single configuration and the overall solution's consistency and coverage.

The results show six configurations, of which, three are associated with ROA levels higher than the benchmark computed for the companies of the same sector of economic activity as described above. The three remaining configurations play the same role for high EBITDA margins. The fact that there are several conditions inducing successful financial performance (ROA and EBITDA margins higher than the benchmark of the whole sector) confirms that QCA results introduce Equifinality.

The first configuration (C1) is characterized by the required presence of Lean bundles and by the absence of both Process Technologies and IoT, while the presence or absence of TTM technologies is indifferent. Going into further details, Hard practices are Core to the outcome, meaning that they are essential conditions for high profitability, while Soft practices are Peripheral and just support it. The second configuration (C2) is equal to the fourth one (C4). It is meaningful to note that this combination of causal conditions predicts High ROA and High EBITDA margin equally. The Configuration of Lean practices is the same of C1, but in C2 (and C4) they are implemented together with the technologies to reduce Time to Market, that are Core conditions, but without IoT. Process technologies can be present or not, without affecting the outcome.

The third configuration (C3) insists instead on the implementation of Industry 4.0's technologies alone, in particular it is characterized by the presence of IoT as a Core condition and of Process Technologies as a Peripheral condition that supports the outcome. TTM technologies, instead are absent in C3 as well as Hard Lean practices. The right mix of process technologies and technologies applied to products, like IoT can produce a positive financial performance.

The fifth configuration (C5) contains a combination of Lean and advanced technologies. We see again Soft practices, but this time as a Core condition, together with TTM technologies and the absence of both PT and IoT.

C6 resembles C3, but this time Process technologies are Core, together with IoT. The absence of Hard Lean practices is still required.

4.3.1 Discussion

Overall, these six configurations present a rich set of combinations that elicit successful financial performance. There are configurations associated with a positive outcome that are composed only of Lean practices (C1), only of Industry 4.0 technologies (C3, C6) or a mix of the two (C2, C4 and C5). This suggests that there is not one way to obtain a good financial performance, and that it is not the implementation of Lean, Industry 4.0 or of their combination that assures to companies a competitive advantage. Despite this, some common patterns can be recognized in the solutions proposed.

The key finding that is possible to welcome from this analysis, is that companies that have reorganized their processes and supply chains following Lean principles and that adopt Lean practices also for the management and involvement of Human resources in the improvement processes must not use Process technologies and IoT in order to have a successful financial performance. It seems at least unnecessary to automate processes that have been already streamlined and simplified. To support this finding, the results prove also the contrary: that companies that have implemented Process Technologies and IoT must not implement Hard Lean techniques to have high ROA and EBITDA margin and are indifferent to Soft practices. The results obtained from the database analysed run counter to that trend of literature, described in chapter two, that suggests the implementation of Industry 4.0 subsequent to Lean rationalization of the processes (Kolberg and Zühlkeet, 2015), (Wang *et al.*, 2016), (Nicoletti, 2013), (Mayr *et al.*, 2018).

To go into further detail, it is possible to group the six configurations proposed from the solutions in three broader groups. Each of them represents a possible approach that companies can choose to obtain a high profitability, it provides suggestions for the implementation of Lean practices, of Industry 4.0's technologies and gives some rules to follow for their effective integration. The first one will be referred to as the "Lean approach" and contains C1. Configuration one, indeed, suggests the adoption of Lean practices without the implementation of Industry 4.0's technologies such as PT and IoT. On one hand, this Lean approach underlines the efficiency of Lean processes that do not need to be supported by advanced Process Technologies or IoT to bring a positive impact on profitability. On the other hand, this first approach helps in realizing that technical and analytical Lean tools (Hard practices) still play a fundamental role for companies. They are necessary for enterprises that want to outperform competitors with this first approach and are really effective only if accompanied by softer techniques that focus on the involvement of employees in improvement processes to stimulate their commitment. The importance of this set of practices related to the management of Human Resources is recognized also by Furlan *et al.* (2011), that admit that their role is to "shape the organizational environment in which the basic techniques are implemented” (Furlan *et al.*, 2011, p. 837). More in general, Lean literature recognizes Soft practices as able to prepare the ground for the future implementation of Hard practices such as JIT and TQM.

The second group, that is named “Smart manufacturing approach” is the opposite of the Lean one and consists of C3 and C6. In these similar configurations, Process Technologies and Internet of Things are the most important technologies and need to be implemented without Hard Lean practices. One possible explanation for these configurations that distance themselves from part of the literature is that not all the businesses are suitable for Lean implementation. This could be the case of Process manufacturing companies and Processing industries, where it seems more difficult to adopt Lean practices, partly because their operations are completely different from traditional manufacturing and assembly processes and partly because the goods, by their nature, flow continuously in the shop floor (King, 2017). Examples of process manufacturing goods include refined oil, gasoline, food, beverages, pharmaceuticals, chemicals, plastics, metals, paper and paper pulp. Within the sample analysed, indeed, there is a reasonable concentration of companies manufacturing basic metals, paper, rubber, food, pharmaceutical and chemical products.

King (2017) points out which are the main differences of Processing industries with regards to traditional manufacturing ones. First of all, the machines used for Process manufacturing companies, at each stage of production, are larger and far more expensive than the traditional ones. They have a great impact on throughput and performance and prevent the implementation of common engineering and Lean practices, like the use of small machines for simultaneous processing. Secondly, the difference that seems more relevant to the Author is the degree of differentiation that increases as the material flows along the processes. Processing industries, indeed, start with few raw materials from which hundreds of different goods are produced. On the contrary, manufacturing processes at their very first stages assemble thousands of components that result in fewer final products. This difference has a deep impact on the dynamic of the flow and requires Lean practices to be redesigned before they can be implemented in these contexts. These companies, by the way, can benefit from the use of Industry 4.0 technologies. Within Process industries, great results have been reached for example, with the development of monitoring systems for the performance of the plants, based on advanced technologies such as sensors and communication technologies, that create an interrelated network of machines (Scali et al., 2017).

