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Lean 4.0: an Empirical Study on Lean Production Practices and Industry 4.0 Technologies Benefits in SMEs

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È doveroso dedicare questo spazio del nostro elaborato alle persone che hanno contribuito, con il loro instancabile supporto, alla realizzazione dello stesso.

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Glossary

Abbreviation	Extended Word
3D	Three Dimensions
5S	Sort, Set in order, Shine, Standardize, Sustain
AGVs	Automated Guided Vehicles
AR	Augmented Reality
Co-bots	Collaborative Robots
CPS	Cyber Physical Systems
CSF	Critical Success Factor
e-Kanban	Electronic Kanban
FIFO	First In First Out
HCI	Human Computer Interactions
HMI	Advanced Human-Machine Interface
HP	Hypothesis
I 4.0	Industry 4.0
IaaS	Infrastructure as a Service
ICT	Information and Communication Technologies
I-IoT	Industrial Internet of Things
IoT	Internet of Things
JIT	Just in Time
KPIs	Key Performance Indicators
LA	Lean Automation
LEs	Large Enterprises
OT	Operations Technology
PaaS	Platform as a Service
RFId	Radio Frequency Identification
SaaS	Software as a Service
SMED	Single Minute Exchange of Die
SMEs	Small and Medium Enterprises
SMO	Simulation-based Multi-objective Optimization
TPM	Total Production Maintenance
TPS	Toyota Production System
VR	Virtual Reality
VSM	Visual Stream Mapping

1. Abstract

This dissertation examines how Industry 4.0 and Lean Production are integrated and applied in Small and Medium Enterprises. More precisely, the main aim is to understand if the application of Lean 4.0 provides these companies with three specific benefits: improvement in data collection, improvement in decision-making and innovation of routine processes.

As Industry 4.0 is changing the industrial manufacturing landscape both in Italy and around the world, it is important to study how companies benefit from its integration with the most well-functioning production system: Lean Production. In particular, this topic needs to be investigated in SMEs, as they represent the 99% of Italian panorama.

Many different authors and practitioners have studied Lean 4.0 in Large Enterprises, showing clearly the presence of the above-mentioned benefits. On the other side, there seem to be no proper research on the practical application of Lean 4.0 and its main benefits in SMEs.

Aiming at coping with this gap in literature, a survey involving 189 Italian companies has been performed in order to collect all the data necessary to develop an analysis on this topic. The main tool employed to gather this information has been a framework, previously validated, that corresponds to a matrix.

The main contributions of this dissertation are a set of different analyses that highlight the main findings and results on the topic of Lean 4.0 benefits in SMEs. More in details, SMEs seem to recognize the previously mentioned benefits to a certain extent, that can be ranked as 3.47 out of 5. In terms of limits, the low amount of answers collected, and the tricky survey structure have been listed among the main criticalities. Finally, some suggestions for future research have been provided, such as the possibility of performing the same analysis on different typologies of benefits or a quantitative study on the profit increase/productivity growth associated with Lean 4.0.

2. Extended Executive Summary

2.1 Introduction

Since the beginning of industrialization, technological and industrial progresses have led to the evolution of the so-called *industrial revolutions*, all of them characterized by a significant increase in labour productivity. The industrial revolution humanity has been going through since 2011 is the 4th one, often named *Industry 4.0,* which represents "a vision of the future of Industry and Manufacturing in which information technologies are going to boost competitiveness and efficiency by interconnecting every resource (data, people and machineries) in the Value Chain" (Politecnico di Milano, 2017).

However, manufacturing companies are still overwhelmed by changes and investments associated with Smart Technologies, which prove themselves useful and effective when they support production systems already in place. In this regard, *Lean Production* represents one of the most widespread and proven production systems ever invented. Companies often resort to the Lean paradigm because it allows to organize efficiently the production flows by reducing every kind of waste, increasing productivity and above all creating customer-centred operations. However, this well-established production system has to face the new emerging needs of modern companies that, in turn, are well-addressed by Industry 4.0 technologies.

In light of this, the topic of *Lean 4.0* (i.e. the synergies between Lean Production and Industry 4.0) has been widely addressed by recent research. In particular, it has been highlighted that the relationship between the two paradigms is *bi-directional*, meaning that Industry 4.0 technologies are perceived as supporters of Lean Production, allowing a more efficient and modern implementation of this philosophy. In this context, many authors have shown that the integration between Smart Technologies and Lean practices leads to three main benefits: data collection improvement, decision-making improvement and routine processes innovation (e.g. Haddud and Khare, 2020; Pereira et al, 2019).

It is worth mentioning that most of studies carried out to tackle the Lean 4.0 topic tend to take as reference Large Enterprises, as they are likely to have budget and internal competences necessary to conduct experiments and assess results. Conversely, literature seems to address Lean 4.0 in SMEs mainly in a theoretical way (e.g. Hoellthalera et al, 2018; Kolla et al, 2019), completely neglecting the practical integration between Lean Production and Industry 4.0 and the benefits related to it. This aspect sheds the light on a relevant gap in literature. In fact, taking into consideration the essential role played by SMEs in economies all over the world, they should not be neglected when it comes to innovative and advantageous ways of managing their operations, such as the practical combination of Smart Technologies and Lean practices.

In light of this, the main aim of this dissertation is to investigate the practical integration of Lean Production and Industry 4.0 in SMEs. In particular, the authors are interested in understanding whether the three main benefits highlighted in the context of big companies (i.e. improvement in data collection, improvement in decision-making, innovation of routine processes) apply also for SMEs.

This Extended Executive Summary is organized as follows: section 2.2 provides a Literature Review on the main topics associated with this dissertation, leading to the formulation of the research hypotheses; section 2.3 sheds light on the methodology used to investigate the research hypotheses, section 2.4 highlights the results of the study and their interpretation; section 2.5 summarizes the main conclusions and it addresses the limits and developments of the research.

2.2 Literature Review

The purpose of this literature review is to guide readers through the main topics associated with the central aim of this dissertation. In particular, it has been produced on the basis of scientific publications and conferences from Scopus, Research Gate, ScienceDirect and Google Scholar. Additionally, some reports produced by Politecnico di Milano have been used. All these papers and articles have been searched using different keywords and selected among thousands of results based on their relevance, year of publication and number of citations.

2.2.1 Lean 4.0

Lean 4.0 is a term that embodies the relationship between Lean Production and Industry 4.0. This concept has been studied in the last years by researchers and practitioners to understand how both approaches, when implemented together by companies, can raise operational and financial performance levels to a different pattern (Rossini, Costa, Portioli Staudacher, & Tortorella, 2019).

In particular, the literature analysis has shown two main points of view about the relation between Lean Production and Industry 4.0: *mono-directional* and *bi-directional* relationship. According to the former, Lean Production and Industry 4.0 are perceived as two different paradigms. Many authors, indeed, have supported the belief that Lean Production and Industry 4.0 are not positively related because high-tech and capital-intensive efforts of Industry 4.0 might conflict with the ground principles of simple, continuous and small improvements from Lean Production (e.g. Rüttimann and Stockli, 2016; Maguire, 2017). On the other side, according to the bi-directional point of view, Lean Production and Industry 4.0 are two complementary aspects that support each other. In fact, many studies have demonstrated that Industry 4.0 supports Lean Production practices adoption, through technology and digitalization, allowing an improvement of the practices already in use. Vice versa, Lean is considered fundamental for a better implementation of Industry 4.0 (e.g. Wagner et al, 2017; Sanders et al, 2017).

Throughout the years, the second vision (i.e. bi-directional) has completely overcome the first one (i.e. mono-directional), making the integration between Lean Production and Industry 4.0 even more realistic. Comprehensibly, there will always be some discordances between these two different paradigms, however, they result to be quite inconsistent if compared to the many evidences of Lean 4.0 successful implementation all around the world (Macchi, 2017).

It is worth mentioning that the bi-directional relationship sheds the light on an important touchpoint between Lean Production and Industry 4.0: the *Learning Process,* which is considered necessary for the proper implementation of Lean 4.0 (Prinza at el, 2018). In particular, many authors have agreed on the fact that, in order to properly train the workers to use Smart Technologies in solving production problems, it is necessary to resort to the *Learning Factory* approach (Bauer at el, 2019). This solution, in fact, is able to gradually establish a connection between the two aspects - Lean Production and Industry 4.0 - and make people aware of which are the improvements that can be achieved using them both.

2.2.1.1 *A framework for Lean 4.0*

As far as Lean 4.0 and its main aspects are concerned, the practical connection between Lean Production practices and Smart Technologies represents the best way to analyze how these elements affect each other. In particular, this connection can be easily explained through the creation of a matrix (table 1) in which columns contain Smart Technologies and rows report Lean Practices. In this context, the intersections within the matrix are populated with the number of papers found in literature which report a positive synergy between the Lean practice and Industry 4.0 technology.

More specifically, the columns represent the most well-known Smart Technologies: Additive Manufacturing, Advanced Automation, Advanced Human Machine Interface, Industrial Internet of Things, Industrial Analytics, Cloud Manufacturing and Digital Twin/Simulation. As for the rows, they are represented by the Lean practices proposed in the House of Lean framework (Liker, 2004): Kaizen, Andon, Poka Yoke, Total Production Maintenance (TPM), Jidoka, Standardization, 5S, Visual Management, Kanban, Just in Time, Muda Reduction, Visual Stream Mapping (VSM), Heijunka, SMED and People and teamwork.

Lean 4.0 Matrix	Additive Manufacturing	Advance Automation	Human-Machine interaction	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin / Simulation
Kaizen			2		2		2
Andon			2	2			
Poka Yoke		2	2	2	1		
TPM		2	4	2	2	5	2
Jidoka		7	2	8	4	4	2
Standardization		2	2			3	
5S			1	2			
Visual Management			5	11	2	3	2
Kanban		2		2	2		9
JIT	2	7	2	9	4	2	17
Muda reduction	2			6	2	2	4
VSM		2	2	2	8		3
Heijunka					3		
SMED	2						
People and teamwork			3				2

Table 1 - Lean 4.0 framework

As shown in table 1, not all the intersections contain a number. This does not mean that these intersections are not possible, but that there seems to be no evidence of them in literature. Looking at the matrix, some considerations can be drawn:

- As regards columns, Additive Manufacturing is the Smart Technology that seems to have little evidence of its integration with Lean practices.
- As regards rows, SMED, 5S, People and Teamwork, Heijunka, Andon and Standardization are the Lean practices that seem to have fewer intersections with Industry 4.0 technologies.

The following paragraphs are devoted to summarizing some literature used to build the matrix.

Starting from **Additive Manufacturing**, it has been noted that 3D printing technology facilitates the achievement of Lean manufacturing principles, pointing the small batches production as main benefit. First of all, this technology allows ***JIT*** manufacturing to decrease lead times, enhance logistics efficiency and also reduce distance and delivery costs, as 3D printers can be installed near customer's locations (Chen and Lin, 2017). In addition, 3D printing implementation is able to reduce wastes (***Muda Reduction***) related to overburdened or uneven workload because more tasks are performed by machines (Pereira, 2019). Finally, both Feldmann and Gorji (2017) and Wang et al (2016) argued that ***SMED*** can be enhanced by Additive Manufacturing because it allows to produce complex parts, cutting down set-up times and enabling one-piece flow production.

In terms of **Advanced Automation,** several authors argue that the implementation of autonomous robots increases the flexibility of Lean manufacturing systems (e.g. Lutz at al, 2016). In particular, Advanced Automation results to be supportive to ***Jidoka*** (Wagner et al, 2017) in light of its relationship with TPM and Poka Yoke. In fact, it has been demonstrated that ***TPM*** takes advantage from this Smart Technology thanks to maintenance robots that are able to repair parts and prevent breakdowns without the intervention of operators (Rosin et al, 2020). Moreover, Durakbasa (2016) pointed out that sensor technology and robotics allow the flexible implementation of automation in process control and quality assurance – two of the main aspects of ***Poka Yoke***. As for ***Standardization***, Boudella et al (2018) and Wang et al (2016) proposed the use of autonomous robots that work in conjunction with an operator, in order to help standardize procedures. Additionally, it has been noted that this technology leads to an improved identification of objects, reducing the effort of ***VSM*** creation (Mayr, et al., 2018). Nevertheless, several authors agreed on the fact that the Lean practice that mostly benefits from Advanced Automation is ***JIT***, as well as its main application: ***Kanban*** (Mayr et al, 2018; Wagner et al, 2017; Rüßmann et al, 2015). In fact, autonomous robots are able to adjust production planning in real-time, reacting to disruptions and adapting to find alternative solutions.

As far as **Advanced HMI** is concerned, as this technology can be adapted to different contexts and situations, it is easily compatible with Lean Production practices. Firstly, HMI can be used to foster ***Visual Management*** by replacing physical shadow boards (Neges et al, 2017). In addition, Davies et al (2017) suggested using Virtual Reality to easily visualize the processes and understand the possible changes, leading to ***Kaizen*** enhancement. At the same time, several authors agreed on the support that Augmented Reality is able to provide ***Jidoka*** and its tools (***Andon, Poka Yoke*** e ***TPM***) with (e.g. Mayr et al, 2018; Rauch et al, 2016). To cite one example, Rammelmeier et al (2017) demonstrated that Augmented Reality and head-mounted displays enhance Poka Yoke, as they can be used to achieve zero-error picking and improve quality control. Augmented Reality has been proposed also with the aim of making processes more stable and standardized, helping the Lean practice of ***Standardization*** (Longo et al, 2017). Besides, it can be used to promote the ***5S*** approach by creating games that motivate personnel to clean or place tools correctly (Pötters et al, 2017). In terms of ***JIT***, Kolberg and Zühlke (2015) presented an approach, based on the use of Augmented Reality and CPS-based wearable devices, that provides operators with information about cycle time and tasks. Additionally, HMI allows operators to observe and map current and future state of processes, without the need of understanding the conventional ***VSM*** symbols (Davies et al, 2017). Lastly, it enhances ***People and Teamwork***, as Augmented Reality interfaces are able to facilitate employees training (Longo et al, 2017).

I-IoT represents another technology that has a lot of literature evidence on its support to Lean Production. Firstly, ***Andon*** principle is addressed by IoT, as it allows products to communicate with equipment and send warning messages (Kolberg and Zühlke, 2015; Mrugalska and Wyrwicka, 2017). According to many authors, this technology improves the application of ***Jidoka***: Mrugalska and Wyrwicka (2017), indeed, proposed the use of IoT to ensure that products are automatically redirect in the event of referral errors. Speaking of ***TPM***, Eleftheriadis and Myklebust (2016) presented a project in which IoT is used to monitor quality parameters, suggesting corrections to the production system in real-time. Additionally, part recognition – enabled by RFID – allows the identification of incorrect components and their removal, which contributes to the idea of ***Poka Yoke*** (Mayr, et al., 2018). Focusing on ***Visual Management***, RFID can assist in carrying out ***5S*** more efficiently, as it ensures the identification and localization of objects, leading to a reduction of search time (Fescioglu-Unver et al, 2015). Additionally, IoT supports ***JIT,*** as it can track products in real-time and send production progress data back to managers (Wagner et al, 2017). In the same way, Sanders et al (2017) proposed e-***Kanban***, which allows products to be tracked electronically and ensures that the right item arrives to the right destination at the right time. IoT can be used also to reduce wastes – enhancing ***Muda Reduction*** – by taking advantage of real-time product tracking in order to see product waiting and unnecessary transportation (Mayr et al, 2018). The last practice related to IoT is ***VSM*** that, through the use of Auto-ID, enables the instant localization of objects and the tracing of product flow (Kolberg et al, 2017).

In terms of **Industrial Analytics**, it is another technology that, in literature, has a lot of connections with Lean Production. More in details, speaking of ***Kaizen***, Kassner et al. (2017) presented an IT architecture for data driven manufacturing that intends to address the weaknesses of traditional manufacturing IT. Considering ***Jidoka*** and its tools - in particular ***Poka Yoke*** - Lettau (2013) described the use of Machine learning-based condition monitoring measurement technology for the end-of-life-test of electric drivers production as both a warning and control system. At the same time, TPM is enhanced by predictive analytics, which uses complex algorithms to predict defects based on large datasets (Kieviet, 2016). As regards ***Visual Management***, Zhong et al. (2015) used analytics to extract relevant data from sensors distributed in the production system, leading to visualization of relevant information for operators. Furthermore, also ***JIT*** takes advantage from Big Data and data analytics techniques. In fact, analyzing detailed real-time process information provides insights into parameters, helps to identify trends and allows to deduce rules for the production system (Ding & Jiang, 2017). On the same basis, Rauch et al. (2016) argued that data analytics applied during product development processes improves the use of ***Kanban***. Moving the focus to ***Muda Reduction*** principle, Stojanovic et al (2015) proposed the use of this Smart Technology to identify, in real-time, the root causes of unusual conditions in the production system. Moreover, new software tools employing Advanced Analytics can be used to support the planning process itself (Mayr et al, 2018; Zywicki et al, 2017), leading to ***Heijunka*** enhancement. However, the Lean practice mostly mentioned in literature in relation to Industrial Analytics technologies is ***VSM.*** In particular, the main benefit is the improvement of transparency through a real-time display of value streams that helps in identifying waste within production processes and leads to a lean value creation (Mayr, et al., 2018). The literature is full of practical examples demonstrating the power of this combination (e.g. Lugert et al, 2018; and Wagner et al, 2017).

As regards **Cloud Manufacturing**, Silva et al (2018) developed a Cloud Computing-based allocation able to process inputs for electronic work instructions creation and the generation of standardized work to support ***Standardization*** principle. Moreover, Mayr et al (2018) have stated that this technology strongly supports ***TPM***, as it enables the reduction of machines downtime, scraps and rework, and increase of quality, while providing maintenance data to workers and dynamically scheduling maintenance activities. In addition, Ma et al (2017) proposed a Cloud based system that allows to detect anomalies and make corrections, leading to ***Jidoka*** enhancement. Furthermore, to improve ***Visual Management***, Tao et al (2017) and Zhong et al (2015) suggested using Cloud Computing to make information related to the production system available to all the operators. Then, Azambuja et al. (2013) proposed a real-time information exchange platform based on this Smart Technology to facilitate ***JIT*** supply between producer and its suppliers. Finally, it has been noted how the use of cognizant computing can enhance ***Muda Reduction*** through reductions in lead-times, inventory volumes, process wastes and less rework Ogu et al (2018).