The third and last approach is the “Lean and Smart Product Development approach”, that can be recognized in C2, C4 and C5. It suggests that Lean practices get on well with technologies that reduce the Time to Market and are dedicated to the development of new products, like

Additive Manufacturing, 3D scanners and Augmented Reality. One of the principal goals of Lean manufacturing, indeed, together with the minimization of waste, human effort, space for manufacturing operations and investments, is the reduction of engineering time to develop new products (Modi and Thakkar, 2014). TTM technologies can help in the systemization of this effort. Product development aims to "integrate engineering and industrial design requirements through a structured process that allows the achievement of lower cost, higher quality, and shorter development time" (Nunes *et al.*, 2017, p. 1219). Rauch *et al.* (2016) with their work confirm that "Lean Product Development and an Industry 4.0 oriented Smart Product Development are not contrarily but go hand in hand" (Rauch et al., 2016, p. 31). The Authors describe Lean Product Development as the introduction of principles and methods of Lean management in product development to reduce the increased complexity brought by global competition and customers' requirements and decrease lead-time in such activities. They also welcome the new opportunities that are brought by modern technologies related to the fourth industrial revolution and encourage product development to leave traditional methods and embrace the development of smart and intelligent solutions through Industry 4.0's technologies. Given that each of these three approaches bring high profitability in terms of EBITDA margin or ROA, each company should select carefully which configuration to use and whether to invest only on a Lean transformation, on the new advanced process technologies of Industry 4.0 or on the right mix of Lean and technologies for the development of products. This choice is a strategic one for firms, that should be made taking into consideration business' characteristics, needs and considering the companies' long-term objectives.

CONCLUSIONS

Lean management is the Japanese approach widely used among several industries, that has been studied for decades by now. The five principles provide guidance at the strategic level, presenting the ideals to follow for Lean thinking companies. The practices, instead, are the elements that operationalise these principles. Its beneficial effects such as the reduction of waste, the improvement of productivity and quality are well known and accepted both from practitioners and scholars. In essence, Lean introduces “a low-tech approach that excels for simplicity and effectiveness usually aligned with a shared business vision.” (Tortorella and Fettermann, 2018, p. 2975).

Industry 4.0 is a popular term recently used to describe the trend towards automation and digitisation of the manufacturing operations of companies. It can be well represented by its main four components, Internet of Things, Cyber Physical Systems, Smart Factory and Internet of Services. Industry 4.0 comprises a variety of technologies that pursue the improvement in product quality, the decrease in Time to Market and a positive impact on enterprise’s performance (Oesterreich and Teuteberg, 2016).

The union between Lean and Industry 4.0 concepts is a bet that an increasing number of companies are taking, encouraged by the first successful results obtained from their conjoint implementation. The integration of the Japanese practices with the new advanced technologies of Industry 4.0 allows enterprises to overcome some of the obstacles and barriers experienced and adds new challenges for their further and successful combination. On one hand, Lean principles and techniques are seen as a prerequisite for the technologies of Industry 4.0 used especially in production (Von Haartman, 2016). On the other hand, Industry 4.0’s applications help Lean manufacturing activities to realize more efficient and higher quality production systems (Tortorella and Fettermann, 2018). The literature on the integration of Lean and Industry 4.0 is still scarce, but in most of the cases indicates a positive effect for their association.

This is the context in which the empirical study proposed by this work has been developed. The sample analysed is composed of 454 Italian manufacturing firms and has been created through the survey on Lean management and on the introduction of Industry 4.0’s technologies proposed by the University of Padua in collaboration with CUOA Business School. The answers, collected in a database, have been analysed and presented, first of all, with the simple aim of describing the sample’s composition.

The enterprises, that have an average age of 32 years, belong to twenty-one selected sectors of economic activities. At least 80% of the firms of the sample can be classified as SMEs according to the European Commission’s requirements, while 70% of them are Family businesses. The most profitable Manufacturing approach used is the Design to order, that is in line with the high levels of customization required from customers. Nonetheless, 54% of the companies are involved in B2B commerce, selling to other industrial firms. The most common layout among enterprises is still the Functional one, even if Line layout is adopted from slightly less companies.

Industry 4.0 has reached 69% of the respondents to the survey, confirming its leading role in the future of manufacturing. The technologies of Industry 4.0 most implemented are Data processing systems, common in 65% of the companies and Robotics, used by 54% of them. According to their median year of adoption, Robots and Cobots are also the oldest technologies, whereas Augmented reality is the most recently introduced within companies.

Almost half of the firms (49%) in the sample implement Lean management. Lean principles have reached Italy years after their development in Japan, and this is reflected by the median year of their adoption among companies that is 2013. The most common practices, are 5S and Pull logic, often obtained through Kanban systems. The promoters of Lean transformations are usually CEOs and Directors, whereas the people that participate more actively in the process are First line Managers and Operators. Moreover, most of the companies

have both internal employees in charge exclusively of Lean projects and also engage external consultants. The importance of training and developing employees’ capabilities in Lean companies is confirmed from the widespread recourse to masters, courses and workshops.

A breakdown of the sample reveals that an integration of Lean and Industry 4.0’s technologies is attempted by 38% of the companies, while there are more companies that implement Industry 4.0’s technologies, but are not Lean (30%), rather than the other way around (9%). Only 22% of firms do not implement neither Lean nor the technologies of the fourth industrial revolution. The core analysis of this work has been performed on the 114 Lean and Smart enterprises composing the first group of the sample.

The main purpose of the Qualitative Comparative Analysis conducted was to discover whether there are some configurations of Lean bundles and of Industry 4.0’s technologies that elicit successful financial performance. The QCA is a technique of qualitative, holistic comparison developed by Ragin (1987), originally designed for social sciences, that uses the logic of the Boolean algebra to create and simplify the Truth Tables and propose a set of configurations as solutions. Two bundles of Lean practices (Hard and Soft practices) and three clusters of Industry 4.0’s technologies (Process Technologies, IoT and Technologies for the reduction of Time to Market) have been selected as causal conditions while the outcomes chosen to represent firm’s performance are ROA and EBITDA margin.

The analysis has found no Necessary causal condition to the outcome. The results for Sufficiency propose instead six configurations of attributes that equally lead to a successful performance, three of which cause high ROA levels, while the remaining three impact positively EBITDA margins.

It is possible to arrange these configurations in three groups. Each of them represents a possible approach that companies can choose to obtain a high profitability. The "Lean approach" (C1), suggests the implementation of both Hard and Soft Lean practices, and not to invest on Process technologies and IoT. From the results seems that streamlined processes are sufficient to obtain a good profitability and do not need to be automatized. Contrary to expectations, according to the sample analyzed, Lean practices do not pave the way to the implementation of Industry 4.0's technologies. This holds true for the "Smart Manufacturing approach" (C3, C6) that, unlike the first one, proposes the adoption of both Process technologies and IoT, but without implementing Lean practices, in particular the Hard ones. This runs counter to that part of literature that suggests the introduction of Industry 4.0 subsequent to a Lean rationalization of the processes (Kolberg and Zühlkeet, 2015), (Wang *et al.*, 2016), (Nicoletti, 2013), (Mayr *et al.*, 2018). A possible explanation can be that many of the companies in the sample are Process manufacturing, where it seems more difficult to adopt Lean practices, partly because their operations are completely different from traditional manufacturing and assembly processes and partly because the goods, by their nature, flow continuously in the shop floor (King, 2017). On the contrary, they can benefit from the introduction of smart manufacturing solutions like sensors and communication technologies (Scali et al., 2017). The third and last approach is the "Lean and Smart Product Development approach" (C2, C4, C5) that proposes a mixed adoption of Lean practices and of the Technologies that reduce the Time to Market. The decrease of engineering time to develop new products is one of Lean's objectives (Modi and Thakkar, 2014) and can be pursued and obtained thanks to a systematic adoption of technologies like Additive Manufacturing, 3D printing and Augmented Reality.

The main takeaway from this work is that companies can decide how to shape the path to achieve their long-term objectives, but there are rules that must be followed if they want to implement Lean and Industry 4.0's technologies, with combinations of practices and technologies that get on well, and others that should never be implemented together to have a successful performance.

To conclude, the empirical analysis on the combined implementation of Lean management and Industry 4.0's technologies presented in this work entails some limitations that further researchers can overcome. For example, in the selection of the bundles to use as causal conditions, not all the Lean practices and Industry 4.0's technologies that companies have declared to implement have been taken into consideration. They have been selected according to past literature, but it is possible that different compositions of the clusters can explain other aspects of companies' profitability and financial performance. Moreover, measures different from ROA and EBITDA margin can be chosen to judge firms' performance. Additionally, the use of a fuzzy-set QCA instead of a crisp-set one, can lead to a more nuanced analysis and can help to obtain richer results.

BIBLIOGRAPHICAL REFERENCES

Books

ANDERSON, C., 2012. *Makers: The New Industrial Revolution*. United States: Crown Publishing Group.

BICHENO, J., HOLWEG, M., 2016. *The Lean Toolbox. A handbook for lean transformation.* Fifth Edition. Bukingham England: Picsie Books.

FORD, H., 1926. *Today and Tomorrow*. Garden City, N.Y.: Doubleday, Page & Company.

FURLAN, A., edited by, 2018. *Allineamento per il successo*. Milano: Guerini Next

KING, P.L., 2017. *Lean thinking per le aziende di processo,* Milano: Ulrico Hoepli Editore.

KOTLER, P., KELLER, K., 2011. *Marketing management*, 14th edn. NJ: Upper Saddle River, Pearson Education.

KRISHNAN, K., 2013. *Data Warehousing in the Age of Big Data*. Burlington, MA: Morgan Kaufmann.

LIKER, J., & HOSEUS, M., 2008. *Toyota culture: The heart and soul of the Toyota way*. New York: McGraw-Hill.

OHNO, T., 1988. *The Toyota production System: Beyond Large Scale Production*. Portland, Oregon: Productivity Press.

RAGIN, C.C., 1987. *The comparative method: moving beyond Qualitative and Quantitative Methods,* Berkeley, CA: University of California.

SANTOS, J., WYSK, R., TORRES J., M., 2006. *Improving Production with Lean Thinking.* Hoboken, New Jersey: Published by John Wiley & Sons, Inc.

SHINGO, S., 1985. *A Revolution in Manufacturing: The SMED System*. USA: Productivity press book.

SPEAR, S., 2009. *Chasing the rabbit*. *How Market Leaders Outdistance the Competition and How Great Companies Can Catch Up and Win*. New York: McGraw-Hill.

WOMACK, J.P., AND JONES, D.T. 2003. *Lean Thinking. Banish waste and create wealth in your corporation*. UK: Simon and Shuster.

WOMACK, J.P., AND JONES, D.T., 1996. *Lean Thinking: Banish Waste and Create Wealth in your Organisation.* New York: Simon and Shuster.

WOMACK, J.P., JONES, D.T. AND ROOS, D., 1990. *The Machine that Changed the World*. New York: Rawson Associates.

Articles and Other resources

ABU, F., GHOLAMI, H., SAMAN, M.Z.M., ZAKUAN, N., STREIMIKIENE, D., 2019. The implementation of lean manufacturing in the furniture industry: A review and analysis on the motives, barriers, challenges, and the applications, *Journal of Cleaner Production*, Vol. 234, pp. 660-680.

ALBLIWI, S., ANTONY, J., ABDUL HALIM LIM, S., VAN DER WIELE, T., 2014. Critical failure factors of Lean Six Sigma: a systematic literature review, *International Journal of Quality & Reliability Management*, Vol. 31 No. 9, pp. 1012-1030.

ANAND, G., WARD, P.T., TATIKONDA, M.V., SCHILLING, D.A., 2009. Dynamic capabilities through continuous improvement infrastructure, *Journal of Operations Management*, Vol. 27 No. 6, pp. 444-461.

ANTONY, J., 2008. Can Six Sigma be effectively implemented in SMEs? *International Journal of Productivity and Performance Management*, Vol. 57 No. 5, 2008 pp. 420-423.

ASTM, 2013. F2792-12a Standard Terminology for Additive Manufacturing Technologies., MIT Libraries.

ATTARAN, M., 2017. Cloud Computing Technology: Leveraging the Power of the Internet to Improve Business Performance. *Journal of International Technology and Information Management*. Vol. 26, Issue 1, Article 6, pp. 112-137.

BATTINI, D., FACCIO, M., PERSONA, A., SGARBOSSA, F,. (2009). Design of the optimal feeding policy in an assembly system. *International Journal of Production Economics*. Vol 121, pp. 233-254.

BAUER, W. POKORNI, B., FINDEISEN, S., 2019. Production Assessment 4.0 - Methods for the Development and Evaluation of Industry 4.0 Use Cases, *Advances in Manufacturing, Production Management and Process Control*, Edited by Karwowski, W., Trzcielinski, S., MRUGALSKA, B., DI NICOLANTONIO, M., ROSSI, E., Springer International Publishing, pp. 501-510

BCG, 2017. When Lean Meets Industry 4.0. Next Level of Operational Excellence. Available at: http://image-src.bcg.com/Images/BCG-When-Lean-Meets-Industry-4.0-Dec-2017_tcm104-179091.pdf

BHASIN, S. 2012. Performance of Lean in large organisations. *Journal of Manufacturing*

BORTOLOTTI, T., BOSCARI, S., DANESE, P., 2015. Successful lean implementation: Organizational culture and soft lean practices. *International Journal of Production Economics*, Vol. 160, pp. 182-201.