The **Simulation** of all possible outcomes is able to simplify the application of many Lean practices enabling, also, the creation of a **Digital Twin** of industrial processes. Firstly, Kamar and Kie (2018) used real-time simulation in the context of continuous improvement – i.e. ***Kaizen*** – to optimize the production system in terms of stocks, movements, overproduction and waiting. Moreover, Digital Twin allows a realistic simulation of the production plan that is able to enhance ***TPM*** application in the company. In fact, it is able to better control processes in real-time to do maintenance when is needed (Lacour, 2012). Also, it can prevent defective parts to go through the following stages and check their quality, following the ***Jidoka*** principle (Bauters et al, 2018). In terms of ***Visual Management***, Saez et al. (2018) proposed the use of simulation to provide visual data to managers, leading to an increased visibility on the processes. In addition, Dallasega et al. (2017) described a simulation-based solution for production planning that enhances ***JIT***, by achieving on-demand production and delivery of components, leading to a drastic reduction of the inventory levels on manufacturing environment. In the same way, Mayr et. al. (2018) proposed to use simulation to represent products, as well as to test different parameters of ***Kanban*** and find optimal ones such as batch size, minimum inventory and delivery frequency. However, literature is full of similar examples regarding the combination of Kanban and Digital Twin/Simulation (e.g. Kolberg and Zühlke, 2015; Ferro et al, 2017). Furthermore, Mayr et al. (2018) argued that Digital Twin concept supported by simulation technologies enables dynamic ***VSM***, through the real-time replication of the whole manufacturing system, allowing the access to updated information as well as a more predictable and reliable planning. The last practice considered is ***People and Teamwork***: Lu and Yue (2011) suggested the use of simulation to facilitate employees training, allowing them to practice in a simulated environment.

2.2.1.2 *Main benefits of Industry 4.0 technologies on Lean practices*

Smart technologies – if aligned with Lean principles and concepts – are able to reduce non-value adding activities in organizations, as well as improve workers satisfaction. However, according to the literature, the most common benefits that Lean practices can take from Smart technologies are related to *improvement of data collection*, *improvement of decision making* and *routine processes innovation* (figure 1). In the following paragraphs, a description of some of the literature on these topics is reported.

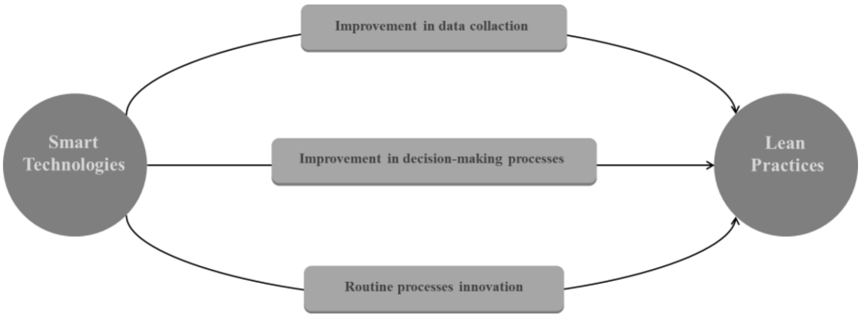

Figure 1 - Casual Map of Industry 4.0 benefits on Lean Production

The benefit of Industry 4.0 on **data collection improvement** has been supported by many authors. Firstly, Sanders et al (2016) showed that these technologies provide great solutions to the main challenges for Lean Production implementation – such as missing data and inappropriate track of components/finished goods – by providing better communication and synchronization of data and wireless tracking. The same conclusion was drawn by Haddud and Khare (2020), who underlined that Industry 4.0 empowers the Just-in-Time logic through a timely information sharing, that allows to have the right parts available, in the required quantities and qualities, at the right time. This improvement in data collection leads to a more accurate demand forecasting, a better management of procurement and a better inventory management and control. Moreover, the authors showed the great advantages that Kaizen takes from the fact that, thanks to Industry 4.0, information is easily captured, shared, processed and forwarded to the right people. On top of that, since Industry 4.0 technologies are able to provide data in real-time, they help complete the required equipment maintenance faster. The real-time provision of data has been deemed to be the best feature of IoT and Cloud Computing. In fact, it allows to give instant feedbacks about performance, enhancing Visual Management, and provide better communication between production stakeholders, helping People and Teamwork. These technologies are helpful also in Maintenance as they are able to gather precise information about maintenance needs and automatically send signals to employees (Pereira et al, 2019). In addition, it has been noted how Cloud

Computing capability of storing information about connected products is a strong leverage in Value Stream Mapping activities (Uriarte, Ng, & Moris, 2018).

As far as **decision-making** is concerned, its simplification and improvement represent one of the main benefits of the integration between Lean Production and Industry 4.0. First of all, simulation is deemed to be one of the most common techniques applied to support decision-makers in designing manufacturing systems (Negahban & Smith, 2014), for example through the use of the so-called simulation-based multi-objective optimization (SMO) (Uriarte et al, 2018). Additionally, it has been underlined that this technology, as well as the communication between different devices, is able to promote real-time decision-making over the traditional complex process (Tamás, Illés, & Dobos, 2016). Generally speaking, Rosin et al (2020) argued that Industry 4.0 provides organizations with systems able to review the set of alternatives where the decision-maker can choose the action to take. As a result, different Lean practices – such as Just-In-Time and People and Teamwork – are enhanced and supported. On top of that, it has been noted how IT-enabled information sharing allows a lower information lead-time, resulting in a shorter and more efficient decision-making process (Ghobakhloo & Fathi, 2020). In particular, IoT devices are able to provide autonomous optimized decisions in terms of flow, facilitating the Just-In-Time logic and leading to an improved management of the whole supply chain (Pereira et al, 2020). Moreover, IoT allows companies to capture data about process and products more quickly, to have global visibility on the overall supply chain, to work with more efficient and intelligence operations that, thanks to autonomous data collection and analysis, allows on-the-fly decision making (Miragliotta, Sianesi, Convertini, & Distante, 2018). Finally, Haddud and Khare (2020) demonstrated that Industry 4.0 technologies are able to enhance visual management techniques by providing a smart visualization of the supply chain, resulting in easier decision-making process. At the same time, these new technologies allow to collect and analyze previous risk events, making possible to predict possible future incidents and improving the precision of decisions in terms of risk management.

The last benefit taken into consideration is **routine processes innovation**. In particular, Industry 4.0 process innovation strategy always aims at increasing the production process efficiency, reducing waste and lowering marginal production cost - that is in line with Lean principles - and these improvements come with changes in routines and established industrial standards (Buer et al, 2018). In addition, Karkoszka and Honorowicz (2009) said that the proper combination between Kaizen method and operations of the innovative character gives the biggest effects and benefits. Moreover, Innovations allow following the newest trends and modern technologies, kaizen guarantees the continuity competences and essential standardization. Moreover, Industry 4.0 techniques implementation can enhance flexibility of the production system, solving the problem of ineffective maintenance (Al-Hyari et al, 2019). In this case, a good example is represented by the application of AR to enhance the maintenance activity where unskilled workers can be connected to skilled engineers for proper guidance (Masoni, et al., 2017). On top of that, Industry 4.0 technologies can aid in enhancing quality parameters such as quality production and services (Foidl & Felderer, 2015). For example, intelligent quality control system can enhance the product quality as well as process improvement (Vinodh et al, 2020). Lastly, autonomous and collaborative robotics appear having great potential in creating hybrid workplaces where humans and robots work in a collaborative way, promoting People and Teamwork (Pereira et al, 2019).

2.2.2 SMEs and Research Hypotheses

In order to define what a SME is, different countries use different parameters such as size, age, number of employees, annual turnover, sales and asset value of the organization (Yadav et al., 2019). As a consequence, it doesn’t exist a definitive global definition of Small and Medium Enterprises (Karlsson & Åhlström, 1997). Nevertheless, since the European Commission has agreed on a description, SMEs located in European countries are associated with the same characteristics. More specifically, organizations are recognized as micro, small or medium according to their number of employees, turnover, and balance sheet total (European Commission, 2020), as shown in table 2.

Company Category	Staff Headcount	Turnover	Balance Sheet Total
Medium	< 250	≤ € 50 m	≤ € 43 m
Small	< 50	≤ € 10 m	≤ € 10 m
Micro	< 10	≤ € 2 m	≤ € 2 m

Table 2 - SMEs definition according to European Commission

SMEs are largely considered as the backbone of the industrial and economic growth of a nation, as well as important contributors in terms of employment (Singh, Garg, & Sharma, 2010). In fact, they play a crucial role in Europe because they represent 99% of all businesses (European Commission, 2020) and provide 90 million workers with jobs**.** Additionally, they represent significant players in supply chain networks. Despite their importance, literature seems to neglect SMEs when it comes to Lean 4.0 and its practical implications. In fact, all the papers and academic articles used to develop the previous section (see section 2.2.1) take as reference Large Enterprises (LEs).

It is noteworthy that, on the other side, Lean Production and Industry 4.0 separately are quite well-studied in the context of SMEs. In particular, there are some topics that tend to be addressed by many researches: **enabling and inhibiting factors** (i.e. specific characteristics of SMEs that make them particularly suitable or, on the other side, unsuitable for Lean Production/Industry 4.0), **critical success factors** (i.e. the high-impact factors necessary for Lean Production/Industry 4.0 implementation) and **impacts** (i.e. how Lean Production/Industry 4.0 affects SMEs). In addition, there are some studies that investigate which **Lean practices** and **Industry 4.0 technologies** are actually adopted by SMEs. A summary of the findings associated with these topics are reported in the table below.

Lean Production	**Inhibiting Factors**	Low negotiation power, Lack of cooperation, Management distrusts business partners, Wrong organizational culture, Lack of management commitment and support, Lack of benefits understanding, Lack of knowledge and skills, Lack of employees' involvement, Resistance to change, Backsliding to old methods, Poor processes and quality control systems, Lack of budget, infrastructures, services, time, Less able to influence demand volatility and variability	Salaheldin, 2005; Wilson and Roy, 2009; Kolosar, 2018; Alkhoraifa et al, 2019; Yadav et al, 2019; and others
	Enabling Factors	SMEs are focused on specific business, Supportive organizational culture, Private ownership, Ease of communication, Teamwork, Multi-skilled workforce, Informal relationships, Less bureaucracy and requirements, Flexible production planning, Governments' support and grants, Closeness to customers	
	Critical Success Factors	Management Commitment and Leadership, Organizational Culture, Training of employees, Employees' Involvement and Participation, Communication, Financial Capability and Supply Chain Integration	Panizzolo et al, 2012; Dora et al, 2015; DeSanctis et al, 2018; Yadav et al, 2019; and others
	Impacts	Operational, Financial, Administrative, Social, Environmental Impacts	Kilpatrick, 2003; Driouach et al, 2019 ; Yadav et al, 2019; and others
	Lean Practices adopted	Kaizen, Total Production Maintenance, Visual Management, Kanban, Value Stream Mapping and SMED	Yadav et al, 2019; Alkhoraifa et al, 2019;
Industry 4.0	**Inhibiting Factors**	SMEs might be dependent on their suppliers, Lack of expertise, Employees' wrong perception of technologies, Organizational behavior, Short-term strategy, Lack of financial, technical and human resources	McAdam et al, 2001; Moeuf et al, 2018; Mittala et al, 2018 Moeuf et al, 2020; And others
	Enabling Factors	Fast decision making, Few layers of management, Simple and direct communication, High flexibility at all levels, Easy to introduce change and new methods, Closeness to customers	

	Critical Success Factors	Strong Presence of Managers, Employees' Training, Continuous Improvement Strategy, Carrying out a Study before starting the Project, Collaborations with Academic Members, Industry 4.0 Technologies' Simplification	Nwaiwu, 2020; Moeuf et al, 2020
	Impacts	Improvements in flexibility, productivity and lead times; improvements of monitoring activities, better control, optimization of resources and activities	Ren, et al, 2015; Moeuf et al, 2018; Mittala et al, 2018;
	Technologies adopted	Cloud Computing, Internet of Things and Simulation	Fornasiero et al, 2013; Bonfanti et al, 2015; Moeuf et al, 2018; and others

Table 3 - Lean Production and Industry 4.0 in SMEs

As mentioned before the research on Lean 4.0 in SMEs is still immature, especially when it comes to the practical combination of Lean Production and Industry 4.0. This might be due to the fact that, although these companies explicitly declared to be aware of the great potential associated with the combination of Industry 4.0 and Lean Production, not all of them have a clear knowledge and a consolidated experience with traditional Lean practices (Raucha et al, 2017). At the same time, they still face digitization with reluctance and skepticism (Hoellthalera et al, 2018). This is confirmed by table 3, which reveals that SMEs seem not to adopt all the Lean practices and Industry 4.0 technologies.

In light of this, most of researchers have focused their attention on investigating Lean 4.0 in LEs, as shown in table 4; as a consequence, to date, there is poor no research investigating Lean 4.0 in the context of SMEs, and to understand whether the main benefits highlighted in section 2.2.1.2 are also valid for this typology of company.

Papers	Industry 4.0	Lean Production	Lean 4.0
Large Enterprises	37	43	24
Small and Medium Enterprises	9	12	0

Table 4 - Comparison between LEs and SMEs

This sheds a light on a relevant gap in literature, that justifies this research work and leads to the formulation of the research hypotheses that have guided the operative part of the research:

HP 1: ***The integration between Industry 4.0 technologies and Lean Production practices positively affects SMEs in terms of improvements of the decision-making process.***

HP 2: ***The integration between Industry 4.0 technologies and Lean Production practices positively affects SMEs in terms of improvements of data collection process.***

HP 3: ***The integration between Industry 4.0 technologies and Lean Production practices positively affects SMEs in terms of innovation of routine processes.***

2.3 Methodology

The methodology used to test the research hypothesis is the one proposed by Polit and Beck (2004), whose main stages are reported in the following table.

Phase of Research	Techniques and Tools	Objective
Conceptual phase	Literature analysis	Scope and problem relevance identification
	Critical thought	Understanding the current situation
	Discussion with professors	Finding gaps in literature and formulating the hypotheses
Design and Planning phase	Nonexperimental research – Qualitative Analysis	Selection of the overall plan for conducting a study
	Sampling Plan composed by approximately 1200 SMEs	Selection of the sample of population for the analysis
	Validation through the use of survey	Definition of the method to collect data and finally validate the research
Empirical phase	Data collection	Collection of data from the sample of population
	Data preparation for the analysis	Preparation of data to get the dataset eventually used for the analysis of results
Analytic phase	Data Analysis	Analysis of data in order to identify relationships and patterns within it
	Results Discussion	Deep analysis and interpretation of the information gathered throughout the survey
Dissemination phase	Dissemination writing	Writing the report, with introduction, model, comparisons, data analysis and conclusions Drafting opened points for discussion: Follow-up

Table 5 - Polit and Beck's (2004) model of research

During the **Conceptual phase,** a deep literature analysis has been performed, together with critical discussions about the research ideas with professors. Thanks to these activities, it was possible to define the state-of-the-art about synergies between Lean practices and Industry 4.0 technologies, as well as to identify the main gaps in literature and formulate the research hypotheses.

The **Design and Planning phase** has been useful to plan the activities and prepare the resources necessary to run them. This phase is divided into three steps. Firstly, in the *research design* step, it has been decided to validate the hypothesis by means of a survey. In the *sample of population* step, approximately 1200 companies have been gathered from different sources taking into account the two main targets of the survey: manufacturing SMEs and consulting/service companies working directly with SMEs. In conclusion, the *validation* process (Beta test) has been extremely useful to test the worth and intelligibility of the survey. In this process, two trustworthy companies have been called to express their opinion about the structure and content of the survey. Thanks to their suggestions, the initial draft (appendix 1) has been gradually modified to its definitive version (appendix 2). This survey has been organized in three sections: the first one aims at investigating some characteristics of the respondent companies, the second one analyses the application of Lean Production practices and Industry 4.0 technologies and the last one is all about the three benefits.

The **Empirical phase** involves two steps: *data collection* and *data preparation* for the analysis. During the *data collection* step, the survey has been sent to the group of companies via e-mail. The total number of answers has been 326 out of 1200 companies involved in the sample of population, which is considered totally appropriate for the kind of research carried out in this dissertation. During the *data preparation* step, starting from the Excel file automatically provided by Opinio, some cleaning operations – namely, elimination of uncomplete, out of target and not relevant answers – have been conducted to obtain a dataset suitable for the analysis of results (see the detailed steps in section 2.4). In particular, the resulting dataset was populated by the complete answers of 75 companies, all of them in line with the targets of this research.

During the **Analytic phase,** data is analyzed to identify relationships and patterns within it. More specifically, the information gathered through the survey has been analyzed in two stages. Firstly, results associated with questions 1 to 15 of the survey (appendix 2) have been described and elaborated by means of tree charts and comparisons with literature findings. Secondly, answers to questions 16, 17 and 18 have been critically discussed through five different analyses to have all the perspectives and data necessary to either confirm or reject the research hypotheses.

The last phase has been the **Dissemination** one, which has allowed to spread the results, explain the model, draw meaningful conclusions and define the open points of discussion for further research. It has been conducted by writing down the steps followed throughout the research.

2.4 Results and Discussion

The description and discussion of the results is organized in the following seven sections. Section 2.4.1 describes the respondent companies and their answers to survey questions from 1 to 15 (see appendix 2). Section 2.4.2 compares those answers to the literature about Lean 4.0 in SMEs. Sections from 2.4.3 to 2.4.7 are meant to discuss, taking different perspectives, the results associated with the last survey questions, those related to research hypotheses. Figure 2 shows these analyses structure and their subjects.

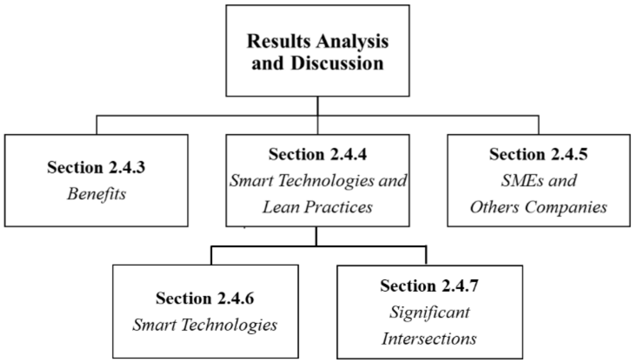

Figure 2 – Sections of the analysis and their subjects

2.4.1 Description and Representation of Respondent Companies

The first step of results' analysis has been to check how many significant answers have been collected. In particular, the answers have been divided according to the first question of the survey, asking whether they apply Lean Production practices and Industry 4.0 technologies (or work directly with SMEs that do). Considering that the number of complete answers has been 197 (out of 326), 114 respondent companies have declared not to be part of the target, meaning that they do not apply Lean practices and Smart Technologies. In addition, 8 out of the 83 left companies have proved to be large manufacturing companies and, therefore, they have not been considered as relevant. In conclusion, 75 companies have provided an answer that can be considered significant. Considering the first question of the survey (see appendix 2), a lower number of "Yes" compared to the amount of "No" represents a result totally in line with the expectations, given the target:

- The literature review had shown that SMEs adopt a little range of Lean practices and Industry 4.0 technologies. Since many companies that received the e-mail were SMEs, it seems reasonable that most of the sample declared not to apply Lean Production and Industry 4.0.
- As a consequence, companies working directly with SMEs are likely not to be involved in projects related to Lean Production and Industry 4.0.

The second step has been an analysis of the 75 respondent companies based on the characteristics investigated in the survey's first section (see questions 2 – 12, appendix 2). First of all, it is noteworthy that 64% of them is represented by manufacturing SMEs that apply Lean Practices and Smart Technologies, whereas the residual 36% is associated with other companies working directly with SMEs that adopt Lean Production and Industry 4.0, as shown in figure 3.