BOULILA, N., 2019. Cyber-Physical Systems and Industry 4.0: Properties, Structure, Communication, and Behavior. Available at: https://www.researchgate.net/publication/332420221_Cyber-Physical_Systems_and_Industry_40_Properties_Structure_Communication_and_Behavior.

BRICCO, P., 2018. 1965-2018, com'è cambiata l'Italia dal Triangolo industriale al Poligono della crescita. *Il sole 24 ore*. June 5th. Available at: https://www.ilsole24ore.com/art/1965-2018-com-e-cambiata-l-italia-triangolo-industriale-poligono-crescita-AEadIwwE [Accessed 14 October 2019]

BUER, S.V., STRANDHAGEN, J.O., CHAN, F.T.S., 2018. The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda. *International Journal of Production Research*, Vol. 56, No 8, pp. 2924-2940.

CAMUFFO A., 2012. It's a lean world: Italy. *The LMJ*, Available at: https://the-lmj.com/2012/01/its-a-lean-world-italy/ [Accessed 14 October 2019]

CHEN, H., ROGER, C., STOREY, V., 2012. Business Intelligence and Analytics: From Big Data to Big Impact. *MIS Quarterly*. Vol. 36, n°4, pp. 1165-1188.

CARDOSO, J., VOIGT, K., WINKLER, M., 2009. Service Engineering for the Internet of Services. *Enterprise Information Systems*. pp. 375-387. Berlin, Heidelberg: Filipe, J., Cordeiro J., Springer Berlin Heidelberg.

CONTI, R., ANGELIS, J., COOPER, C., FARAGHER, B., GILL, C. 2006. The effects of lean production on worker job stress. *International Journal of Operations & Production Management*, Vol. 26 No. 9, pp. 1013-1038.

CORÒ, G., VOLPE, M., 2013. Evoluzione delle relazioni commerciali con la Cina e del ruolo delle imprese italiane nell'area asiatica. *L'Industria, Rivista di economia e politica industriale*. Il Mulino: Rivisteweb. Vol. 3, pp.535-556.

CUA, K., K. MCKONE, R. G. SCHROEDER., 2001. Relationships between Implementation of TQM, JIT, and TPM and Manufacturing Performance. *Journal of Operations Management*, Vol. 19, Issue 6, pp. 675-694.

DAL FARRA, S.P., QUEIROZ, M.J, PRADO P.H.M, DE QUEIROZ, R.S.B., 2019. The allure of ubiquity: Brand equity and Brand authenticity influenced by distribution channels. *Brazilian Journal of Management*, Santa Maria, Vol. 12, N°3, pp. 418-433.

DALING, L., ABDELRAZEQ, A., SAUERBORN, C., HEES F., 2019. A Comparative Study of Augmented Reality Assistant Tools in Assembly. *Advances in Usability and User Experience*, pp. 755 -767.

D'AVENI, R., 2018. The 3-D Printing Playbook: Business Models for Additive Manufacturing. *Harvard business review*.

DAVYDOV, D., RIABOVOL, D., 2019. Innovation in the Sphere of Augmented and Virtual Reality Technologies in EU Member States and Other Countries of the World. *Problems of Economy*. Vol. 39, Issue 1, pp. 5-11.

DELBRIDGE, R., LOWE, J., OLIVER, N., 2000. Shopfloor Responsibilities Under Lean Teamworking. *Human Relations*, Vol. 53, Issue 11, pp. 1459-1479.

DELOITTE, 2019a. Italia 4.0: siamo pronti? Il percepito degli executive in merito agli impatti economici, tecnologici e sociali delle nuove tecnologie. Available at: https://www2.deloitte.com/content/dam/Deloitte/it/Documents/process-and-operations/Report%20Italia%204.0%20siamo%20pronti_Deloitte%20Italy.pdf

DELOITTE, La Fratta, S., Sabatini M., 2019b. Italy 4.0. Pursuing the digital future amid macro-gloom. *Industry 4.0, digital manufacturing enterprises, and digital supply networks series.*

DETTMER, W.H. (2008). Beyond Lean Manufacturing: Combining Lean and the Theory of Constraints for Higher Performance. Available at: https://www2.deloitte.com/content/dam/insights/us/articles/DTLR1781_Italy4-0/DI_Italy-4-point-0.pdf

DETTY, R.B., YINGLING, J.C., Quantifying Benefits of Conversion to Lean Manufacturing with Discrete Event Simulation: a Case Study. *International Journal of Production Research*, Vol. 38, No. 2, pp. 429-445.

DEWIL, R., VANSTEENWEGEN, P., CATTRYSSE, D., 2014. Construction heuristics for generating tool paths for laser cutters. *International Journal of Production Research*, Vol. 52, n° 20, pp. 5965-5984.

DOLGUI, A., PASHKEVICH, A., 2009. Manipulator motion planning for high-speed robotic laser cutting, *International Journal of Production Research*, Vol. 47, n°20, pp. 5691-5715.

DORLEON, G., GERVAIS, S., 2017. Industry 4.0 - What we need to know. Available at https://www.researchgate.net/publication/329388831

EBRAHIM, M., 2014. 3D Laser scanners: history, applications, and future. *LAP LAMBERT Academic Publishing*.

ELHOSENY, M., ABDELAZIZ, A., SALAMA, A.S., RIAD, A.M., KHAN M., SANGAIAH A.K., 2018. A hybrid model of Internet of Things and cloud computing to manage big data in health services applications. *Future Generation Computer Systems*, Vol. 86, PP. 1383-1394.

EUROPEAN COMMISSION, 2015, *User guide to the SME Definition*. Luxembourg: Publications Office of the European Union.

EUROSTAT, 2018. Cloud computing - statistics on the use by enterprises. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Cloud_computing_-_statistics_on_the_use_by_enterprises [Accessed 14 October 2019]

EUROSTAT, 2019. Digital economy and society statistics - enterprises. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Digital_economy_and_society_statistics_-_enterprises#Use_of_3D_printing [Accessed 14 October 2019]

FÆGRI, T.E., DYBÅ, T., DINGSØYR, T., 2010. Introducing knowledge redundancy practice in software development: Experiences with job rotation in support work, *Information and Software Technology*, Volume 52, Issue 10, pp. 1118-1132.

field for SMEs.

FIN, J.C., VIDOR, G., CECCONELLO I., MACHADO, V.D.C., 2017. Improvement Based on Standardized Work: an Implementation Case Study. *Brazilian Journal of Operations & Production Management*, Vol. 14, pp. 388-395.

FIUME, O.J., 2004. Lean at Wiremold: beyond manufacturing, putting people front and center. *Journal of Organizational Excellence*, Vol 23, Issue 3, pp. 23-32.