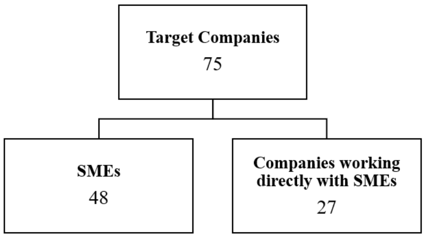

Figure 3 - Distribution of respondent companies

Then, by means of the following tree charts (figures 4-5), the two targets have been analyzed in terms of how they are distributed according to the above-mentioned characteristics.

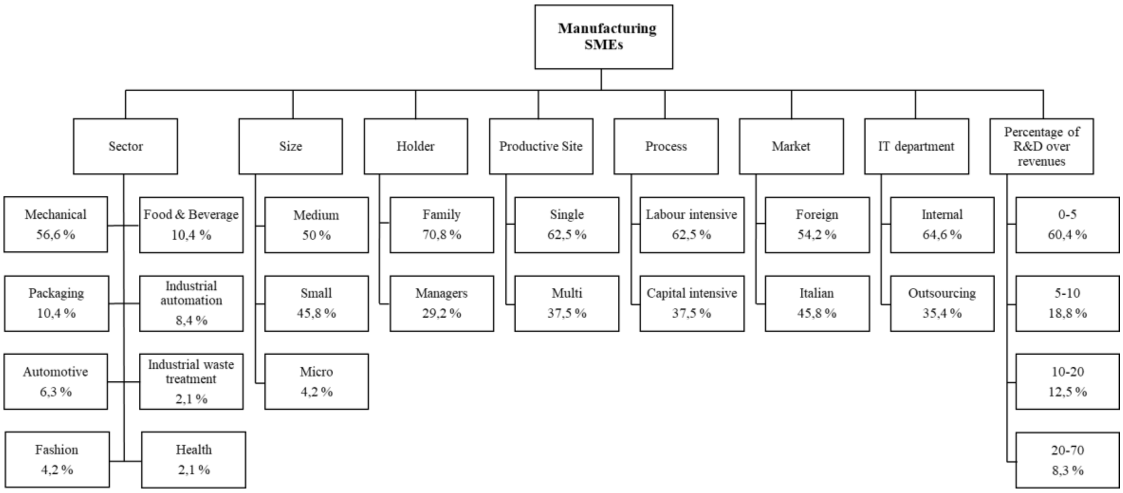

Figure 4 - Distribution of manufacturing SMEs according to the dimensions of analysis

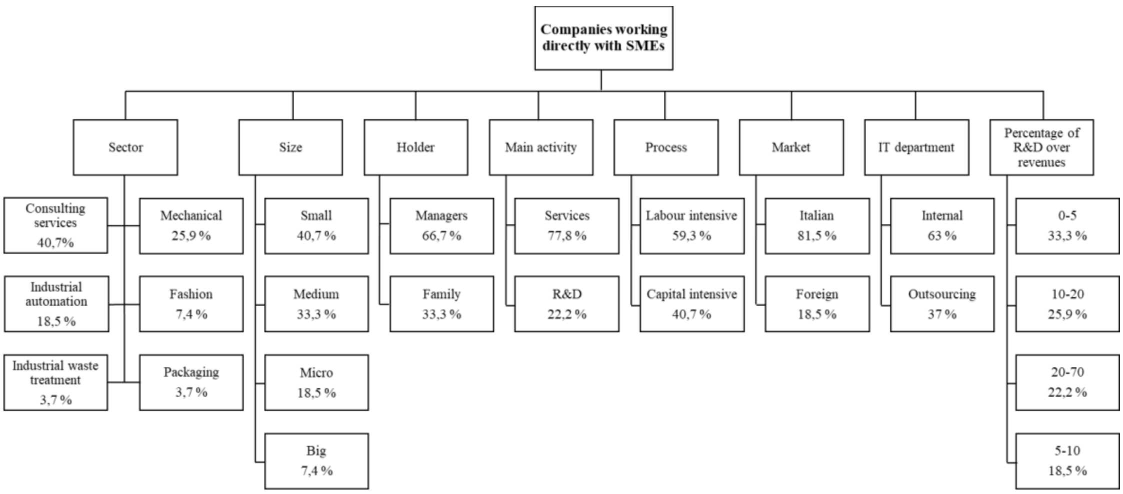

Figure 5 - Distribution of other respondent companies according to the dimensions of analysis

The following step of results description has been to analyze SMEs' adoption of Lean practices and Smart technologies separately. Starting from Lean practices, it is noteworthy that three out of four foundations principles of House of Lean (Liker, 2004) – Kaizen, Visual Management, Standardization – have turned out to be quite applied by SMEs. Conversely, Heijunka is placed among the least applied practices and this might be due to the production flexibility and informal rules on operational planning characterizing SMEs (Yadav et al, 2019). In addition, the two pillars of the House – JIT and Jidoka – are ranked very differently. This might be due to the fact that Jidoka is strictly related to automatization of processes, which requires specific competences and resources. In fact, the main tools associated with Jidoka – Poka Yoke, Andon, TPM – are not much applied as well. On the opposite side, Kanban – the main practice of JIT – is adopted almost as much as Kaizen. This might be related also to the fact that it represents one of the most proven Lean practices. Finally, it is worth mentioning the wide adoption of People and Teamwork. In fact, this is completely in line with SMEs' organizational structure, which is short and fluid (Laufs et al, 2016), and their supportive organizational culture, which enhances teamwork and collaboration (Yadav et al, 2019).

As far as Smart Technologies are concerned, according to respondent companies, Industrial Analytics and Industrial Internet of Things are the most applied technologies; while Additive Manufacturing, Digital Twin/Simulation and Advanced Human-Machine Interface the least ones. At the same time, a fair amount of respondent companies has declared to adopt Advanced Automation, Cloud Manufacturing, Advanced Human-Machine Interface. Generally speaking, Industrial Analytics, Internet of Things and Cloud Manufacturing represent the most consolidated and accessible Smart Technologies. However, SMEs do not adopt Cloud Manufacturing as much as Industrial Analytics and Internet of Things and this might be due to SMEs' lack of expertise, as well as to the weak influence they are likely to have towards their supply chain partners. As for Digital Twin and Simulation, the low adoption might be related to the fact that these technologies are still not completely developed; while SMEs' lack of financial resources and specific competences might be the reasons why they are still sceptical in investing in Additive Manufacturing and Advanced Human-Machine Interface.

The last step of this analysis is related to Lean 4.0. In particular, the framework shown in the Literature Review has been rebuilt based on the survey answers (table 6). In this way, it is possible to clarify which intersections between Lean Production and Industry 4.0 are mostly implemented by SMEs. As expected, the most numerous intersections are the ones associated with the most adopted practices and technologies, and vice versa.

Lean 4.0	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen	5	7	6	16	15	7	
Andon		1		3	2	2	
Poke Yoke	2	2	2	2	3	3	
TPM (Total Production Maintenance)		2	1	3	2	1	1
Jidoka		1		2	2	1	
Standardization	3	6	2	4	3	1	2
5S	3	3	3	7	11	5	1
Visual Management	3	3	5	5	3	1	2
Kanban	1	7	4	5	12	7	2
JIT (Just in Time)	1	6	1	5	8	3	1
Muda Reduction		1	1	1	5	2	
VSM (Value Stream Mapping)	1	3	1	2	1		1
Heijunka				1	1		
SMED	1	1		2	3		
People and Teamwork	2	3	4	8	5	3	

Table 6 - Lean 4.0 framework for SMEs

2.4.2 Comparison with the Literature

This section is meant to make a comparison between the survey results and the literature findings in terms of Lean practices and Smart Technologies adoption. Starting from Lean practices, Literature Review (table 3) shows that Kaizen, TPM, Standardization, 5S, Visual Management, Kanban, VSM and SMED are the mostly used practices in SMEs, while Heijunka, Andon and Jidoka are not even mentioned. For some of these practices, the results of the questionnaire are in line with the literature. Firstly, Kaizen, Kanban and 5S seem to be the most used practices in SMEs, as well as Visual Management and Standardization. Secondly, Heijunka, Andon and Jidoka seem to be the least used practices in SMEs. On the contrary, according to the 75 respondent companies, SMED, VSM and TPM rank among the least adopted practices. In particular, they have turned out to be applied as much as Muda Reduction and Poka Yoke, which are not mentioned at all by literature. Finally, People and Teamwork and Just in Time appear to be quite used in SMEs, even if their role is totally underestimated by researchers.

As for Smart Technologies, according to the literature (table 3), Cloud Manufacturing, IoT and Simulation are the most widespread in SMEs. However, survey results have revealed that IoT is the only technology confirming this statement. In fact, many technologies are more applied than Cloud Manufacturing, while Simulation turns out to be the least adopted. Besides, Additive Manufacturing confirms the literature, as it seems to be not so much used in SMEs. Lastly, the presence of Industrial Analytics, Advanced Human-Machine interface and Advanced Automation in SMEs seems to be totally underestimated by literature and researchers. In fact, Industrial Analytics appears to be the most applied technology, while Advanced Automation results to be even more applied than Cloud Manufacturing.

All in all, the survey results for both Lean Practices and Smart Technologies present some differences from the literature findings. This might be due to different reasons:

- An evolution of SMEs over the last years might have generated different results from the ones found in literature.
- Researchers might not be focusing enough on Lean Production and Industry 4.0 application in SMEs.
- Literature statements might be purely theoretical and not based on empirical studies and researches.
- The respondent companies of the survey might not be representative of the overall Italian SMEs market. In fact, the sample of population is represented by 75 companies only.
- The respondent companies might not be completely aware of Lean practices and Smart technologies definitions.

Finally, it is worth comparing the framework built in the previous section (table 6) to the one proposed in the Literature Review (table 1). This comparison needs to be performed merely by looking at the presence of the intersections within the two frameworks, as the numbers inside them are incomparable: the ones in table 1 represent the amount of papers and academic articles that describe that intersection in LEs, while the ones in table 6 represent the number of answers to this dissertation survey. In addition, for the framework created from the survey answers, only the cells presenting a number higher than 4 have been considered, as less than four answers is not enough to claim that a certain intersection exists.

In terms of density, the Literature Review framework is populated by many more intersections. This is in line with the expectations because the Literature Review showed that, nowadays, SMEs do not adopt Lean Production practices and Industry 4.0 technologies as LEs do. Looking at the columns of table 6, the first clear evidence is that, differently from LEs, SMEs seem not to apply Digital Twin/Simulation at all. This might depend on the fact that these technologies are quite new and, above all, quite complex. In fact, their implementation requires companies a lot of commitment, competences, and investments. A similar reasoning might apply for Advanced Human-Machine Interface, which turns out to be much more adopted by LEs than SMEs. On the other side, Cloud

Manufacturing, Industrial Analytics, IoT and Advanced Automation are adopted quite in the same way. In fact, these technologies represent the ones that, according to respondent companies, are mostly applied by SMEs. Additionally, most of these technologies are suitable to be combined with Lean Production practices, as extensively explained in the Literature Review (see section 2.2.1.1). Moreover, Additive Manufacturing seems to be almost not applied by SMEs but, surprisingly, also by LEs. Once again, this might be due to the high costs and competences necessary to implement it. However, Additive Manufacturing – because of its own characteristics – is compatible with just a few Lean Production practices, as shown in section 2.2.1.1 of the Literature Review.

2.4.3 Benefits Perception

The main aim of this analysis is trying to understand if the respondent companies perceive the three benefits mentioned in the research hypotheses in the same way. For each of the three benefits, the Weighted Mean – weighted on the number of answers for each intersection – has been calculated and the results of this operation, from now on, will be called **Benefit Impacts**. These values provide an indication of "how much" the respondent companies perceive the single processes as getting benefits from Lean Production and Industry 4.0 integration. Then, the Arithmetic Mean between those Benefit Impacts has been calculated (for more details see Appendix 4) and called, from now on, **Total Impact**. Generally speaking, this value allows to understand to what extent the integration between Lean Production and Industry 4.0 is perceived as beneficial by SMEs. These values are reported in table 7.

Benefits (based on 75 respondent companies)	**Benefits Impacts**
Data Collection	3.5
Decision-Making	3.4
Process Innovation	3.5
Total Impact	**3.5**

Table 7 - Means used to perform the analysis

As table 7 shows, the Total Impact is slightly higher than 3, the average number of the scale proposed in the survey (from 1 to 5). This means that, according to the respondent companies, the integration of Industry 4.0 technologies and Lean Production practices benefits SMEs to a certain extent. Additionally, the Benefit Impacts are strongly similar among each other, indicating that respondent companies perceive these benefits quite in the same way.

As the Benefit Impacts appear to be so similar among each other, it might be interesting to investigate if they come from different distributions of answers. In particular, for each benefit, it has been analysed how the values used to calculate the Benefit Impact are distributed with respect to the Total Impact value (i.e. 3.5). In order to do so, it has been necessary to divide those values according to different ranges, which have been chosen looking at the Benefits Boxplots (figure 6). The plot shows that the range of the average values is the one between 3.2 and 3.8, as it is common to all the three benefits.

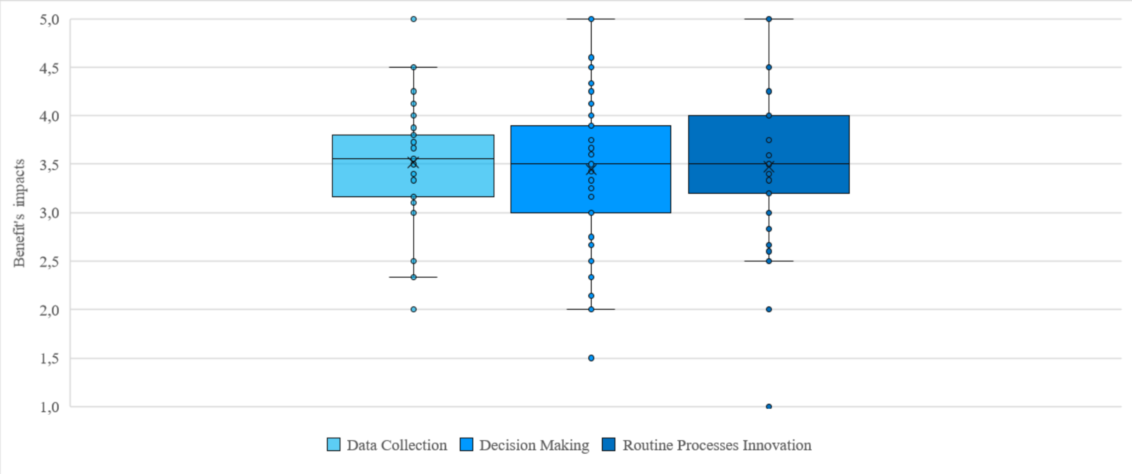

Figure 6 - Benefits Boxplots

In order to perform a proper analysis, the values used to calculate the Benefit Impact have been assigned different colours:

- Yellow if they are in between 3.2 and 3.8. As explained before, this range includes the values closest to the Total Impact.
- Red if they are lower than 3.2. In this case, the values are considered as much lower than the Total Impact.
- Green if they are higher than 3.8. In the same way, these values are considered as much higher than the Total Impact.

Figure 7 summarizes the colour distribution of each benefit considering the amount of values belonging to each category. A comparison between the columns of the same range along the three benefits leads to some general considerations:

- The tallest column related to values lower than 3.2 (i.e. red) is associated with decision making, while the data collection and routine process innovation ones are shorter and balanced.
- The columns related to values between 3.2 and 3.8 (i.e. yellow) of decision making and routine process innovation present a very similar height, while the data collection one is quite taller.
- The tallest column related to values higher than 3.8 (i.e. green) is associated with routine process innovation, while the other two benefits are characterized by shorter ones.

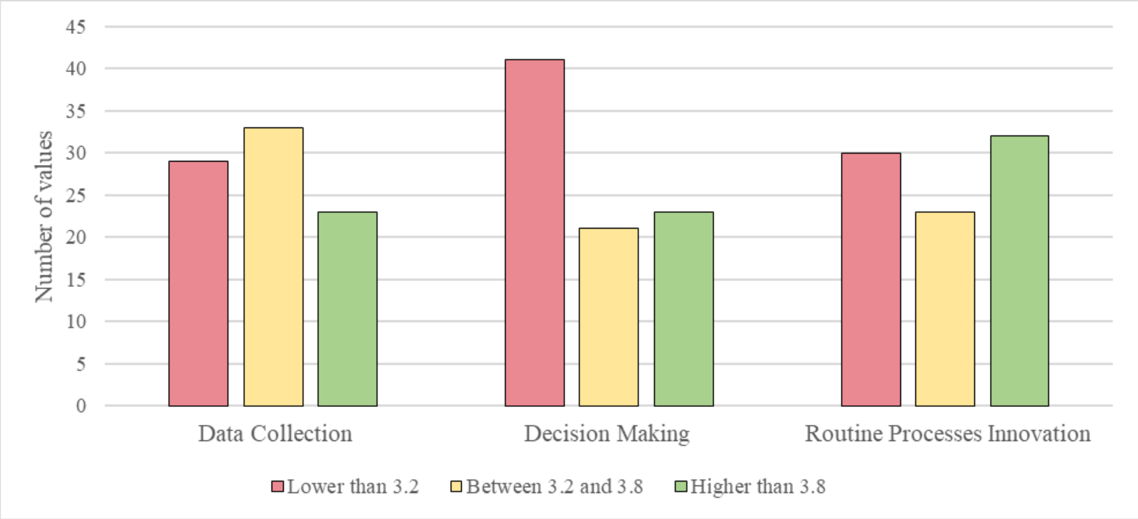

Figure 7 - General color distributions for the three benefits

In light of this, it is possible to state that the three benefits are characterized by different answers distributions. However, as the Benefit Impacts are so similar, these differences need to counterbalance one another:

- **Data collection improvement** is characterized by a higher amount of yellow values than red and green ones, confirming that the perception of this benefit is in line with the Total Impact value. In fact, the implementation of some Smart Technologies – such as Cloud Manufacturing – naturally leads to simplify the data collection process. However, this simplification takes place when these technologies are coupled with expertise and competences in terms of data analysis and interpretation. If companies lack these features, they might not be able to totally perceive their benefits.
- Conversely, **decision-making improvement** is characterized by way more red values than yellow and green ones. This might be due to the organizational structure of SMEs, that are likely not to have a proper department that makes decisions for the whole company. Normally, the different departments make decisions for themselves. Therefore, it might be difficult to perceive the benefit related to decision making because there is not a centralized view of this process in those companies. Nevertheless, decision-making Benefit Impact is in line with the other ones and this might be explained mathematically. In fact, it is likely that the few companies belonging to the green range have assigned to this benefit a value much higher than 3.8, while the many ones belonging to the red one have declared a value close to 3.2.

- **Routine processes innovation** is characterized by more red and green values than yellow ones. This tendency towards either green or red values might depend on the Smart Technology considered. In fact, the introduction of some Industry 4.0 technologies naturally brings changes in SMEs. As a consequence, the employees tend to face changes in their daily activities. For instance, Advanced Automation is able to automatize some manual tasks, allowing workers to focus on more important activities. Even if this is an inner feature of Advanced Automation, it leads to a change in the way people work on a daily basis who will perceive it as an innovation. On the other side, some Smart Technologies do not affect the routine processes, as they refer to data collection, treatment and sharing. This might be the case of Cloud Manufacturing, that does not impact the daily tasks of many employees. However, the amounts of red and green values are quite balanced, reconfirming the fact that this benefit is perceived as much as the other two.

All in all, it is possible to conclude that the similar results obtained in terms of Benefit Impacts come from very different distributions of answers. This might be justified by the different benefits characteristics or by the diverse perception that SMEs have of them after implementing Smart Technologies.

2.4.4 Analysis on Smart Technologies and Lean Practices

The perspective taken in this analysis is the one of Lean Production practices and Industry 4.0 technologies. In fact, the main aim is twofold:

1) Understanding how beneficial SMEs perceive Industry 4.0 technologies according to the 75 respondent companies.
2) Understanding how SMEs perceive the benefits on Lean Production practices according to the 75 respondent companies.

To do so, for each technology and practice, the Arithmetic Mean among the Weighted Means associated with each benefit has been calculated (tables 8 and 9). This value represents the general benefit perceived on each practice and from each technology. Then, both Industry 4.0 technologies and Lean Production practices have been divided according to the three ranges described in the previous analysis, in order to get a clear understanding of how they are distributed. This division has been graphically represented by coloring the general benefits cells according to the colors related to the three ranges.

Starting from Industry 4.0 technologies, table 8 shows three main evidence:

- There is no technology in the green range, meaning that none of them is perceived as much more beneficial than the others.
- Five out of seven technologies belong to the yellow range, meaning that they are perceived as beneficial quite in the same way. It is noteworthy that these technologies correspond to the most adopted ones by SMEs (see section 2.4.1). As a consequence, they can be considered trustworthy in the way they perceive these technologies as beneficial in their integration with Lean. In addition, the majority of them are IT. This reconfirms the fact that, to date, SMEs are more comfortable dealing with the most proven and accessible Smart Technologies.
- There are two technologies in the red range: **Additive Manufacturing** and **Digital Twin/Simulation**. These technologies represent the least adopted by SMEs and, consequently, it might be hard for them to clearly judge how beneficial they are. This might be related to the complexity – in terms of financial investment and necessity of specific competencies – associated with them. In addition, **Additive Manufacturing** is useful in very specific situations that might not occur in small business. A similar reasoning applies for **Digital Twin/Simulation.** In fact, these technologies are particularly advantageous when companies deal with a high degree of complexity, which might not be the case of SMEs.

	Industrial IoT	Advanced Automation	Industrial Analytics	Cloud Manufacturing	Advanced HMI	Additive Manufacturing	Digital Twin/Simulation
DC	3.8	3.7	3.5	3.5	3.3	3.3	2.9
DM	3.6	3.5	3.6	3.4	3.3	3.1	2.8
RPI	3.6	3.8	3.7	3.4	3.4	3.0	2.8
	3.7	3.7	3.6	3.4	3.3	3.1	2.8

Table 8 – Impacts per benefit and general impacts of Industry 4.0 technologies

As far as Lean practices are concerned, table 9 leads to some interesting considerations:

- Once again, most of the practices belonging to the yellow range represent the most adopted by SMEs (see section 2.4.1). As a consequence, they can perceive more clearly the befits on these practices. In addition, these practices include three out of four foundations of the House of Lean (Liker, 2004) (**Standardization, Visual Management, Kaizen**) and its main pillars (**Just in Time**, **Jidoka, People and Teamwork, Muda Reduction**). This indicates that SMEs are perceiving a real benefit on those practices that are fundamental to build an up and running Lean system.
- On the opposite side, the practices belonging to the green and red ranges represent the least adopted ones (see section 2.4.1). However, some differences should be highlighted. Firstly, the red range is populated by **Andon, VSM** and **SMED.**

These practices play a strictly operational role, and their functioning might not be particularly affected by Industry 4.0. In fact, literature tends not to mention them when it comes to Smart Technologies benefits (see section 2.2.1.2). Secondly, the green range includes **TPM** and **Heijunka**. Literature presents much evidence of the different ways in which Industry 4.0 benefits the Maintenance processes. Hence, according to respondent companies, SMEs definitely appreciate the three benefits on this practice. Conversely, literature tends to neglect Heijunka, also in the context of LEs. As a consequence, to date, there is no consolidated knowledge about the way this practice takes advantage from Smart Technologies. However, according to respondent companies, SMEs perceive these benefits quite a lot.

	TPM	Heijunka	Standardization	Visual Management	People and Teamwork
DC	3.8	3.0	3.6	3.9	3.9
DM	4.2	5.0	3.5	3.6	3.5
RPI	4.1	4.0	3.9	3.7	3.8
	4.0	4.0	3.7	3.7	3.7
	Jidoka	**Kaizen**	**Just in Time**	**Poke Yoke**	**5S**
DC	3.7	3.5	3.5	3.4	3.3
DM	3.2	3.6	3.4	3.3	3.6
RPI	3.8	3.6	3.6	3.4	3.4
	3.6	3.6	3.5	3.4	3.4
	Muda Reduction	**Kanban**	**Andon**	**VSM**	**SMED**
DC	3.4	3.4	3.3	3.2	3.0
DM	2.8	3.2	3.0	3.4	2.7
RPI	3.6	3.2	2.9	2.8	3.0
	3.3	3.3	3.1	3.1	2.9

Table 9 - Lean Production practices Weighted and Arithmetic Means

2.4.5 Relationship Analysis on Smart Technologies

This analysis is meant to explore even more Smart Technologies and the relationships between them. More specifically, it has been performed on a simplified version of the framework presented in section 2.4.1 (table 6), wherein 3 out of 7 columns and 10 out of 15 rows have been excluded. In fact, in this analysis only the intersections with more than 7 answers have been taken into consideration, aiming at working on a larger and more reliable sample (table 10).

Semplified Matrix Lean 4.0	Advanced Automation	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing
Kaizen	7	7	15	16
5S		7	11	
Kanban	7		12	7
JIT (Just in Time)			8	
People and Teamwork		8		

Table 10 - Simplified framework of Lean 4.0 in SMEs

Starting from this simplified framework, the analysis has been performed row by row. All the considerations reported in the following paragraphs have been pointed out by comparing the four technologies pairwise and they have been expressed only if more than three of the considered rows show the same trend. This analysis has been performed separately for each benefit and the common findings have been summarized in figure 8.

More precisely, two typologies of relationship between technologies have been proposed:

- The two considered technologies show a direct connection (e.g. the same respondent company has declared the same benefit value for both Cloud manufacturing and IoT). In this case, the graphical representation occurs with a straight line between the two technologies.
- The two considered technologies present a positive relationship. In particular, a positive relationship takes place when two conditions hold true:
    1. Respondent companies that declare to adopt two technologies together assign high benefits values to both of them.
    2. Respondent companies that declare to adopt only one of those two technologies assign lower benefits values to it.

  In particular, a positive relationship is represented with a straight line and a +.

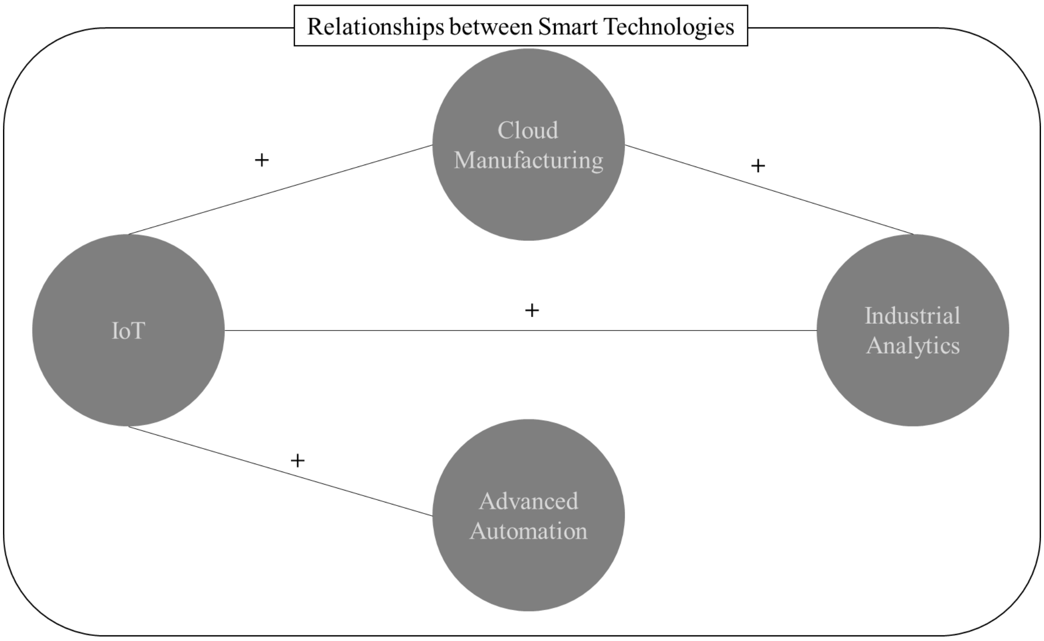

Figure 8 - Relationship between Smart Technologies

Figure 8 summarizes the relations among Smart Technologies identified among all the three benefits, leading to some general conclusions:

1. The presence of three Information Technologies over only one Operations Technology is an aspect that might justify the stronger relation present between the first three technologies excluding, in some way, the last one. However, this does not mean that Advanced Automation is not related to the other technologies.

In fact, Information Technologies are more widespread in the SMEs context and, consequently, companies might perceive them as easier to adopt.

2. Another important factor is related to the absence of connections between Cloud Manufacturing and Advanced Automation and between Advanced Automation and Industrial Analytics. This may be related to the fact that the link between Information Technologies and Operations Technology is IoT. In fact, Cloud Manufacturing and Industrial Analytics are used for analysis and storage of data, while Advanced Automation is used for more practical operations.
3. Generally speaking, IoT appears to be positively related to all the other technologies. This might be the consequence of its versatile nature that makes it adaptable to different contexts, as well as different Lean practices.
4. Finally, there seems to be no "negative relationships" among the analysed technologies. In other words, there is no case in which respondent companies that declare to adopt two technologies together assign high benefits values to one of them and low values to the other one.

2.4.6 Benefits analysis for the Eleven Intersections

This analysis has been performed following the lead of the one in section 2.4.5, as the focus is on the eleven intersections of the simplified framework. However, in this case a framework for each benefit has been created. In addition, the three frameworks (table 11) are populated by the Arithmetic Means of the benefit values declared by respondent companies for each specific intersection. These values will be named as Impact Levels from now on.

This analysis revolves around a comparison among the Impact Levels associated with the intersections. The main aim is to understand if the values of those particular Lean practices and Smart Technologies are different between each other and if there are some outliers. In addition, it has been performed looking at the three benefits separately, aiming at understanding whether the exceptions are consistent along them.

Data Collection	Advanced Automation	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing
Kaizen	3.57	3.75	3.40	3.57
5S		3.57	3.27	
Kanban	3.14		3.75	3.29
JIT (Just in Time)			4.13	
People and Teamwork		3.88		

Decision Making	Advanced Automation	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing
Kaizen	3.29	3.69	3.40	3.29
5S		3.29	3.73	
Kanban	2.14		3.92	3.00
JIT (Just in Time)			4.13	
People and Teamwork		3.75		

Process Innovation	Advanced Automation	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing
Kaizen	3.29	3.75	3.73	3.71
5S		3.43	3.18	
Kanban	2.71		3.67	3.43
JIT (Just in Time)			4.00	
People and Teamwork		3.63		

Table 11 - Benefits Weighted Means for the Simplified Matrix

Considering that respondent companies have been asked to evaluate the benefits with a value from 1 to 5, the most common answer has been 3. However, table 11 shows that there have been some exceptions (see red and green cells):

- The intersection between Just in Time and Industrial Analytics. More accurately, this intersection is perceived as more beneficial than the others from all the three benefits point of view. This might be due to the fact that Industrial Analytics is able to speed up the order processing activity, leading to an enhancement of Just in Time philosophy.
- The intersection between Kanban and Advanced Automation. In this case, two out of three benefits present an Impact Level lower than 3. Therefore, this intersection is perceived as less beneficial than others. This might be related to Advanced Automation and Kanban nature, that are characterized by no common elements. In fact, Kanban is mainly applied to improve production schedule and set priorities, while Advanced Automation is aimed at preventing mistakes and time waste by increasing the level of automation of processes.

2.4.7 Comparison Analysis between SMEs and Other Companies answers

The main aim of this analysis is understanding whether the answers provided by the two targets are consistent. In fact, throughout the previous sections, the respondent companies have been considered as a unique group. To perform this analysis, instead, they have been split in the two targets: SMEs and companies working directly with SMEs – called Other Companies from now on.

Table 12 shows the subdivision of survey answers between the two groups. It goes without saying that the framework of SMEs – associated with 48 answers – presents more complete intersections than the one of Other Companies, associated with 27 out of 75. Besides, these differences in distributions might be related to the fact that Other Companies have been asked to fill in the survey by referring to SMEs they work with and, for sure, it is more difficult to understand the benefits of something that is applied and used by others.

Lean 4.0 SMEs (48)	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen	X	X	X	X	X	X	
Andon		X		X	X	X	
Poke Yoke	X	X	X	X	X	X	
TPM (Total Production Maintenance)		X		X	X		X
Jidoka		X		X	X	X	
Standardization	X	X	X	X	X		X
5S	X	X	X	X	X	X	X
Visual Management	X	X	X	X	X	X	X
Kanban		X	X	X	X	X	X
JIT (Just in Time)	X	X	X	X	X	X	X
Muda Reduction		X	X	X	X	X	
VSM (Value Stream Mapping)		X		X			X
Heijunka				X			
SMED	X	X		X	X		
People and Teamwork	X	X	X	X	X	X	

Lean 4.0 Other Companies (27)	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen	X	X	X	X	X	X	
Andon							
Poke Yoke			X		X		
TPM (Total Production Maintenance)		X	X	X	X	X	
Jidoka					X		
Standardization		X	X				
5S	X	X	X	X	X	X	
Visual Management	X	X	X	X			X
Kanban	X	X	X	X	X	X	X
JIT (Just in Time)		X		X	X	X	
Muda Reduction					X		
VSM (Value Stream Mapping)	X	X	X	X	X		
Heijunka					X		
SMED							
People and Teamwork	X	X	X	X	X	X	

Table 12 - Frameworks for the two targets split by number of answers

An important aspect of this analysis is that it is not focused on the Impact Levels of each intersection, but on the comparison – for each benefit – between the distribution of those Impact Levels and the Benefit Impact (respectively 3.5, 3.4 and 3.5 for data collection, decision-making and process innovation). Therefore, the matrices shown in table 13 summarize the above-mentioned distributions, which have been coloured using the same ranges of section 2.4.3. More specifically:

- Green corresponds to Impact Levels higher than 3.8;
- Yellow corresponds to Impact Levels in between 3.2 and 3.8;
- Red corresponds to Impact Levels lower than 3.2;

	SMEs						
	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/ Simulation
Data Collection Improvement							X
Decision-Making Improvement							X
Routine Processes Innovation							X

	Others Companies						
	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/ Simulation
Data Collection Improvement							X
Decision-Making Improvement							X
Routine Processes Innovation							X

Table 13 - Matrixes of synthesis for the two targets benefits

Looking at table 13, it is possible to draw some considerations:

- Digital Twin/Simulation cannot be analysed and compared because of the limited number of intersections (only two) for Other Companies.
- IoT and Cloud Manufacturing are the only technologies associated with the same trend for the two targets, even if it is reversed. This means that the percentages of green, yellow and red spots are similar along the benefits, so – on average – the overall value for these technologies is close to the Total Impact (i.e. 3.5). This might be the consequence of IoT and Cloud Manufacturing nature, as they are easily applicable to many different scenarios.
- Finally, the other four technologies might be divided in two groups:
    1. Advanced Automation and Industrial Analytics are characterized by a major presence of green and yellow spots, meaning that both the two targets perceive them as positive from all the benefits points of view.
    2. Additive Manufacturing and Advanced Human-Machine Interface present a different distribution of green and red spots between the two targets. In particular, other companies are associated with only green spots, while the opposite happens for SMEs. This might be justified by the difficulty of these technologies' implementation in SMEs. In particular, their beneficial aspect appears not to be perceived so much by the SMEs using them, but only by the other companies that are offering to SMEs that specific technology implementation.

In conclusion, this analysis highlights the fact that the perception of the three benefits by the two targets is not the same for all the technologies. This suggests that, changing the perspective of the analysis, it is possible to obtain some remarkable insights.

Consequently, it is necessary to deepen into Lean 4.0 main benefits through different points of observation.

2.5 Conclusions

In light of the whole discussion conducted in the analysis of results, it is possible to state that the three hypotheses formulated in section 2.2.2 are **confirmed**. In fact, the different analyses performed in section 2.4 have demonstrated that SMEs seem to recognize an improvement in data collection, decision making and an innovation of routine processes associated with the integration of Industry 4.0 and Lean Production to a certain extent, which can be ranked as 3.5 out of 5. It is worth mentioning that the validation of the three hypotheses has been performed considering the overall framework and not the specific intersections. In fact, the three hypotheses have been formulated in general terms, meaning that they refer to the impacts that Lean 4.0 as whole exerts on SMEs. In addition, a detailed analysis on the intersections is impossible to be conducted with the few amount of data collected.

It is worth mentioning the **limits** associated with this dissertation. First of all, the number of answers collected through the survey (i.e. 75) is not enough to draw conclusions that can be strongly generalized. For the same reason, the considerations related to the analysis performed in section 2.4.7 somewhere are a bit weak and, at the same time, the characteristics investigated through questions from 1 to 12 in the survey resulted to be not relevant. Another criticality lies in the fact that, unfortunately, the databases used to find companies to involve in the survey were not able to filter on the application of Lean Production and Industry 4.0. Consequently, it is likely that many useful companies have not been contacted. Considering these criticalities, it would be interesting to test the results by collecting more answers. In this context, it would be useful to try to investigate once again the companies' characteristics that might produce some interesting findings. For instance, the same analysis on the benefits might be performed by dividing the companies based on the sectors they belong to. However, if this was not the case, it would be necessary to look for new characteristics and study how the answers are distributed according to them.