GALEAZZO, A., FURLAN, A., 2018. Lean bundles and configurations: a fsQCA approach. *International Journal of Operations & Production Management*. Vol. 38, No 2, pp. 513-533.

GALIN, R., MESHCHERYAKOV, R., 2019. Automation and robotics in the context of Industry 4.0: the shift to collaborative robots. *IOP Conference Series: Materials Science and Engineering*, pp. 1-5.

GHOBAKHLOO, M. 2018. The future of manufacturing industry: a strategic roadmap toward Industry 4.0, *Journal of Manufacturing Technology Management*, Vol. 29 No. 6, pp. 910-936.

GÖHNER, L., BRASIL DE BRITO MELLO L.C., DE MELLO BANDEIRA, R.A., 2017. Implementation of Lean Manufacturing in Multinational Companies with production subsidiaries in Brazil: A Roadmap. *European Journal of Management Studies*, Vol. 22, Issue 2, pp. 99-123.

GUO, N., LEU, M.C., 2013. Additive manufacturing: technology, applications and research needs, *Frontiers of Mechanical Engineering*, Vol.8, Issue 3, pp. 215-243

HALLAVO, V., KUULA, M., PUTKIRANTA, A., 2018. Evolution and effect of LEAN bundles: a longitudinal study, *Benchmarking: An International Journal*, Vol. 25 No. 9, pp. 3789-3808.

HASHMI, H., KHAN, N., HAQ, M.A., 2015. The impact of Lean management implementation of organizational performance. *LogForum*, Vol. 11, Issue 4, pp. 375-385.

HOLMEMOA, M.D.Q, ROLFSENA, M., AND INGVALDSENA, J.A., 2018. Lean thinking: outside-in, bottom-up? The paradox of contemporary soft lean and consultant-driven lean implementation. *Total Quality Management & Business Excellence*, Vol. 29 Issue 1/2 pp. 148-160

HORBAL, R., KAGAN, R., KOCH, T., 2008. Implementing Lean Manufacturing in High-mix Production Environment. *IFIP International Federation for Information Processing*, pp.257-267. US Boston, MA: Springer.

HU, Q., MASON, R., WILLIAMS, S., FOUND, P. 2015. Lean implementation within SMEs: a literature review. *Journal of Manufacturing Technology Management,* Vol. 26, Issue 7, pp. 980-1012.

HUTTMEIR, A., DE TREVILLE, S., VAN ACKERE, A., MONNIER L., PRENNINGER, J., 2009 Trading off between heijunka and just-in-sequence. *Int. J. Production Economics,* Vol. 118, pp. 501-507.

IFR, 2019a. Executive Summary World Robotics 2019 Industrial Robots. Available at: https://ifr.org/downloads/press2018/Executive%20Summary%20WR%202019%20Industrial%20Robots.pdf

IFR, 2019b. WR Industrial Robots 2019 - Sources & Methods. Available at: https://ifr.org/downloads/press2018/WR%20Industrial%20Robots%202019_Chapter_1.pdf

IFR, 2019c. Executive Summary World Robotics 2019 Service Robots. Available at: https://ifr.org/downloads/press2018/Executive_Summary_WR_Service_Robots_2019.pdf

ISO, 2012. ISO 8373:2012. Robots and robotic devices - vocabulary. Geneva: ISO.

ISO, 2016. ISO/TS 15066:2016(E). Robots and robotic devices - Collaborative robots. Geneva: ISO.

ISTAT, 2019. Esportazioni delle regioni Italiane, IV trimestre 2018. 12 marzo.

JAIN, A., SINGH, H., BHATTI, R.S., 2018. Identification of key enablers for total productive maintenance (TPM) implementation in Indian SMEs. A graph theoretic approach. *Benchmarking: An International* Journal, Vol. 25 No. 8, pp. 2611-2634. Emerald Publishing Limited

JAYARAM, A., 2016. Lean Six Sigma Approach for Global Supply Chain Management Using Industry 4.0 and IIoT. *Paper Presented at the 2nd International Conference on Contemporary Computing and Informatics, IC3I,* Noida, pp. 89-94.

JENSON, I., LEITH, P., DOYLE, R., WEST, J., MILES, M.P., 2016. Testing innovation systems theory using Qualitative Comparative Analysis. *Journal of Business Research,* Vol. 69, Issue 4, pp. 1283-1287.

KABST, R., LARSEN, H.H,, BRAMMING, P., 1996. How do lean management organizations behave regarding training and development? *International Journal of Human Resource Management,* Vol. 7, Issue 3, pp. 618-639.

Kagermann, H., Wahlster, W., Helbig J., 2013. Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0, *Final report of the Industrie 4.0 Working Group,* München.

KAMBLE, S., GUNASEKARAN, A., DHONE, N.C., 2019. Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies, *International Journal of Production Research*, Taylor & Francis, pp. 1-19

KHAN, A., TUROWSKI, K., 2016. A survey of current challenges in manufacturing industry and preparation for Industry 4.0. *Proceedings of the First International Scientific Conference "Intelligent Information Technologies for Industry"*, Russia: Springer, Vol. 1, pp.15–26.

KIM, D.G., CHOI, S.O., 2018. Impact of Construction IT Technology Convergence Innovation on Business Performance. *Sustainability*, Vol. 10, No 11, 3972.

KLINGENBERG, B, GEURTS, G.T., 2009. A theoretical framework for financial performance measurement of operations management strategies. *Proceedings for the Northeast Region Decision Sciences Institute (NEDSI)*, pp. 427-430.

KLINGENBERG, B., TIMBERLAKE, R, GEURTS, G.T., BROWN, R.J., 2013. The relationship of operational innovation and financial performance - A critical perspective. *International Journal of Production Economics*, Vol. 142, Issue 2, pp. 317-323.

KOLBERG, D., ZÜHLKE, D., 2015. Lean Automation enabled by Industry 4.0 Technologies. IFAC-PapersOnLine, Vol. 48, Issue 3, pp. 870-1875.

LAMMING, R., 1996. Squaring lean supply with supply chain management. *International Journal of Operations & Production Management*, Vol. 16 No. 2, pp. 183-196. MCB University Press.

LANEY, D., 2001. 3-D Data Management: Controlling Data Volume, Velocity and Variety. *META Group Research Note*, pp.1-4.

LANGSTRAND, J., 2009. Pettersen, J.: Defining lean production: some conceptual and practical issues. *The TQM Journal*, Vol. 21, Issue 2, pp. 127-142.

Lean Manufacturing, *International Journal of Emerging Technology and Advanced Engineering*, Vol. 4, Issue 3, pp.339-344.