Starting from the results obtained in this dissertation, many **open points of discussion** might be investigated. First of all, the same qualitative research might be performed in order to study different benefits, such as outcomes quality improvement or increased customer satisfaction. Secondly, it might be interesting to follow a case-study methodology to relate the respondent companies answers to the reasons why they provided those answers, aiming at understanding the SMEs' enabling and inhibiting factors behind their perception of Lean 4.0 benefits. In a similar way, the case-study methodology might be used to investigate the reasons why companies that appear to be similar have declared different levels of benefit. Furthermore, the same three benefits might be addressed following a quantitative approach. In particular, it would be appropriate to analyze the effects of Lean 4.0 benefits on profit or productivity growth. Finally, after collecting more answers, it might be interesting to perform a detailed analysis on each specific intersection. In this way, it would be possible to investigate the benefits that the specific combinations between Lean Production practices and Industry 4.0 technologies bring to SMEs.

3. Introduction

Since the beginning of industrialization, technological and industrial progresses have led to the evolution, in different steps, of the so-called *Industrial Revolutions*. These steps were usually characterized by a drastic increase in productivity.

The *I Industrial Revolution* has been triggered by the introduction of the flying shuttle of Jhon Kay in 1733, as well as the steam power of James Watt in 1769. Both these new technologies have been invented in England because of its economic and commercial solidity of that period.

Moreover, the *II Industrial Revolution* conventionally started in 1870 with the discovery of electricity, chemical products, and crude oil, together with the change concept of mass production. This change was mainly due to the technological and scientific advantage of Europe over the rest of the world in 19^{th} century.

In addition, the beginning of the *III Industrial Revolution* can be set in the second half of 20^{th} century with the rise of electronics, telecommunications and, of course, computers. Thanks to these new technologies, the third industrial revolution have opened the doors to space expeditions, research, and biotechnology.

Finally, in 2011, it has been introduced, for the first time, the concept of *Industry 4.0* – one of the two main topics of this dissertation – in Germany at the Hannover Messe. More specifically, Industry 4.0 is “a vision of the future of Industry and Manufacturing in which information technologies are going to boost competitiveness and efficiency by interconnecting every resource (data, people and machineries) in the Value Chain” (Politecnico di Milano, 2017).

Many manufacturing companies, nowadays, are still overwhelmed by the change that Industry 4.0 introduced. In fact, Smart Technologies prove themselves useful and revolutionary only when they support production systems already in place. Thus, in order to show companies that these technologies are worth the investment, they need to be introduced in organizational contexts that have been up and running to many decades. In this regard, one of the most widespread and well-functioning production system ever invented is *Lean Production*, which is applied by many different companies all over the world.

More specifically, Lean Production was born in Japan, during the same years of *III Industrial Revolution* development, as “a mere response to the state of the Japanese automobile industry after the World War II” (Ohno, 1973). In fact, automobile industry in Japan was seriously damaged by the war and, on top of that, it was hard to survive in the competitive environment established by Europe and America with the mass production system.

In this context, Taiichi Ohno was appointed to come up with a solution to recover from this cumbersome situation. More specifically, since in that period efficiency was the main driver, he was asked to find a way to increase productivity in the factory. For this reason, he carefully studied Ford’s production process and understood that it was necessary to adapt it to the current Japanese industry. In particular, he put together the two pillars of Jidoka and Just-in-Time, giving birth to the *Toyota Production System* (TPS). This system is associated with the term “Lean” because it allows to use less resources (e.g. human effort, machinery, inventory, etc.) than mass production, with the final aim of “doing more with less”.

Lean Production represents one of the most efficient systems to organize production flows as it allows to reduce any kind of waste, leading to customer-centered operations and increased profitability. For this reason, lots of companies have been implementing it throughout the years, irrespectively of the industry. However, this established method needs to face the new emerging needs of modern companies that, in turn, are well-addressed by Industry 4.0 technologies. In light of this, the topic of Lean 4.0 (i.e. the synergies between Lean Production and Industry 4.0) has been widely addressed by the research.

Initially, two prevalent lines of thought about the relation between Lean Production and Industry 4.0 have been highlighted: *mono-directional* and *bi-directional* relationship. The former is associated with the belief that Lean Production and Industry 4.0 are not positively related because high-tech and capital-intensive efforts of Industry 4.0 can conflict with the ground principles of simple, continuous and small improvements from Lean Production. The latter, on the opposite side, considers the two paradigms as positively related. More specifically, Industry 4.0 technologies are perceived as supporters of Lean Production, allowing a more efficient and modern implementation of this philosophy. In the last years, the second vision has overcome the first one, making possible the integration between Lean Production and Industry 4.0.

In this context, the literature has focused on understanding which kind of benefits are associated with the integration of Lean Production and Industry 4.0. Many authors have shown that Smart Technologies affect Lean practices on three main aspects: data collection, decision-making and routine processes. While the first two processes result to be improved by Lean 4.0 synergies, the last one appears to be innovated.

Despite this recent interest in Lean 4.0, it is worth mentioning that most of the studies carried out to tackle this topic tend to take as reference Large Enterprises. In fact, it is easier to conduct experiments and assess results in these kinds of companies as they are likely to have the budget and internal competences necessary to approach Industry 4.0. On the other side, SMEs tend to be quite neglected, especially when it comes to the practical combination between Lean practices and Industry 4.0 technologies and the benefits associated with it. In fact, the literature presents some academic articles and publications that address Lean 4.0 in SMEs in a theoretical way (e.g. critical success factors for Lean 4.0 implementation), but the practical synergies and their benefits are always analysed in the context of big companies.

This aspect sheds light on a relevant gap in literature. In fact, since SMEs play a crucial role in the economies all over the world, they should not be neglected when it comes to innovative and efficient ways of managing their operations. In light of this, the main aim of this dissertation is to understand the practical integration of Lean Production and Industry 4.0 in SMEs, as well as the benefits related to their synergies. Therefore, the authors have tried to answer the following questions: *how Lean practices and Industry 4.0 technologies are integrated in SMEs? Do these integrations provide benefits in terms of data collection improvement, decision-making improvement, and routine processes innovation?*

The steps of the research, necessary to properly answer this question, are represented by this dissertation's chapters. In chapter 4, a literature review provides an overview of the main topics related to the analysis conducted in this dissertation (i.e. Lean production, Industry 4.0, Lean 4.0 and SMEs), clearly showing the aforementioned gap in research. Besides, it leads to the creation of a framework and the research hypotheses that will be tested and validated through the methodology shown in chapter 5. More specifically, this chapter explains how the different phases of Polit and Beck’s (2004) model have been followed to prepare all the activities and resources necessary to actually conduct the analysis, as well as to obtain and assess the results. Then, chapter 6 provides the description and discussion of survey’s results. In particular, this chapter presents the five analyses performed, together with their different points of view, targets and findings. Finally, chapter 7 reports the dissertation’s conclusions. More specifically, it has been divided into three different sections: validation of hypotheses, criticalities of analyses and suggestions for future research on Lean 4.0 in SMEs.

4. Literature Review

The purpose of this literature review is to guide readers through the main topics associated with the central aim of this dissertation: analyzing the integration between Lean practices and Industry 4.0 technologies in the context of SMEs and testing three typologies of impacts relate to these synergies (i.e. improvements in decision-making, improvements in data collection and innovation of routine processes).

In particular, section 4.1 provides an overview of Lean philosophy and its principles, as well as a deep explanation of the practices presented in the House of Lean framework. In a similar way, section 4.2 summarizes the groups of technologies related to Industry 4.0 and some of their main application fields. Thanks to these sections, readers will have a clear understanding of the practices and technologies investigated in the following chapters. Section 4.3 provides the state-of-the-art about the relationship between Lean Production and Industry 4.0, highlighting some recurring topics related to this field of research. After this introduction, the main synergies between Industry 4.0 technologies and Lean practices, as well as the main typologies of impacts that the former has on the latter. These last analyses allow to build the framework that will be used afterwards in the dissertation to test three different impacts of Industry 4.0 technologies on Lean practices. Finally, section 4.4 is focused on SMEs. After a brief introduction about these typologies of companies, it presents the main dimensions of analysis about Lean and Industry 4.0 implementation in SMEs separately, highlighting that a study about synergies between them is currently missing.

These sections have been produced on the basis of scientific research and academic conferences from Scopus, Research Gate, ScienceDirect and Google Scholar. Additionally, some reports produced by Politecnico di Milano have been used, as well as some relevant websites. All these papers and articles have been searched using different keywords - which are reported in table 14 for the different sections – and selected among thousand results on the basis of their relevance, year of publication and number of citations.

Section	Title	Keywords
4.1	Lean Production	*Lean, Lean Production, Lean Manufacturing, Lean Approach, Lean Practices, Lean Tools, House of Lean*
4.2	Industry 4.0	*Industry 4.0, Smart Technologies, Information Technologies, Operational Technologies, Internet of Things, Additive Manufacturing, Advanced Human Machine Interface, Advanced Automation, Cloud Manufacturing, Industrial Analytics*

4.3	Lean 4.0	*Lean 4.0, I4.0 and Lean, Smart Technologies and Lean, Lean evolution, Lean and digitalization, Lean 4.0 impacts, Lean 4.0 and data collection, Lean 4.0 and decision making, Lean 4.0 and process innovation, Industry 4.0 impacts on Lean, impact of Lean digitalization*
4.4	Small and Medium Enterprises	*SMEs, SMEs Characteristics, Lean in SMEs, Lean Practices in SMEs, Smart Technologies in SMEs, Industry 4.0 in SMEs, Critical Success Factors Lean SMEs, Critical Success Factors Industry 4.0 SMEs*

Table 14 - Keywords used for sections of Literature Review

4.1 Lean Production

Lean Production represents a production system whose main aim is "to do more with less", meaning to use the lowest amount of resources to obtain the highest efficiency level and deliver the best quality. In particular, it allows to increase factories' productivity by detecting and eliminating all the possible sources of waste: the non-value adding activities (i.e. those activities customers are not willing to pay for).

This production system, that is also known as *Toyota Production System* (TPS), was developed by some Japanese engineers – Kiichiro Toyoda, Taiichi Ohno, and others – as "a mare response to the state of the automobile industry after World War II" (Ohno T., 1973). Since that industry was particularly affected by the war, companies needed to find a way to compete with the mass production established in Europe and America by aiming at efficiency. This is the reason why Ohno had the brilliant idea of joining the two pillars of *Jidoka* and *Just-in-Time,* giving birth to the TPS.

In light of this, Lean Production is characterized by two main goals. The first main goal is associated with profitability. From the Lean perspective, profit is seen as selling price minus costs (Ohno T., 1973): in order to increase profit, it is necessary to work on decreasing costs as much as possible. Secondly, Lean revolves around customers and their satisfaction. This concept is strictly related to waste elimination, one of the main points of TPS. In fact, fulfilling customers' needs is possible only by deeply understanding what they are willing to pay for and, consequently, setting up a process made of value-adding activities only, with the final aim of creating the most value for them. Removing the non-value adding activities is a process that starts from acknowledging the different typologies of wastes, also known as *Muda*. In this regard, Ohno identified seven sources of waste: unnecessary movement of products, unnecessary people's physical movement, inventory, waiting time, over-production, over-processing, defects (Liker, 1996). In addition, it is worth mentioning that *Muda* might be caused by *Mura* (i.e. fluctuation of demand) which, in turn, might be the cause of *Muri* (i.e. unnecessary stress given to employees and processes) (Womack, 2007). Thanks to this careful waste elimination, the organization is able to reach many benefits: increase employees' satisfaction, improve quality performance, decrease process breakdowns, to name just a few.

An important point to highlight is that a strong way of thinking stands behind Lean Production. For this reason, the implementation of this production system is possible only if the whole organization is willing to integrate that way of thinking in their culture and mindset. In fact, commitment and engagement of employees, as well as their orientation to change, represent the main ingredients for Lean success.

The implementation of this methodology is possible by performing the so-called *Lean Principles* (Womack & Jones, 1996). These principles represent five actions that must be carried out continually and cyclically, in line with the concept of continuous improvement. This first principle is *Value Identification* and it is perfectly summed up by the slogan "customer first" (Walker, 1990). As mentioned before, lean revolves around understanding customers' needs and trying to satisfy them. In light of this, *value* represents what the customer is willing to pay for, that is the basis on which all the processes in the factory must be built. In this regard, the production activities must be value-adding only and all the causes of inefficiency need to be eliminated because wastes are the least elements customers are willing to pay for. These concepts naturally lead to the second principle: *Mapping the Value Stream.* It represents the production of value for the customer that goes through all the interconnected activities necessary to transform raw material into finished products (Lovelle, 2001). In other words, this second principle aims at eliminating all the sources of waste within the process, in order to create a smooth and valuable sequence of activities. This is possible only by analyzing the process flow and highlighting the value-adding activities, optimizing the necessary non-value adding activities and eliminating the non-value adding activities. According to the third principle, the activities resulting from the second actions need to be arranged in a *Continuous Flow.* The main aim is creating a process that flows without any obstacle. As a consequence, everything that impedes the smoothness of the process is recognized as waste and so it must be eliminated (Krafcik, 1988). In this regard, an important concept that comes to help is *takt-time*. It represents the production pace necessary to satisfy customers' requests (Myerson, 2012) and it is calculated as the ratio of the total time to deliver a product over the volume of product to be delivered. The way this continuous flow is arranged is the central topic of the fourth principle: *Pull Production.* It refers to the fact that the ideal production system should be pulled by the actual customers' demand, which means that the production is triggered by customers' orders (Sperman & Zazanis, 1992). This principle is strongly in line with the concept of *Just-In-Time*: in order to fulfill customers' orders at the moment, the system needs to have available the right components, at the right time, in the right place. It goes without saying that a high level of visibility over the process is necessary to keep up with the huge reactivity associated with the just-in-time production (Myerson, 2012). While these first four actions lead to wastes elimination and streamlined flows, the fifth one – *Striving for Perfection* – is related to the daily attitude that allows the practical implementation of Lean Production. More specifically, the fifth principle stresses the importance of putting a strong effort on daily operations with the final ambition of pursuing perfection. This aspiration is well represented by *Kaizen* (i.e. continuous improvement), which embodies organization members' active participation in improving daily activities, continuously striving for perfection. In other words, the continuous improvement process involves actively the different expertise, skills and competences of actors in the field. Practically speaking, implementing Kaizen means to apply cyclical way of working characterized by standardization of activities and processes, measurement of time and resources' consumption, evaluation of possible improvements, innovation when the process is saturated. In light of this, it is clear the necessity of a precise planning of the process, as well as a high degree of control over it.

Although the *Five Principles* is one of the most common ways used to explain Lean Manufacturing, it represents only one of the several frameworks developed throughout the years. A more practical standpoint is taken by the *House of Lean* (Liker, The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer, 2004), which illustrates lean practices as different components of a house structure (figure 9). The house results to be particularly useful to explain Lean thinking because it shows the importance of all the single elements to guarantee the system balance, as well as it calls to mind the idea of a structural system. Liker's house is founded on four main concepts: *Toyota Way Philosophy, Visual Management, Stable and Standardized Work, Heijunka* (i.e. levelled production). These foundations allow the two pillars – *Just-In-Time* and *Jidoka* - to stand stable. In between these two pillars there are *People & Teamwork* and *Waste Reduction*, that work together to achieve the goal of *Continuous Improvement.* Finally, the roof consists in the main goals achievable through a successful Lean implementation: *Best Quality*, *Lowest Cost*, *Shortest Lead Time*, *Best Safety*, *High Morale*. This representation of Lean Production has been particularly useful in the dissertation because it shows the most common lean practices. As a consequence, it has been taken as point of reference to list them. For this reason, each of them will be explained in a quite detailed way.

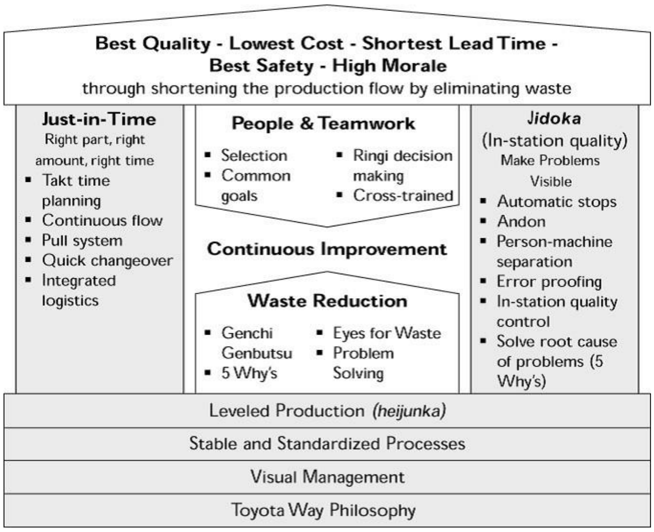

Figure 9 - House of Lean Production (Licker, 2014)

4.1.1 Toyota Way Philosophy

As suggested previously, Lean is not just a way of working, it is a way of thinking, a real philosophy (Pettersen, 2009). This philosophy promotes a cultural transformation within organizations that revolves around two concepts. The first one is C*ontinuous Improvement*, which is related to the strong desire of perfection that organizations should pursue through the attitude of Kaizen. The second concept is *Respect for People,* that highlights the fact that workforce is the most important asset of a company and, consequently, needs to be closely involved in the implementation of the philosophy (Womack, 2007). In light of this, Lean Philosophy results to be designed in a way that recognizes the power of people in pursuing the continuous improvement objective. In addition to these two main pillars, there are three more values recognized as essential in Lean implementation: *Challenge*, *Genchi Genbutsu* and *Teamwork* (Toyota Motor Corporation, 2003). *Challenge* refers to acting with a long-term perspective and facing all the obstacles with courage and creativity. *Genchi Genbutsu* means "going to the source" and refers to finding the root causes of problems in order to address them directly by implementing corrective actions. Finally, *Teamwork* is related to a growth of team performance which is enhanced by individuals' personal improvements.

4.1.2 Visual Management

Visual Management refers to the use of visual tools – such as warning signals, cards, stripes, colored borders, graphic devices and so on – with the aim of clearly communicating information. Thanks to these tools, operators involved in a certain activity should be able to understand the state of it at any time (Womack & Jones, 1996). Even if the increase of visibility level is one of the main benefits associated with *Visual Management*, the objective is not purely descriptive. In fact, having clear results and progresses of activities allows to detect criticalities and solve them real-time (Parry & Turner, 2006), as well as to identify improvement plans for the future. One of the most common practices associated with visual management is the *5S methodology*, which promotes the optimization of workplace with the aim of eliminating process inefficiencies (Michalska & Szewieczek, 2007). This methodology refers to five Japanese words, which suggest actions to be taken (e.g. re-organization of workplace, cleaning and tidying of it, and so on) in order to always be in line with the pre-defined standards, reduce time to look for tools and materials, make the workplace tidy and safe, get people used to clean and organize, and so on.

4.1.3 Stable and Standardized Processes

In light of the smooth flows that Lean Methodology aims to create, *Standardization* results to be essential. Basically, it refers to the division of the process into an organized set of activities, which need to be defined carefully and then performed repeatedly always in the same way. Thanks to this way of working, it is possible to reach high levels of productivity, quality and safety (Pascal, 2002), as well as to get a better knowledge and control over the process. For this reason, it is important to stick with the sequence and avoid any kind of variations and quality issues. Obtaining a standardized process is possible through the interconnection of three elements: *Takt-Time*, *Work Sequence* and *Standard Work in Process.* In terms of *Takt-Time*, the main aim is to align the rhythms of production and market (Feteke & Hulvej, 2013). This synchronization allows to avoid inefficiencies, wastes and delays by reducing the risk of both over- and under-production. As for *Work Sequence*, this component is related to the balancing of lines (Gurumurthy & Kodali, 2011) which allows workers to perform their tasks always in the same way. In this regard, it is worth mentioning the importance of ergonomics in this phase. Finally, *Standardized Work in Process* refers to keeping the least amount of inventory needed to guarantee a one-piece flow.

4.1.4 Heijunka

Heijunka is a Japanese word that stands for “production smoothing or levelling”. It promotes the creation of a system which is constant and measurable but also flexible. This concept is completely in line with the just-in-time logic because disruptions in the production process and variability in the workload are minimized by providing the right components, in the right sequence, at the right time. This reduction of variability is the reason why the system can be flexible in a way that respects the demand even if the necessity of changing the sequence arises. The main benefits associated to Heijunka is a better organization of workforce and the management of a steady process over time (Hüttmeir, De Treville, Van Ackere, & Prenninger, 2009).

4.1.5 Just-In-Time

Just-in-Time refers to producing “the right item, at the right time, in the right quantity, following the takt-time” (Monden, Toyota Production System: An Integrated Approach to Just-In-Time, 1993), with the aim of reducing and eliminating all the typologies of wastes (Brown & Mitchell, 1991). In light of this, it promotes the creation of a working schedule which is carefully studied and planned with the aim of smoothing and optimizing the production flow as much as possible. In this way, it is possible to realize a decrease of costs and wastes (i.e. time, capacity and materials). In addition, this way of working allows operators to focus their attention on their tasks, leading to better quality and higher punctuality. As a consequence, both the two goals of Lean – customer satisfaction and profitability (reached through cost reduction) - are respected. The main practice associated with Just-in-Time is *Kanban*, that is a plastic card containing all the pieces of information related to the current stage of production, the following ones and everything that is necessary to know to complete the process (Kumar & Panneerselvam, 2007). These cards are sent backwards in the process, leading to connection of different processes in the plant, as well as better control of components quantities and flows.

4.1.6 Jidoka

Jidoka, also known as “automation with a human touch” (Liker, The Toyota Way: 14 Management Principles from the World’s Greatest Manufacturer, 2004), is defined as “the decision to stop and fix problems as they occur rather than pushing them down the line to be resolved later” (Liker & Meier, 2006). The main aim is to provide operators and equipment with the ability of autonomously detect defects and stop the work. In addition, operators are held liable for quality checks before delivering products to following production steps, so that problems and defects are not pushed forward in the process. In light of this, *Jidoka* supports the *Just-in-Time* logic (Monden, 1983). Three of the most well-known *Jidoka* techniques are *Andon*, *Poka-Yoke* and *Total Productive Maintenance*. *Andon* is a well-visible board that indicates the state of production lines and provides notifications when operators detect problems and defects. *Poka-Yoke* is a methodology that allows to eliminate the possibilities of producing defective products (Dudek-Burlikowska & Szewieczek, 2009) through the use of warning (i.e. notifications when something is different from the standard) and control systems (i.e. machines automatically stop when something is different from the standard) (Shingo, 1989). *Total Production Maintenance* is a methodology that aims at eliminating the breakdowns (Wilmott, 1994), as well as lowering the delivery time to provide products with high quality and low costs (Wireman, 2004). On the basis of organization's objectives, pillars focused on different groups of wastes are structured and small teams need to analyze and work on them in order to obtain the maximum level of efficiency.

4.1.7 Muda Elimination

The implementation of Lean Manufacturing is associated with the great benefit of reducing the time from customer order to order delivery. This benefit is successfully achieved also through the continuous research and elimination of any possible source of waste (Lean, 1996), which is possible by carefully analyzing the situation and looking at it from different perspective. This problem-solving attitude is strongly promoted by Lean philosophy and many approaches have been developed to address it. Among them, *Value Stream Mapping* represents one of the most well-known. More specifically, it is used to map the current situation to identify in which steps of the process the value is created and eliminate the non-value adding activities (Rother & Shook, 2003). This method is strictly related to one of the most essential value of lean, *Genchi Genbutsu*, which fosters the complete analysis of problems by searching for their root causes and acting on them (Haghirian, 2010).

4.1.8 People and Teamwork

As mentioned before, Lean Manufacturing is a way of thinking before being a way of working. In order to realize the benefits associated with this philosophy, it is necessary that all the people within the organization share the *Kaizen* attitude. In fact, one of the main obstacles to lean implementation is internal resistance. In order to avoid it, it is mandatory to establish the right mindset in the whole organization with the aim of establishing a culture strongly oriented towards Lean philosophy (Bicheno & Holweg, 2016). This task is up to the top management, which must support this lean culture and engage employees by setting specific and measurable goals for them. Additionally, workers' engagement is fostered also by the fact that they are given many tasks and responsibilities, in particular in terms of detecting problems and finding their causes (Poppendieck, 2002). In this regard, also decision-making plays an important role. In fact, lean implementation requires to apply a bottom-up approach, where each member of the organization is invited to collaborate in finding the optimal solutions for problems and to make the most reasonable decision (Sagi, 2015). The basic idea is that all members are essential in the decision-making process and can bring their contribution for continuous improvement (Imai, 1986). Finally, employees are asked to work in teams, whose effectiveness is promoted by a continuous training which is cross-functional and company-wide (Marks, Sabella, Burke, & Zaccaro, 2002).

In light of the great benefits associated with Lean philosophy, its practices have been adopted in many different fields. For instance, *Standardization* and modularization of components and processes is particularly useful in product design, where re-organization of production and simplification of products lead to better global costs. Another good example is represented by production management, where *Heijunka* allows a synchronization between production and market demand and *Visual Management* simplifies the management system, leading to a steadier production flow. It is worth noticing that these two areas are just examples, it is possible to find a wide use of Lean practices and methodologies also in process design, workforce management, suppliers management and so on.

4.2 Industry 4.0

Industry 4.0 definition takes its origin back to Germany in the year 2010. This concept was introduced to the public, for the first time, in 2011 by the German Engineering Federation at Hannover Messe, the world's biggest industrial fair. At the beginning, the first definition was: "Industry 4.0 is the digitalization and automation of the supply chain, including a transaction to greater level of interconnectivity, smarter manufacturing and communication between people, machines and equipment" (Politecnico di Milano, 2016).

However, over the years, the definition changed and, nowadays, Industry 4.0 is defined as a vision of the future in which industrial and manufacturing companies, using digital technologies, will be able to increase their competitiveness and efficiency through the interconnection and cooperation between their own resources (machineries, people and information), both internal (to the firm) and external (spread along the value chain) (Politecnico di Milano, 2016).

Industry 4.0 also represents the advent of the Forth Industrial Revolution, sometimes also called Smart Manufacturing, which takes the automation of manufacturing process to a new level by introducing customized and flexible mass production technologies to reduce the capital employed in economic terms. In other words, Industry 4.0 will manage the integration of all these industrial technologies, emerged during the Third Industrial Revolution, into a complex mechanism in which companies will be able to decrease inefficiencies, by adding value to the knowledge and improving the ability of planning and anticipating the market.

4.2.1 Smart Technologies

Industry 4.0 is mostly based on Smart Technologies that are technologies which allow sensors, databases and wireless access to collaboratively sense, adapt and provide for users within the environment (Elwood S.A., 2008). Smart Technologies could be divided into two main groups: the former, Information Technologies (IT), is more cohesive and is composed by Industrial Internet of Things (I-IoT), Cloud Manufacturing, Industrial Analytics and Digital Twin/Simulation and the latter, Operational Technologies (OT), that is more heterogeneous, includes Advance Automation, Advance Human-Machine Interface and Additive Manufacturing.

Smart Technologies find an application in the majority of industrial and manufacturing company processes. More in details, three main fields are to be considered:

- *Smart Lifecycle* that is mainly related to new product development, its lifecycle management and supplier management.
- *Smart Supply Chain* that includes physical and financial flow management in the logistic-productive system.
- *Smart Factory* that concerns the whole manufacturing processes, such as production, inbound and outbound logistics, maintenance, quality, security and compliance with the standards.

4.2.2 Information Technologies

Information Technologies (IT) refers to the application of network, storage, and compute resources toward the generalization, management, storage, and delivery of data throughout and between organization (Coolfire, 2019). As said before, IT is mainly divided into four categories that have different characteristics and applications.

The first category, **Internet of Things** (IoT), was heard for the first time in 1999 by Kevin Ahston, in relation to the RFId (Radio Frequency Identification) devices (School of Management Politecnico di Milano, 2019). IoT is mainly related to the idea of Smart Objects that are interconnected between each other and that are able to exchange all the information that they have gather. In order to make this concept clearer, an example of Smart Object are modern streetlights that are able to regulate the intensity of the light on the basis of the visibility conditions and, also, traffic lights that create the green wave when a rescue vehicle is passing. IoT has a lot of applications in different fields; however, for the purpose of this dissertation, the focus will be on the Industrial Internet of Things (I-IoT) that is mainly related to the adoption of the Cyber Physical Systems, the connection of the machineries, workers and products, in order to enable new logics for the production management.

As regards the tools and applications of the I-IoT, some of them are already present and tested in the market and some others are under development. The main ones are:

- *RFId* that includes tools like labels and readers; they are able, through the use of radio waves, to codify RFId tags. This technology can read different tags simultaneously and monitor the objects in a long range.
- *Predictive Maintenance* is referred to a system of machines and components with specific sensors whose main aim is to prevent useless maintenance and breakdowns.
- *Intelligence Edge* is a space in which the data is elaborated and transmitted. It is a form of security that decreases the possibility of a big data violation.

Moving to the second category, **Cloud Manufacturing**, the focus is on the concept of Cloud and its types of service. Cloud is a method of running application software, storing related data in a central computer system, and providing on-demand access to the users through the Internet (Politecnico di Milano School of Management, 2018). Therefore, the concept of Cloud manufacturing is related to the application of Cloud in the manufacturing field (production, product development, product design, etc.). This technology has different advantages like the possibility of process standardization and integration; but also speed, transparency and efficiency related to all the procedures that usually are managed on paper. Moreover, digitalization of procedures ensures an immediate traceability of information related to the company's supply chain.

As regard the types of service that Cloud Computing can offer, the main options are:

- *Software as a Service* (SaaS): it is the most complete solution in which the client does not need any informatic skills; he can access, using the Internet, to the service offered by the provider without any need of an application or installation of files.
- *Platform as a Service* (PaaS): in this solution the provider offers the hardware, and the client needs to install the operating system and develop the application.
- *Infrastructure as a Service* (IaaS): the provider offers a virtual hardware to the client; this solution gives to the client the possibility to have a higher flexibility on the physical infrastructure and no burden for the hardware management.

The third solution of the IT is the so-called **Industrial Analytics**. Analytics may be broadly defined as a discipline transforming Big Data into information through systematic analysis (Politecnico di Milano School of Management, 2018). Therefore, Industrial Analytics is the use of analytics in the I-IoT system (Diab, Harper, Lin, & Sobel, 2017).

Industrial Analytics main aim is to identify and recognize machines operational and behavioural patterns, make fast and accurate predictions and act with confidence at the points of decision. This falls into five major analysis:

- *Descriptive* (What happened?): it is related to the description of the data through the use of Business Intelligence and Data Visualization.
- *Diagnostic* (Why did it happen?): this is the step in which the casual relationship between the data and what happened is analysed and understood.
- *Predictive* (What future?): this is the stage of prediction of future events using different typologies of algorithms.
- *Prescriptive* (How to react to recent events?): in this step the simulation of what might happen in the future is made in order to understand how to react to a specific event.

- *Pre-emptive* (How to avoid bad events?): this last step is able not only to understand how to react to a specific situation, but also to pursue some actions in the present that may avoid the appearance of a bad event in the future.

The last technology is **Digital Twin/Simulation**. This technology is also the youngest one. More in details, Simulation helps understand what may happen in the real word. Instead, Digital Twin not only helps understanding what may happen, but also crucially what is happening. In fact, Digital Twin offers the real-time view in a human-friendly 3D visual format. Human operators monitoring and interpreting the AS-IS status of large-scale project, elaborate process and equipment, operational assembly lines and even patients under care, will benefit from the timely easy-to-consume information. In a fast-moving world, where time is of essence, the real-time insights will help prevent many bad decisions, conduct preventive maintenance, and reduce untoward incidents (Raghunathan, 2019).

4.2.3 Operational Technologies

Operational Technologies (OT) refer to technologies that monitor and control specific devices and processes within the industrial workflows (Coolfire, 2019). As IT also OT is divided into three main applications described in the following paragraphs.

The first one is **Advance Automation** that refers to sophisticated automated systems, ideally with the additional capability for self-maintenance and repair, mostly requiring little of no human interaction to operate, apart from top-level guidance (Advance Civilization, 2011). The key benefits of this solution are mainly related to activity-time savings, increase of safety, and decrease of costs.

The main fields of applications are capacity of interaction with the environment, self-learning and automated guided, use of techniques that are able to recognize patterns and ability to interact with the operators (Politecnico di Milano, 2016). An evident case is the one of Co-bots (Collaborative Robots) designed to work side-by-side with humans and to learn by their actions.

Then, **Advance Human-Machine Interface** (HMI) is a user interface or dashboard that connects a person to a machine, system, or device. While the term can technically be applied to any screen that allows a user to interact with a device, HMI is most commonly used in the context of an industrial process (Inductive Automation, 2018). The main applications are related to visually displaying data, tracking production time, trends, and tags, overseeing KPIs, monitoring machine input and outputs and so on.

Two examples could be seen in touch displays and 3D scanners, suitable for acquiring gestural movement (Downs, 2005). Augmented reality is another application of HMI that supports activity like picking of parts in a warehouse and dispatch of repair instruction over mobile devices. Another application of Augmented Reality is virtual training for workers.

Finally, the last application, **Additive Manufacturing** that is also known as 3D printing (Politecnico di Milano, 2016). This technology is able to print layer-by-layer an object from nothing using specific materials and for this reason is considered a real revolution in comparison to plastic removal and asportation.

The main application fields of this technology are Rapid Prototyping, Rapid Manufacturing, Rapid Maintenance & Repair and Rapid Tooling. They can offer construction advantages like complex and lightweight design in aircrafts.

Now that all the main features of the Lean Practices and Smart Technologies has been explained in detail, the attention should shift to the concept of Lean 4.0 that will be explained in the following chapter.

4.3 Lean 4.0

Lean 4.0 embodies the relationship between Lean Production (Lean Production) and Industry 4.0 (Industry 4.0). This concept has been studied in the last years by researchers and practitioners to understand how both approaches, when implemented together by companies, can raise operational and financial performance levels to a different pattern (Rossini, Costa, Alberto, & Tortorella, 2019).

Moreover, the acknowledgement of the relevant integration of technologies into Lean Production has been evidenced in the early 1990s and denoted as Lean Automation (LA). LA is a technique which is used to apply right amount of automation to a given task. In fact, LA provides robust and reliable results and eliminates complicated solutions. With the rise of the Industry 4.0, the concept of LA has evolved in the so-called Lean 4.0 that is this dissertation’s subject of analysis.

It is important to highlight that, before implementing automation, a proper method is needed not to have a worse performance than the starting one. Thus, Lean Production can be the right tool to understand the correct amount of automation needed for increasing companies processes efficiency. This is basically due to the fact that Lean Production is able to recognize which are the non-value-adding activities and, consequently, reduce wastes related to the different process steps. Indeed, companies should implement technology applications or behavioural solutions that aim to minimize or eliminate the root causes of waste going forward (Colotla, Bland, & Knizek, 2018).

To go more in detail with this analysis, the following paragraphs will focus on the different typologies of relationship between the two paradigms (Lean Production and Industry 4.0) and the importance of the Learning Process. Then, a more practical aspect will be investigated: Lean 4.0 real applications with a stress on Lean Production practices and Industry 4.0 technologies that, on literature basis, are used together by companies. Finally, the three main typologies of benefit that Industry 4.0 has on Lean Production are reported and analysed.

4.3.1 Lean and Industry 4.0 relationship – two points of view

Through the analysis of all the papers found, two prevalent opinions about the relation between Lean Production and Industry 4.0 has been highlighted: *mono-directional* and *bi-directional* relationship. The former is related to the belief that Lean Production and Industry 4.0 are not positively related because usual high-tech and capital-intensive efforts of Industry 4.0 can conflict with the ground principles of simple, continuous and small improvements from Lean Production. Indeed, Rüttimann and Stockli (2016) argued that Industry 4.0 initiatives are likely to fail unless they are put into the right context by considering fundamental manufacturing laws. In other words, this suggests that extensive applications of modern ICT that disregard Lean Production implementation will lead to marginal gains that might frustrate managers in face of the high investment levels carried out. Moreover, also Maguire (2017) in his research indicate several potential conflicts between Lean and IT. Those conflicts having the most impact on Lean transformation are all related to business process management, and include: the introduction of too much complexity, automating processes where it does not make sense, and the automation of poor processes.

As a consequence, the main takeaways of this first typology of relationship (i.e. *mono-directional*) are:

- Lean Production represents a prerequisite of the Industry 4.0 because it is able to prevent the digitalization of inefficiencies, but the two paradigms cannot coexist.
- Industry 4.0 represents a revolution leading to new business and entrepreneurial models.
- Lean Production and Industry 4.0 are seen as two different paradigms.

On the other hand, the *bi-directional* relationship considers Lean Production and Industry 4.0 positively related. In fact, Wagner et al. (2017) and Sanders et al. (2017) claim that the concurrent implementation of Industry 4.0 and Lean Production may allow companies to overcome traditional barriers in a Lean transformation achieving major results. Moreover, U. Dombrowskia et al. (2019) affirm, on the basis of the results of an international survey, that the optimization strategy has evolved to the state of the art in manufacturing industries and it is more and more transferred to the other enterprise units. As a consequence, a Lean Enterprise (LE) in which technology, organizational structures as well as human aspects are considered, is the final aim of their research. The objective of LE is to rise cost potentials by avoiding waste along all enterprise processes and simultaneously fulfill customers' demand in the shortest possible time and with the retested quality. It is pretty clear that, from a socio-technical process-systems' prospective, the fully integrated low-waste approach of the LE is the necessary standard for an ever-changing future and a successful implementation of Industry 4.0. However, the digital transformation for people is still considered a big change.

To sum up this second prospective, the main aspects are:

- Industry 4.0 supports Lean Production practices application, through technology and digitalization, allowing an improvement of the practices already in use. Vice versa, Lean is considered fundamental for a better implementation of the Industry 4.0.
- Lean Production and Industry 4.0 are seen as two complementary aspects that support each other.

It is possible to add that studies investigating the *bi-directional* relationship, in general, still lack of empirical evidence to support their finding. For this reason, there is the necessity of studying the impact of this relationship on companies' performance and the influence of external factors on this relationship.