LEE, J., BAGHERI, B, KAO, H., 2015. A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters 3*, pp.18-23.

LEITÃO, P., COLOMBO, A.W., KARNOUSKOS, S., 2016. Industrial automation based on cyber-physical systems technologies: Prototype implementations and challenges. *Computers in Industry*, Vol 81, pp.11-25.

LIU, W., LI, F., LI, Y., 2019. Development and Future Trends of Internet of Things. *Cyber Security Intelligence and Analytics. Advances in Intelligent Systems and Computing book series*. Cham: Xu, Z., Choo, K.K.R., Dehghantanha, A., Parizi, R., Hammoudeh, M. Springer International Publishing. Vol. 928, pp. 648-656.

MA, J., WANG, Q., ZHAO, Z., 2017. SLAE-CPS: Smart Lean Automation Engine Enabled by Cyber-Physical Systems Technologies. *Sensors* Vol. 17 Issue 7 pp. 1-22.

MAHALAKSHMI, R., UTHAYASURIYAN, K., 2015. Impact of job rotation on employee commitment and job involvement in banking sector of Sivaganga district. *IJRCM*, Vol. 6, Issue 8, pp.12-15.

MARIN-GARCIA J.A., BONAVIA, T., 2015. Relationship between employee involvement and lean manufacturing and its effect on performance in a rigid continuous process industry. *International Journal of Production Research*, Vol. 53, No 11, pp.3260-3275.

MARKSBERRY, P., CHURCH, J., SCHMIDT, M., 2014. The Employee Suggestion system: A New Approach Using Latent Semantic Analysis. *Human Factors & Ergonomics in Manufacturing & Service Industries*, Vol. 24, Issue 1 pp. 29-39.

MASOOD, T., EGGER, J., 2019. Augmented reality in support of Industry 4.0 - Implementation challenges and success factors, *Robotics and Computer-Integrated Manufacturing*, VoL. 58, 2019, pp. 181-195.

MATHAISEL D., COMM C., 2000. Developing, implementing and transferring lean quality initiatives from the aerospace industry to all industries. *Managing Service Quality,* Vol 10, n° 4 pp. 248-256.

MAYR A., WEIGELT, M., KÜHL, A., GRIMM, S., ERLL, A., POTZEL, M., FRANKE, J., 2018. Lean 4.0 - A conceptual conjunction of lean management and Industry 4.0, *51st CIRP Conference on Manufacturing Systems*, Vol. 72, pp. 622-628.

MEHRPOUYA, M., DEHGHANGHADIKOLAEI, A., FOTOVVATI, B., VOSOOGHNIA, A., EMAMIAN, S.S., GISARIO, A., 2019. The Potential of Additive Manufacturing in the Smart Factory Industrial 4.0: A Review. *Appl. Sci*. Vol. 9, Issue 18, 3865.

MELL, P., GRANCE, T., 2011. The NIST definition of cloud computing. *Special Publication 800-145.*

MELTON, T., 2005, The benefit of lean manufacturing. What Lean Thinking has to Offer the Process Industries. *Chemical Engineering Research and Design*, Vol. 83 (A6), Issue 6, pp. 662-673

MODI, D.B., HEMAN, T., 2014. Lean Thinking: Reduction of Waste, Lead Time, Cost through Lean Manufacturing Tools and Technique. *International Journal of Emerging Technology and Advanced Engineering*, Vol. 4, Issue 3, pp.339-344

MODI, D.B., THAKKAR, H., 2014. Lean Thinking: Reduction of Waste, Lead Time, Cost through

MONOSTORI, L., KÁDÁR, B., BAUERNHANSL, T., KONDOH, S., KUMARA, S., REINHART, G., SAUER, O., SCHUH, G., SIHN, W., UEDA, K., 2016. Cyber-physical systems in manufacturing. *CIRP Annals*, Volume 65, Issue 2, pp. 621-641.

MOORS, J., ROGIEST, S., 2018. Implementing Big Data Analytics in a Manufacturing Environment: A Theoretical Framework. Proceedings *of the European Conference on Management, Leadership & Governance*, 20489021, pp. 180-187

MUÑOZ, P., 2015. Workshop Comparative Research Designs, An Introduction to Configurational Methods and Fuzzy-Set Qualitative Comparative Analysis. Universidad del Desarrollo. Available at: http://womenentrepreneurs.info/wp-content/uploads/2018/01/Pres_Pablo_QCA.pdf

NELSON, B., STAUFFER, T., 2008. PLCs and DCSs converge. *Process & Control Engineering (PACE)*. Vol. 61, Issue 7, pp. 41-44.

NICOLETTI, B., 2013. Lean and Automate Manufacturing and Logistics. *20th Advances in Production Management Systems (APMS)*, United States. pp.278-285.

NUNES, M., PEREIRA, A., ALVES, A., 2017. Smart products development approaches for Industry 4.0, *Procedia Manufacturing*, Vol. 13, pp. 1215-1222.

OESTERREICH, T., TEUTEBERG, F., 2016. Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*. Vol. 83, pp. 121-139.

PAIVA SANTOS, B., CHARRUA-SANTOS, F., LIMA, T.M., 2018, Industry 4.0: An Overview, *Conference Paper*.

PAVLOVIĆ, M., RADOSAVLJEVIĆ, M., MILOJEVIĆ, R., 2018. The role of Information Technology in the Implementation of Lean Concept *FACTA UNIVERSITATIS* Series: *Economics and Organization*. Serbia: University of Niš, Vol. 15, No 4, pp. 349-362.

PANNU, M., AND KAY, I. 2019, Internet of Things: Analyzing the Impact on Businesses and Customers. *Advances in Neuroergonomics and Cognitive Engineering. Advances in Intelligent Systems and Computing*. Vol. 953, pp. 322-327. Philadelphia, USA: Hasan Ayaz. Drexel University. Springer.

PEREIRA, A., ROMERO, F., 2017. A review of the meanings and the implications of the Industry 4.0 concept. *Procedia Manufacturing*, Vol.13, pp.1206-1214.

PETTERSEN, J., 2009. Defining lean production: some conceptual and practical issues. The *TQM Journal*, Vol. 21, Issue 2, pp. 127-142

POJASEK, R.B., 1999. Poka-Yoke and Zero Waste. *Environmental Quality Management*, Vol. 9 Issue 2, pp. 91-97.

PORTIOLI-STAUDACHER, A., TANTARDINI, M., 2007. Lean production implementation: A survey in Italy. *Dirección y organización: Revista de dirección, organización y administración de empresas*, Nº 35, pags. 52-60.