As it can be easily noticed, both the two types of relationship claim that Lean Production is an application that is fundamental for the implementation of Industry 4.0 technologies but in the first case the two paradigms cannot coexist.

Moreover, we can affirm that, in the last two years, the first typology of relationship (*mono-directional*) is not present or taken into consideration in studies and researches anymore. This means that, over the years, the second vision (*bi-directional*) has overcome the first one making the integration between Lean Production and Industry 4.0 even more realistic. Certainly, there are and always will be some inconsistences between these two different paradigms that, probably, may not be overcome, as the 'stillness' of Lean Production compared to the 'dynamicity' of the Industry 4.0 or the Lean Production tendency to focus on problems simplification more than structuring complex solutions as Industry 4.0 does (Macchi, 2017).

However, there are evidences of the successful implementation of Lean 4.0 all around the world because of the high quantity of touchpoints between the paradigms such as involvement of people, stress on the Learning Process applied mainly on field, processes orientation, attention to measurements and data analysis with a view to improving (Macchi, 2017).

4.3.2 Learning Process as a fundamental passage

As mentioned before, an aspect that needs to be taken into consideration is the concept of Learning Process because of its importance in the *bi-directional* relationship. In other words, it is a process that people pass through to acquire new knowledge and skills and ultimately influence their attitudes, decisions and actions. This process is considered necessary for the proper implementation of Lean 4.0 into different companies.

In particular, Christopher Prinza at el. (2018) wrote: "Due to the training concept, the participants get a feeling for possible solutions, which cannot be conveyed by separate *Learning Factory* – groups of seminars which aim is to sensitize the participants to the subject of digitalization through the use of simulation tools – modules. Furthermore, they get an understanding for the necessity of realizing a Lean Production before implementing digitalization technologies – not only due to a theoretical input, but by experiencing the corresponding benefits by themselves in a very practical way". In addition, also Harald Bauer at el. (2019) refer to the *Learning Factory* as a process that is fundamental for properly train the workers to use Smart Technologies to solve production problems. They wrote: “Rather than teaching new concepts and solutions relevant for Industry 4.0 applications and illustrating how to use them in specific problem situations, the participating group is primarily confronted with a challenge. More particularly, a problem statement is assigned putting the course participants in a realistic problem situation regarding the assembly concept of their factory in which first they have to identify what they need to know in order to apply and further deepen their gained knowledge by solving the stated challenge. Thus, as challenge in the Lean Production, we understand customer values, that participants need to provide within their gear box assembly line. The only support given to participants are hints concerning possible technologies, which might be useful for the specific challenge.”.

As a consequence, we can affirm that the Learning Process, supported by the *Learning Factory* approach, is widely used by companies to introduce Smart Technologies to workers that are able to enhance the Lean Production. This solution is able to gradually establish a connection between the two aspects (Lean Production and Industry 4.0) and make people aware of which are the improvements that can be achieved using them both.

4.3.3 A practical framework for Lean 4.0

As far as Lean 4.0 and its main aspects are concerned, it might be useful to summarize these concepts into a unique framework. In fact, the practical connection between Lean Production practices and Smart Technologies represents the way to analyse how these elements affect each other.

This connection can be easily explained through the creation of a matrix in which columns contain Smart Technologies and rows report Lean Practices. More in details, the columns are: Additive Manufacturing, Advanced Automation, Advanced Human Machine Interface, Industrial Internet of Things, Industrial Analytics, Cloud Manufacturing and Digital Twin/Simulation. As regards the rows, they are fifteen and they are proposed in this order: Kaizen, Andon, Poka Yoke, Total Production Maintenance (TPM), Jidoka, Standardization, 5S, Visual Management, Kanban, Just in Time, Muda Reduction, Visual Stream Mapping (VSM), Heijunka, SMED and People and teamwork.

Then, in order to easily describe the matrix overall structure, each of the following sections will be focused on one Smart Technology (columns) and its relationships with Lean practices (rows). Moreover, the final section will propose the final Matrix architecture with some conclusive considerations.

4.3.3.1 Additive Manufacturing – relations with Lean Practices

Starting from Additive Manufacturing, 3D printing is the concept mainly related to this technology and, in this section, it is going to be studied on its relationship with Lean Practices with some examples on the industrial field.

Chen and Lin (2017) presented a discussion about 3D printing technology, focusing on the technical challenges that must be addressed before its implementation and the main managerial concerns that can influence the cost effectiveness of manufacturing systems. They concluded that 3D printing technology facilitates the achievement of Lean manufacturing principles, pointing the small batches production as the main benefit. Furthermore, this technology allows **JIT** manufacturing to decrease lead times, enhance logistics efficiency and also reduce distance and delivery costs, since 3D printers can be installed near customer's locations.

In addition, 3D printing implementation is able to reduce wastes (**Muda Reduction**) related to overburdened or uneven workload because more tasks are performed by machines. For this reason, employees can focus their attention on value-adding activities (Pereira, Dinis-Carvalho, Alves, & Arezes, 2019).

Moreover, Feldmann and Gorji (2017) argued that **SMED** can also be applied to Additive Manufacturing. However, as set-up times are already technologically reduced to the minimum, the impact is expected to be rather small. Also, Wang et al. (2016) argued that Additive Manufacturing is useful to produce complex parts, cutting down set-up times, enabling the one-piece flow production.

In conclusion, as regards Additive Manufacturing application to Lean Production, literature found evidence that only JIT, Muda Reduction and SMED are the practices on which this technology has more benefits.

4.3.3.2 Advanced Automation - relations with Lean Practices

Advanced Automation is mainly related to the use and implementation of robots, AGVs, etc in the industrial field. Therefore, in this section, Lean practices considered are supported by the use of automated robots.

Starting from **TPM**, it can take a lot of benefits from Advanced Automation implementation due to the introduction of maintenance robots that are able to repair parts and prevent breakdowns without the intervention of operators. This will give operators the possibility of focusing on more value-adding activities. In addition, automatising the maintenance processes means that also human errors will decrease and, as a consequence, the quality of the production will increase, decreasing the time spent for reparation processes (Rosin, Forget, Lamouri, & Pellerin, 2020).

Moreover, Durakbasa (2016) pointed out that sensor technology and robotics are the two main elements for the implementation of automation in the Industry 4.0 framework and that Multifunction Intelligent Measurement Robots allow the flexible implementation of automation in process control and quality assurance – two of the main aspects of **Poka Yoke**.

In light of the relationship of **Jidoka** with TPM and Poka Yoke, Advanced Automation results to be supportive to Jidoka as well (Wagner, Herrmann, & Thiede, 2017).

As regards **Standardization**, Boudella, Sahin, and Dallery (2018) and Wang et al. (2016) proposed autonomous robots applications, namely a picking robot and corobot that works in conjunction with an operator, which helps standardise work procedures.

Another Lean Practice that is highly appointed in literature is the concept of **JIT** – with its main application: **Kanban** – in relation with Advanced Automation technologies. In fact, Wagner, Herrmann and Thiede (2017) claimed that the application of AGVs can further contribute to JIT delivery to the workplace. Refill arrives in the exact moment when new material is required. Consequently, the material supply at shop floor level can be realized by using a one-container-system. Hence, the need to fill several containers with the same material is omitted. In addition, also Rüßmann et al. (2015) proposed using the IoT and autonomous robots to independently adjust production according to unfinished products. These robots can collaborate to respond in real-time and ensure that production runs smoothly. Therefore, the authors discussed the concept of collaborative robots or cobots, which assist employees in their work and benefit from a certain level of autonomy to react to employees' actions. Mayr et al. (2018) also proposed the use of autonomous robots to adjust production planning in real-time. These robots take advantage of the IoT to exchange information about destination and timing of delivery with the product (Kanban principle), making production planning possible; these AGVs can react to disruptions and adapt to find alternative routes.

The final practice of Lean related to Advanced Automation is **VSM**. In this case, the identification of objects is improved by automation and the effort of VSM creation is reduced. As a consequence, the real-time display of value streams is enhanced (Mayr, et al., 2018).

In conclusion, several authors argue that the implementation of autonomous robots increases the flexibility of manufacturing systems. An example is given by Lutz at al. (2016) with the fleet autonomous robots to perform transportation tasks. The system is able to work with flexible production flows and fast changing environments, responding to unpredictable changes and providing an efficient, reliable and predictable path-based navigation. Then, robots are flexible enough to fast react to obstacles and persons, avoiding them and blocking their way, meeting the safety challenges of service robot fleets. This example is clearly related to some of the main Lean Practices named before and in general with the concept of Continuous Improvement, one of the Lean main pillars.

4.3.3.3 Advanced Human Machine Interface - relations with Lean Practices

As regards the third aspect of the OT, many evidences of connections between HMI and Lean Production are present in the literature. In particular, ten over fifteen Lean Practices are considered compatible with the implementation of HMI.

The continuous improvement principle (i.e. **Kaizen**) can take advantage of augmented reality. Davies, Coole and Smith (2017) and Tyagi and Vadrevu (2015) suggested using Virtual Reality to easily visualize the processes in order to have a better overall view and understand the possible changes to be applied.

Then, **Jidoka** is the second principle taken into consideration with all its tools: Andon, Poka Yoke e TPM. In fact, Jidoka with the support of augmented reality, as Kolberg and Zühlke (2015) and Mayr et al. (2018) said, allows employees to obtain visual feedback if errors occur. Moreover, Rauch et al. (2016) supported that visualization technologies hold a huge potential regarding the decreasing of failures and mitigating its impacts during product development procedures. Furthermore, these technologies allow the examination of hazardous situations, maintenance and training scenarios, holding a huge potential to completely change and revolutionize the way humans work and communicate (J. Pfeffer et al., 2015).

As regards **Andon**, Gorecki and Pautsch (2014) said that, unlike traditional Andon lamps, HCI[1] devices like tablets, smartphones, head-mounted displays and smart watches enable a targeted notifications for users. Hence, notifications are displayed in real-time

[1] Human Computer Interface

regardless of the distance between operators and machine. In addition, Smart watches allow to assess the need for action with a glance at the operator's wrist (Mrugalska & Wyrwicka, 2017).

Focusing on **Poka Yoke**, Rammelmeier, Galka and Günther (2017) affirmed that augmented reality and head-mounted displays, as well as RFID-readers can be used to achieve zero-error picking and to improve quality control.

Finally, the combination of virtual representation technologies like virtual reality and augmented reality as well as head-mounted displays facilitates training as well as maintenance instructions, and, as a consequence, the **TPM** application (Palmarini, Erkoyuncu, Roy, & Torabmostaedi, 2018). In addition, as maintenance typically involves non-recurring and context-sensitive activities, interaction with maintenance experts becomes crucial. By displaying virtual elements operators can be guided remotely (S. Benbelkacem et al., 2011).

Another important principle considered is **Standardization**. Precisely, at the monitoring level, augmented reality is proposed by Longo, Nicoletti, and Padovano (2017) to make processes stable and standardized. More specifically, they presented the concept of 'smart operator', in which the operator is assisted by different technological means - including an augmented realty visual device - to help him/her perform the standardised tasks to be executed for each product. In this case, the main aim is to achieve a better level of surveillance and control.

As regards **Visual Management** and **5S** (methodology for the optimization of the workspace), applying augmented reality may replace physical shadow boards, as visual elements guided operators where to place tools. Moreover, integrating gamification through augmented reality might motivate personnel by gaining credits for cleaning or placing tools correctly (Pötters, Kloeckner, & Leyendecke, 2017). In addition, also zoning allows marking destinations by using visual means. Although this procedure implies several drawbacks - firstly, signs and tapes must be adjusted physically; secondly, this concept is not suitable for flexible navigation - HCI and augmented reality can help to overcome this lacking flexibility. In particular, as Koch et al. (2014) and Neges et al. (2017) said, a system for navigation by means of augmented reality is a possible solution, it is based on natural markers like warning signals.

Moreover, Kolberg and Zühlke (2015) presented an approach that consisted in the use of augmented reality and CPS-based wearable devices that provide information to operators about cycle time and tasks to perform via augmented reality, in order to support **JIT** production. Furthermore, the wearable devices are able to receive failure information and display it in real-time to operators. Pfeffer et al. (2015) argued, regarding to problem-solving processes, that virtual reality and augmented reality technologies can enhance efficiency and performance, providing additional real-time information.

In addition, also **VSM** is related to HMI. The virtual VSM allows every stakeholder to be immersed in a virtual model, observing and mapping current and future state of processes, without the need of understanding the conventional VSM symbols (Davies, Coole, & Smith, 2017). More in details, machine performance, for instance, can be analysed by maintenance staff to reduce downtime or used by managers to pursue process optimization (Pereira, Dinis-Carvalho, Alves, & Arezes, 2019).

The last Lean Practice considered in this section is **People and Teamwork**. Augmented reality interface is able to facilitate employees training, at the monitoring level, providing additional information to employees on the tasks to be performed and to provide real-time feedbacks on errors made in a training context (Longo, Nicoletti, & Padovano, 2017).

In conclusion, HMI is one of the more applicable technologies in the Lean framework because it could be easily adapted to different contexts and situations.

4.3.3.4 Industrial Internet of Things - relations with Lean Practices

I-IoT, as HMI, is another technology that has a lot of evidence in the literature on its implementation to support Lean Production. In particular, eleven out of fifteen Lean Practices are discussed in the following section.

Starting from a general concept, Jayaram (2016) proposed a global logistics model for transportation that follows Lean approach. The combination of this approach with I-IoT technology allows a fully autonomous global supply chain, with an optimized process flow, increased overall efficiency and free from defects. The proposed model allows I-IoT to support network communication between production and supply chain, providing real-time data regarding operations and machines. Using the available data, it is possible to optimize processes, increase gains and reduce costs and consumptions, while the model monitors the enterprise, predicting changes and taking autonomous actions itself. Furthermore, the introduction of IoT technology holds a huge potential in the field of providing real-time data to be analysed, eliminating the need for human intervention (Pereira, Dinis-Carvalho, Alves, & Arezes, 2019).

Moreover, at the control level, Mrugalska and Wyrwicka (2017) proposed the use of IoT to ensure that the right products go to the right workstations and automatically redirect products in the event of referral errors. This, definitely, will improve the application of **Jidoka** into the industrial field. In addition, at the optimization level, Cristalli et al. (2013) used IoT to feed an agent-based optimization model, the GRACE[2] project, and detect manufacturing defects, particularly by analysing equipment vibrations. The authors also provided that quality agents can communicate and modify production parameters to improve quality in the event of a problem.

Taking about **TPM**, Eleftheriadis and Myklebust (2016) presented the IFaCOM[3] project, which takes advantage of the IoT to achieve zero defects. This system can be associated with the Control level and the Autonomy level, depending on the level of intelligence related to defect correction. The basic idea is the use of the IoT to monitor quality parameters, in order to suggest corrections to the production system in real-time and to adapt parameters, also in real-time.

The **Andon** principle is addressed by Kolberg and Zühlke (2015) and Mrugalska and Wyrwicka (2017) at the monitoring level. For both the authors, IoT allows products to communicate with equipment and send a warning when the wrong product is being produced. For the control level, Kolberg and Zühlke (2015) proposed extending the possibility of using IoT, but this time by allowing the equipment to react to this error warning by stopping the work or by changing products.

As regards the last tool of Jidoka, Auto-ID technology, such as RFID, can be applied to track material in real-time and to localize objects in the value chain precisely. This result is able to reduce search time as well as improve process transparency. Additionally, part recognition allows the identification of incorrect components and their removal which contributes to the idea of **Poka Yoke** (Mayr, et al., 2018).

To conclude the connection of IoT with the Jidoka principle, the use of IoT ensures the correct identification and assignment. A digital product memory allows to request required components and helps identify incorrect deliveries. This prevents adding value

2 InteGration of pRocess and quAlity Control using multi-agEnt technology
3 Intelligent Fault Correction and self-Optimising Manufacturing Systems

to defective parts. In addition, by using smart sensors and machine learning, machines can automatically adjust to irregularities to ensure optimal product quality (Michels, 2016).

Furthermore, focusing on **Visual Management**, Auto-ID can assist in carrying out **5S** more efficiently. RFID ensures the identification and the localization of objects leading to a reduction of search time (Fescioglu-Unver, Choi, Sheen, & Kumara, 2015). Then, other authors declare that IoT technologies are the proper tool to obtain information on the status of the production system and to make it available to employees in order to better visualize the process itself (Davies, Coole, & Smith, 2017) (Mayr, et al., 2018).

Additionally, Xu and Chen (2017) proposed a framework to support dynamic production planning and scheduling **JIT** production system. This framework, based on IoT, is able to reach to dynamic changes regarding orders, production and available resources, allowing the users to adjust schedules during production in order to maximise productivity. Also, IoT can track product in real-time and send production progress data back to managers (Wagner, Herrmann, & Thiede, 2017).

In addition, Davies, Coole, & Smith (2017) suggested that IoT could improve the principle of **Kanban** with a better synchronization of the working station. In particular, Sanders, Subramanian, Redlich, & Wulfsberg (2017) proposed e-Kanban, which allows each product to be tracked electronically and ensures that the right product arrives to the proper destination at the right time. In fact, by applying Auto-ID, a constant monitoring of work in process is possible. Hence, also transparency of material movements is increased. Moreover, Wagner, Herrmann, & Thiede (2017) presented a system using IoT, called JIT delivery, to automatically send orders.

In the **Muda Reduction**, the monitoring of wastes can be improved by using IoT (Mayr, et al., 2018). The idea shared by the authors is to take advantage of real-time product tracking to see product expectations and unnecessary transportation. Then, this information can be used to reduce waste.

Finally, the last practice related to IoT is **VSM** that, through the use of Auto-ID, enables the instant localization of objects. This can enable a better decision-making process based on real-time facts (Kolberg, Knobloch, & Zühlke, 2017).

In conclusion, IoT technologies are widely used to support the Lean practices in the industrial fields. The main benefits of IoT that are highlighted in the above paragraphs are: the possibility of improving monitoring and control of operation processes, but also the capabilities to predict future events and act as a consequence.

4.3.3.5 Industrial Analytics - relations with Lean Practices

For the Industrial Analytics column, the main aspects on which the different papers found focused are Big Data collection and analysis. Big Data is considered a great source of information that can support Lean Production implementation.

The first consideration is on the Continuous Improvement principle, included in the concept of **Kaizen**. In fact, Kassner et al. (2017) presented an IT architecture for data driven manufacturing that intends to address the weaknesses of traditional manufacturing IT and implement the data-driven factory in Industry 4.0 context. The developed solution has a strong focus on data collection, storage and analytics, as well as on the empowerment of human workers through mobile information provisioning that actively integrates them in smart manufacturing environment, promoting quality, process management and continuous improvement through the whole product life cycle.