RADOVANOVIĆ, M., MADIĆ, M., 2011. Experimental investigations of CO2 laser cut quality: A review. *Nonconventional Technologies Review*. Vol. 15, n°4, pp.35-42.

RAGIN, C.C., 2017. User's guide to Fuzzy-Set / Qualitative Comparative Analysis. Available at: http://www.socsci.uci.edu/~cragin/fsQCA/download/fsQCAManual.pdf

RAUCH, E., DALLASEGA, P., MATT, D.T., 2016. The Way from Lean Product Development (LPD) to Smart Product Development (SPD). *Procedia CIRP, 26th CIRP Design Conference*, Vol. 50, pp. 26-31.

REUTER, V.G., 1977. Suggestion Systems. Utilization, Evaluation, and Implementation. *California Management Review*. Vol. XIX, No. 3, pp. 79-89.

Rüttimann, B. Stöckli, M., 2016. Lean and Industry 4.0 - Twins, Partners, or Contenders? A Due Clarification Regarding the Supposed Clash of Two Production Systems, *Journal of Service Science and Management*, Vol. 9, pp. 485-500.

SALEM, R., MUSHARAVATI, F., HAMOUDA, A.M., AL-KHALIFA, K.N., 2016. An empirical study on lean awareness and potential for lean implementations in Qatar industries. *The International Journal of Advanced Manufacturing Technology*, Vol. 82, pp. 1607-1625. Springer.

SANDERS, A., ELANGESWARAN, C., WULFSBERG, J.P., 2016. Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing, Journal of Industrial Engineering and Management (JIEM), Barcelona: OmniaScience, Vol. 9, Issue 3, pp. 811-833.

SANTOS, M.Y., OLIVEIRA E SÁ, J., COSTA, C., GALVÃO, J., ANDRADE, C., MARTINHO, B., LIMA, F.V., COSTA, E., 2017. A Big Data Analytics Architecture for Industry 4.0. *Recent Advances in Information Systems and Technologies*. *Advances in Intelligent Systems and Computing 570*. pp. 175-184. Á. Rocha et al (eds.) Springer International Publishing AG.

SCALI, C., BACCI DI CAPACI, R., BARTALONI, E., 2017. Ecco come 'Industria 4.0' migliora l'industria di processo. *Automazione e strumentazione*, Vol. 7, pp. 77-81.

SCHROECK, M., SHOCKLEY, R., SMART, J., ROMERO-MORALES, D., & TUFANO, P., 2012. Analytics: The real-world use of big data. *IBM Executive report*, New York, NY: IBM Institute for Business Value, Said Business School.

SCHWAB, K., 2016. The fourth industrial revolution. *Cologny/Geneva–World Economic Forum.*

SHAH, R., WARD, P.T., 2007. Defining and developing measures of lean production. *Journal of operations management*, Vol. 25, Issue 4, pp. 785-805.

SHENAS, D.G., DERAKHSHAN, S., 1994. Organizational Approaches to the Implementation of Simultaneous Engineering. *International Journal of Operations & Production Management*, Vol. 14 No. 10, pp. 30-43. MCB University Press.

STEVENS, G.C., 1989. Integrating the supply chain. *International Journal of Physical Distribution & Logistics Management*, Vol. 19, Issue 8, pp. 3-8

STROZZI, F., COLICCHIA, C., CREAZZA, A., NOÈ, C., 2017. Literature review on the 'Smart Factory' concept using bibliometric tools. *International Journal of Production Research*, Vol. 55, No. 22, pp. 6572-6591.

Systems, Vol. 31, pp. 349-357.

TEZEL, A., KOSKELA, L., TZORTZOPOULOS, P., 2016. Visual management in production management: a literature synthesis. *Journal of Manufacturing Technology Management*, Vol. 27 No. 6, pp. 766-799.

THANGARAJOO Y., SMITH A., 2015. Lean Thinking: An Overview. *Journal of Industrial Engineering and Management*, Vol. 4, Issue 2.

THE INNOVATION GROUP. (2017). Which results did you obtain/ do you expect to obtain from the Internet of Things (IoT) project?. Statista. Statista Inc. Available at: https://www.statista.com/statistics/680342/expected-results-and-the-potential-of-iot-projects-italy/ [Accessed: 14 October 2019].

TORTORELLA, G., CAUCHICK-MIGUEL, P.A., GAIARDELLI, P., 2019. Hoshin Kanri and A3: a proposal for integrating variability into the policy deployment process. *The TQM Journal*, Vol. 31 No. 2, pp. 118-135. Emerald Publishing Limited.

TORTORELLA, G.L., FETTERMANN, D., 2018. Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies. *International Journal of Production Research*, 00207543, Vol. 56, Issue 8, pp. 2975-2987.

URBIKAIN, G., ALVAREZ, A., LÓPEZ DE LACALLE, L.N., ARSUAGA, M., ALONSO M. A., VEIGA, F., 2017. A reliable turning process by the early use of a deep simulation model at several manufacturing stages, *Machines*, Vol. 5, No. 2.

VAIDYAA, S., AMBADB, P., BHOSLEC, S., 2018, Industry 4.0 - A Glimpse. *Procedia Manufacturing*, Vol. 20, pp.233-238.

VANCEA, M. 2007. Ragin, Charles C. The Comparative Method: Moving Beyond Qualitative and Quantitative Strategies. Fuzzy-Set Social Science. *Papers. Revista de sociologia, Analytical Sociology Theory.* No 80.

VERLINDEN, B., CATTRYSSE D., VAN OUDHEUSDEN D., 2007. Integrated sheet-metal production planning for laser cutting and bending, *International Journal of Production Research*, Vol.45, n°2, pp. 369-383.

VESCOVI, T., 2018. Editoriale: Family business e mercati internazionali: è un lavoro per giovani, *Micro & Macro Marketing, Rivista quadrimestrale*, Vol. 2, pp. 175-180.

VON HAARTMAN, R., BENGTSSON L., C. NISS., 2016. Lean Practices as Requisites for the Use of Digital Technology in Production. *Proceedings of EurOMA 2016-Interactions*, pp. 17-22.

Wagner, T., Herrmann, C., Thiede, S., 2017. Industry 4.0 Impacts on Lean Production Systems. *Procedia CIRP*, Vol 63 pp. 125-131.

WANG, B., ZHAO, J.Y., WAN, Z.G., MA, J.H., LI, H., MA, J., 2016. Lean Intelligent Production System and Value Stream Practice. China: Jiangsu, *Paper Presented at the 3rd International Conference on Economics and Management, ICEM*, pp. 442–447.

WANG, G., LASZEWSKI G., 2008. Scientific Cloud Computing: Early Definition and Experience. *In 10th IEEE International Conference on High Performance Computing and Communications*. Dalian, China. IEEE Xplore.

World Trade Organization, 2016. *World Trade Report 2016. Levelling the trading*

ZANGWILL, W.I., KANTOR, P.B. 1998. Toward a Theory of Continuous Improvement and the Learning Curve. *Management Science*, Vol. 44, No. 7, pp. 910-920.

ZHOU, K., LIU, T., ZHOU, L., 2015, Industry 4.0: Towards future industrial opportunities and challenges. *12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*, Zhangjiajie, pp.2147-2152.

Web resources

www.lean.org

[Accessed 8 August 2019].

www.velaction.com

[Accessed 20 August 2019]

https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE_REV2&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=HIERARCHIC&IntCurrentPage=1 (NACE e ATECO) [Accessed 16 September 2019]

Annex: Questionnaire on Italian manufacturing firms

(English version translated from Italian)

SECTION 1: Characteristics and Identifying information

1. Role of the respondent

2. Name of the company

3. Revenues realized in 2018.

4. Percentage of 2018's revenues realized abroad

5. Number of employees.

6. Percentage of labourers on the total number of employees.

7. Is the company a Family Business? (Yes or No)
   - ○ Yes
   - ○ No

8. In which region is the headquarters of the company located?

9. Specify the province.

10. Does the company own plants in other countries and where are they localized
    - ☐ No plant abroad
    - ☐ Europe
    - ☐ Russia
    - ☐ Asia
    - ☐ China
    - ☐ Africa
    - ☐ North-America
    - ☐ Latin America
    - ☐ Oceania

11. Indicate which is the percentage of 2018's revenues for each category of clients, among:

    Final customers

    Distributors

    Industrial companies

    Others

12. Indicate which country represents the main market of the company and the percentage of sales realized in that market in 2018

Principal market ______

% of sales ______

13. How many labourers, in percentage on the total number of labourers, are able to work in more than one station along the process (job rotation)?

______

14. Indicate which percentage of the Total Sales falls in each of the following categories:

Design to Order ______

Manufacture to Order ______

Assembly to Order ______

Make to Stock ______

15. Indicate, among the following, the adopted layout:

○ Fixed-position layout

○ Functional layout

○ Cell layout

○ Line layout

16. Does the company adopt one of the following Industry 4.0 technologies?

☐ Robots in production and Cobots

☐ Additive Manufacturing (3D printers)

☐ Laser cutting

☐ Data processing systems (Big Data and Cloud Computing)

☐ 3D Scanners

☐ Augmented Reality

☐ Internet of Things

☐ None

17. If the company adopts one of the technologies 4.0 described above, specify the year of adoption:

Robots in production and Cobots ______

Additive Manufacturing (3D printers) ______

Laser cutting ______

Data processing systems (Big Data and Cloud Computing) ______

3D Scanners ______

Augmented Reality ______

Internet of Things ______

SECTION 2: Techniques and solutions adopted

18. Does the company apply any Lean technique?

○ Yes

○ No

19. Why don't you adopt Lean Management?

☐ Lack of economic resources

☐ Lack of internal competencies

☐ Lack of an adequate technological infrastructure

☐ Lack of knowledge

☐ Uncertain returns of the investment

☐ Not interesting for our business

☐ Still in phase of valuation

☐ Others (specify)

20. In which year did the company start to apply Lean techniques?

[ ]

21. Why did the company start to apply Lean techniques?

☐ Specific requests of clients

☐ Request of banks/financers

☐ Need of improvement of economic and financial performance

☐ Other reasons

☐ Need of improvement of operative performance

☐ Willingness of the directors to modify the management

☐ Imitation of clients/suppliers

22. Are there in the company any internal employees that are exclusively dedicated to the implementation of Lean techniques?

○ Yes

○ No

23. Does the company refer to external consultants for the implementation of Lean techniques?

○ Yes

○ No

24. Are the Lean techniques applied also in the plants abroad?

- Yes
- No
- The company does not have any plant abroad

25. Indicate which tools, among the following, are implemented and in which department:

	Production	Warehouse	Logistics	Quality Control	Purchasing Office	Commercial Office	Technical Office	Administration	IT
VSM	○	○	○	○	○	○	○	○	○
5S	○	○	○	○	○	○	○	○	○
A3	○	○	○	○	○	○	○	○	○
Pull/Kanban	○	○	○	○	○	○	○	○	○
Flow layout	○	○	○	○	○	○	○	○	○
Visual Management	○	○	○	○	○	○	○	○	○
Standardized work	○	○	○	○	○	○	○	○	○
Kaizen	○	○	○	○	○	○	○	○	○
Poka Yoke	○	○	○	○	○	○	○	○	○
TPM	○	○	○	○	○	○	○	○	○
Suggestion system	○	○	○	○	○	○	○	○	○
Simultaneous engineering	○	○	○	○	○	○	○	○	○
Heijunka	○	○	○	○	○	○	○	○	○
Six Sigma	○	○	○	○	○	○	○	○	○
SMED	○	○	○	○	○	○	○	○	○
Andon	○	○	○	○	○	○	○	○	○

26. Which of the following positions actively participate in the Lean transformation?

- ☐ CEO
- ☐ Directors
- ☐ Managers
- ☐ Operators
- ☐ Others

27. Who is the main supporter of Lean activities?

- ☐ CEO/Owner
- ☐ Directors
- ☐ Others
- ☐ First level function responsibles

28. In which types of training has the company invested?

- ☐ Masters/Courses for employees, directors and responsibles
- ☐ Others
- ☐ Workshop/Courses for labourers

29. Which percentage of employees has been involved in Lean projects?

30. Does the company use any suggestions system?

- ○ Yes
- ○ No

31. Are labourers directly involved in improvement processes?

- ○ Yes
- ○ No

32. Which percentage of the suggestions received from the labourers are implemented?

33. How much has been invested in Lean projects in the last three years? (In absolute terms or in % of the Revenues)

34. Which among the following options better explains the company's method of detection of errors and abnormalities?

- ○ The Quality Control Office is the responsible one
- ○ The labourers are the responsible ones, but they cannot stop the production
- ○ Others
- ○ The labourers are the responsible ones, and they can stop the production to take corrective measures

35. Which of the following options better explains the company's method for the allocation of responsibility and supervision?

- ○ Responsibility is centralized, supervision and control is on the Department Chief
- ○ Responsibility is decentralized, supervision and control are on the team members
- ○ Others
- ○ Responsibility is decentralized, supervision and control are on the team and are allocated to all the members in rotation

To my sister, my father, my mother and my friends,
Simply thank you.