Another Lean Practice compatible with Industrial Analytics is **Jidoka** with its main tools. In fact, **Poka Yoke** is the first one. Lettau (2013) described the use of CM[4] measurement technology, even if it is not a tested method, for the end-of-life-test of electric drivers production as both a warning and control system. Also, **TPM** is considered, in fact, cross-linked machines predictive analytics is a helpful tool for planned maintenance as it allows to analyse the correlation between condition parameters and the probability of default. In addition, unlike conventional CM, predictive analytics uses complex algorithms to predict defects based on large data sets (Big Data) (Kieviet, 2016). Moreover, smart products and CM technology allow for load, wear and defects to be monitored during machine operation. The early detection, isolation, and identification of faults results in less downtime and prevention of consequential damages (Mayr, et al., 2018).

As regards **Visual Management**, Zhong et al. (2015) used Big Data to extract relevant information from the large amount of data collected by the sensors distributed in the production system. Consequently, the visualization of relevant information is made easier to operators.

Furthermore, also **JIT** method applies Big Data and data analytics techniques. The opportunity to analyse detailed real-time process information provides insights into

[4] Machine learning-based condition monitoring

parameters, helps to identify trends, and allows to deduce rules for the production system (Ding & Jiang, 2017). Then, Rauch et al. (2016) supported that data analytics applied during product development processes provides real-time KPI and improves data processing, reducing waiting and operation times and consequently also improves the use of **Kanban**. Furthermore, the standardized data formats can decrease inefficiencies due to excessive and obsolete information, allowing real-time data exchange and promoting the involvement of the whole development team.

Moving the focus to **Muda Reduction** principle, Stojanovic, Dinic, and Stojanovic (2015) proposed using Big Data to identify, in real-time, unusual conditions in the production system and the identification of root causes. Also, Sony (2018) offered horizontal integration of systems between different departments within an organization to make information more accessible to identify all the form of wastes.

Nevertheless, the Lean Practice that is more mentioned in the literature in relation to Industrial Analytics technologies is **VSM**. In fact, Machine Learning and data analytics are able to support VSM in creating a value stream design, resulting in performance improvements. However, the main benefit for VSM is the improvement in transparency through a real-time display of value streams that helps in identifying waste within production processes and leads to a lean value creation. Besides, the effort to carry out VSM is reduced and decisions are based on real-time data (Mayr, et al., 2018).

Thus, some examples of applications are proposed:

- Meudt et al. (2016) proposed a new approach that consists in an upgraded VSM that allows companies to understand the opportunities that are emerging with digitalization and I4.0. This project focused on waste reduction, as well as a comprehensive understanding about every information and material flow within logistic processes, while the analysis of calculated KPIs have allowed the process improvement and production digitalization.
- Lugert et al. (2018) and Wagner et al. (2017) supported the potential of using Big Data technology for improving VSM procedures. A dynamic VSM is an innovative approach that has been proposed to optimize the value stream. This is achieved through the use of data analytics, simulation and a user interface that allows the real-time visualization of results using RFID technology, which enables process improvements and increases employees' involvement.

- Lugert et al. (2018) carried out an empirical survey that relates Lean Management, VSM and Industry 4.0 topics. The main aim was understanding the integration of these approaches in different industrial branches, evaluating the status of VSM from the user's point of view. The majority of participants considers that the static VSM has to be further developed to a dynamic VSM through digitalization technologies that include an integrated data model and optimization tools, which allow quicker and more flexible reaction to unexpected changes.
- Wang et al. (2016) implemented a value stream analysis and design, applying a FIFO logic that is able to determine the safety inventory, based on Big Data model that collects information from the products and their attributes of process.

All these examples highlight the importance of an integration between VSM and Industrial Analytics in the manufacturing field (Pereira, Dinis-Carvalho, Alves, & Arezes, 2019).

Finally, the last Lean practice considered is **Heijunka**. In fact, new software tools using Advanced Analytics can be utilized to support the planning process itself. For example, the software AnaPro levels the production program automatically based on production specification, structure of technological process, workplace and sales (Mayr, et al., 2018). This application can reduce the effort of levelling the production program, planning is automated and short-dated adjustments can be integrated smoothly (Zywicki, Rewers, & Bozek, 2017).

In conclusion, data analysis has the potential to contribute to improve system performance of the whole supply chain because of the consolidation of information is facilitated using Big Data and data analytics.

4.3.3.6 Cloud Manufacturing - relations with Lean Practices

The second-to-last column is the Cloud Manufacturing one. Cloud Manufacturing, in general, can contribute to eliminate media discontinuity between the planning and design phases on the one hand and the production phase on the other hand. For example, Plug and play[5] allows the autonomous integration of a technical system based on a modular design and a service-oriented architecture. Thus, production plants can easily be adapted

[5] Feature of the SaaS solution of Cloud Computing

and customized. In addition, the services are provided via standardized interfaces and operate independently of hardware-specific characteristics (Mayr, et al., 2018).

Concerning product development processes, the implementation of cloud manufacturing can be very useful, reducing the wastes that results from wrong sent information or disconnected users (Rauch, Dallasega, & Matt, 2016). Mayr et al. (2018) presented a use case that exemplifies how cloud computing and machine learning-based condition monitoring can enhance **TPM**. According to the authors, these technologies have enabled the improvement of production, reducing machines downtime, scraps and rework, increasing quality, while providing maintenance data to workers and dynamically scheduling maintenance activities.

As a consequence, also **Jidoka** concept can be considered. In fact, Ma, Wang, and Zhao (2017) proposed a system (SLAE-CPS) that allows anomalies to be detected and corrections to be made autonomously on the product through the use of cloud computing supported also by IoT and autonomous robots.

Moreover, as regards **Standardization**, Silva et al. (2018) developed a cloud computing-based allocation able to process inputs for electronic work instructions creation and the generation of standardized work.

Furthermore, Tao et al. (2017) and Zhong et al. (2015) suggested, for a better use of **Visual Management**, using cloud computing to make information related to the production system available to all the operators.

Then, Azambuja et al. (2013) proposed a real-time information exchange platform based on cloud computing to facilitate **JIT** supply between producer and its suppliers. This kind of project was also reported by Pereira et al. (2019) and Abreu et al. (2017), who believed that this application is able to automatically create work instructions and generate an optimal standard work based on operation description, sequences, production times, assembly lines and assigned products.

To conclude, the last Lean Practice considered is **Muda Reduction** for which Ogu et al. (2018) argued that cognizant computing can enhance Lean Practices through the elimination of wastes, providing several benefits in lean manufacturing context. The identified benefits are related to increased financial savings and returns, reduction in lead-times, inventory volumes, process wastes and less rework. The available real-time information provided by cognizant computing will allow managers and executives to make better decisions, reducing wastage, minimizing business risks and ensuring a better customer satisfaction.

4.3.3.7 Digital Twin/Simulation - relations with Lean Practices

The last column, Digital Twin/Simulation, is the latest introduction in the Industry 4.0 context. In general, the use of simulation technologies can be very useful for analysing and reconfiguring production system following Lean principles.

Firstly, Stojanovic and Milenovic (2018) integrated Big Data analysis and numerical Twin Simulation into continuous improvement process (**Kaizen** principle) aimed at finding a streamlined solution for the optimization of the process. Kamar and Kie (2018), on the other hand, use real-time simulation in the context of continuous improvement to optimize the production system in terms of stocks, movements, overproduction and waiting.

Moreover, Digital Twin allows a realistic simulation of the production plan that is able to enhance **TPM** application in the company. Also, it is able to better control processes in real-time to do maintenance when is needed (Lacour, 2012). In addition, Bauters et al. (2018) focused their work on a video-based system for automatically analysing manual assembly work tasks through a 3D-model. This system captures information about the way tasks are performed by the operators, being able to detect anomalous events that are linked with video data for further analysis. Based on this, the system can detect best practices and generate event list enriched with video data and KPIs to analyse the operator’s performance. Also, this can prevent defective parts to go in the following stages and check their quality following the **Jidoka** principle.

Furthermore, Saez et al. (2018) proposed the use of simulation to provide visual data to managers. This application is able to improve the **Visual Management** practice increasing visibility on the processes.

As regards **Kanban**, a lot of examples are proposed:

- D. Kolberg and D. Zühlke (2015) affirmed that through simulation methods or a virtual real-time representation of physical objects based on a CAD model (Digital Twin), new Kanban loops can be planned with more foresight and seamlessly integrated into the existing production environment. In fact, simulation ensures the identification of ideal Kanban parameters like lot size, stock and delivery frequency. Moreover, external changes can be included while the system refreshes parameters autonomously.

- Alves, Roßmann, and Wischnewski (2009) suggested to simulate changes in the Kanbans used.
- Mayr et. al. (2018) proposed to use simulation to represent products, as well as to test different parameters of Kanbans and find optimal ones such as batch size, minimum inventory and delivery frequency.
- Ferro et al. (2017) carried out a survey with the aim of analysing the integration of Discrete Event Simulation in operation management tools, such as, MES, ERP, RFID, core manufacturing simulation data and e-Kanban. The authors argued that these tools should be simultaneously used in order to solve problems related to operations and manufacturing system.

As a consequence of the use of Kanban, also **JIT** should be considered relevant in the implementation of Digital Twin/Simulation. In fact, Dallasega et al. (2017) described a simulation-based real-time solution for production planning that allows to achieve on-demand production and JIT delivery of components, leading to a drastic reduction of the inventory levels on manufacturing environment. In addition, Rüßmann et al. (2015) affirmed that simulation is used to test different response scenarios to production flow disruptions in real-time, but it is up to managers to apply the changes.

Furthermore, as regards **Muda Reduction**, simulation is also proposed to identify sources of waste by Zhuang, Liu, and Xiong (2018). These authors used the concept of Digital Twin to simulate scenarios for solving production problems and reduce wastes on a virtual copy of a production system.

Moreover, Nåfors et al. (2018) proposed a simulation model supported by 3D scanning and **VSM**, which facilitates the understanding of the existing production system and increases the flexibility regarding the design of a new one. Furthermore, Mayr et al. (2018) argued that Digital Twin concept supported by simulation technologies enables dynamic VSM, through the real-time replication of the whole manufacturing system, allowing the access to updated information as well as a more predictable and reliable planning.

Finally, the last practice considered is **People and Teamwork**. In fact, Lu and Yue (2011) suggested the use of simulation to facilitate employees training, allowing them to practice in a simulated environment.

In conclusion, the possibility to create a twin of an industrial process and use it to simulate all the possible outcomes is able to simplify the application of the above-mentioned Lean practices.

4.3.3.8 The framework

After the detailed description of each matrix column, done in the previous sections, the matrix itself is proposed (table 15).

Lean 4.0 Matrix	Additive Manufacturing	Advance Automation	Human-Machine interaction	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin / Simulation
Kaizen			2		2		2
Andon			2	2			
Poka Yoke		2	2	2	1		
TPM		2	4	2	2	5	2
Jidoka		7	2	8	4	4	2
Standardization		2	2			3	
5S			1	2			
Visual Management			5	11	2	3	2
Kanban		2		2	2		9
JIT	2	7	2	9	4	2	17
Muda reduction	2			6	2	2	4
VSM		2	2	2	8		3
Heijunka					3		
SMED	2						
People and teamwork			3				2

Table 15 - Lean 4.0 framework

More in details in the table above, each number corresponds to the amount of papers found supporting each specific intersection of the matrix. Some of them are mentioned into column’s chapters as a support to the matrix creation.

As can be easily seen, not all the intersections contain a number. This does not mean that the intersections are not possible but only that there seems to be no evidence of them in literature. In fact, even when only one paper was found in support of that specific intersections, it was enough for considering the existence of that interchange.

Finally, so far, some considerations can be made:

- Firstly, as regards the columns, Additive Manufacturing is the only column that has little evidence of its possible integration with Lean Practices.

- Secondly, as regards the rows, SMED, 5S, People and Teamwork, Heijunka, Andon and Standardization are the Lean Practices that have no more than two intersections with I4.0 technologies.

In conclusion, this matrix will be used as starting point for a practical analysis performed in order to verify if the theoretical context corresponds to the real one.

4.3.4 Main benefits of Industry 4.0 technologies on Lean practices

The different benefits that Industry 4.0 implementation can have on Lean Practices are the last topic, related to Lean 4.0 concept, that need to be taken into consideration. In particular, in this section the focus is not on a single Smart technology or Lean Practice - even if some of them might be used as examples - but it is on the generic concept of Industry 4.0 and on the main benefits that it could have on Lean Production.

On the basis of literature, the most common benefits taken to Lean from Smart technologies enabled by the Forth Industrial Revolution are related to *improvement of data collection*, *improvement of decision making* and *innovation of routine processes* as shown in the following casual map (figure 10).

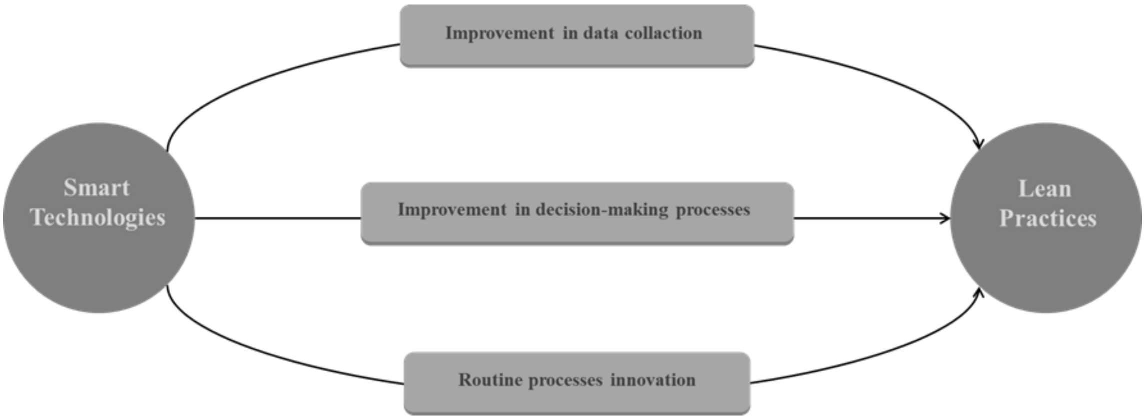

Figure 10 - Casual Map of Smart Technologies benefits on Lean Practices

In fact, Smart technologies - if aligned with Lean principles and concepts – are able to reduce value adding activities in organizations, as well as improve workers satisfaction. In general terms, every emerging technology can provide potential benefits in the existing reality. However, it is necessary to evaluate carefully how effective that technology is in each real case and context. This is important because mistakes have been made over the years with different technologies, creating many problems in different companies. These mistakes were mainly due to a lack of knowledge on Lean Practices already present in the existing organizations and, more in particular, about continuous improvement and empowerment (Pereira, Dinis-Carvalho, Alves, & Arezes, 2019).

The following sections (i.e. 4.3.4.1, 4.3.4.2, 4.3.4.3) are devoted to each of the three main impacts mentioned above in order to give more details about each single benefit and its main implications.

4.3.4.1 *Improvement of Data collection*

The first significant benefit deduced from the literature lies in improvements in **data collection** which, nowadays, represents an essential task to successfully perform any kind of organizational activity. Unfortunately, collecting the required data is still an arduous task for many companies. However, Industry 4.0 technologies allow to solve this problem, tackling efficiently the complexity of Lean Production systems (Uriarte, Ng, & Moris, 2018).

This is supported by Sanders, Elangeswaran and Wulfsberg (2016), who identified some of the main challenges for Lean Production implementation, such as missing data, inappropriate track of goods and inability to track process variations. The authors showed that Industry 4.0 offers great solutions to these problems, providing better communication and synchronization of data and wireless tracking of goods. Consequently, Industry 4.0 solutions support companies in becoming Lean without "striving-for-lean" efforts.

The same conclusion was drawn by Haddud and Khare (2020), who studied the benefits of Industry 4.0 on Lean practices. More specifically, they underlined that Industry 4.0 empowers the Just-in-Time logic through a timely information sharing, that allows to have the right parts available, in the required quantities and qualities, at the right time. The timely and accurate information provided by these new technologies leads to a more accurate demand forecasting, a better management of procurement and a better inventory management and control. At the same time, Just-in-Time is enhanced by the traceability capability offered by Industry 4.0, which ensures that the one-piece-flow logic is respected. Besides, a better product traceability is associated with more supply chain visibility, increasing the potential of Poka-Yoke practice. Moreover, the authors showed the great advantages that Kaizen takes from the fact that, thanks to Industry 4.0, information is easily captured, shared, processed and forwarded to the right people. On top of that, since Industry 4.0 technologies are able to provide data in real-time, they help complete the required equipment maintenance faster.

The real-time provision of data has been deemed to be a characteristic of different Industry 4.0 technologies, such as IoT and Cloud Computing. Thanks to this feature, IoT is used to give instant feedbacks about performance, enhancing Visual Management, and provide better communication between production stakeholders, helping People and Teamwork. This technology is helpful also in Maintenance as it is able to gather precise information about maintenance needs and automatically send signals to employees (Pereira, Dinis-Carvalho, Alves, & Arezes, 2019). In addition, Wagner, Herrmann and Thiede (2017) demonstrated that IoT empowers Just-In-Time since it allows to collect data in the necessary spatial resolution and fulfill the required sampling rate of application. As for Cloud Computing, it has been noted how its capability of storing information about connected products is a strong leverage in Value Stream Mapping activities (Uriarte, Ng, & Moris, 2018). Moreover, thanks to the information sharing available through this technology, Cloud is deemed to be suitable to create standard work instructions in an optimized way, leading to an empowerment of Lean standardization (Pereira, Dinis-Carvalho, Alves, & Arezes, 2019).

4.3.4.2 *Improvement of Decision-Making process*

In literature, the most widespread definition of **decision-making** is "the process of choosing among alternative courses of action for the purpose of solving a problem or attaining better situation regarding the opportunities that exist" (Al-Tarawneh, 2012). Since it allows to manage the complexity of organizations, this process is largely considered as one of the most critical and essential managerial functions. This is the reason why companies need to be always up to date about the new ways to optimize their decision-making procedures. In particular, the simplification and improvement of decision-making represents one of the main benefits of the integration between Lean Production and Industry 4.0.

First of all, simulation is deemed to be one of the most common techniques applied to support decision-makers in designing manufacturing systems (Negahban & Smith, 2014). For instance, in the last years the use of the so-called simulation-based multi-objective optimization (SMO) has been able to drop significantly the long time needed to create and evaluate different what-if scenarios. This approach regards the application of simulation to empower optimization techniques, with the aim of providing decision-makers with optimal, or nearly optimal, solutions. Taking into consideration that Lean philosophy influences the way processes are run and how the organizational culture is built, SMO can be complementary to Lean practices in different stages and, eventually, become part of the lean toolbox. In fact, SMO can support those Lean practices employed to address decision-making by providing a knowledge-driven perspective (Uriarte, Ng, & Moris, 2018).

Additionally, it has been underlined that the use of simulation, as well as the communication between different devices, is able to promote real-time decision-making over the traditional complex process (Tamás, Illés, & Dobos, 2016). In support of this, Mayr et al. (2018), in their study on how some Industry 4.0 technologies affects the implementation of Lean principles, demonstrated that real-time data acquisition improves process transparency and product quality information. In this way, improvement activities – such as Kaizen – are based on complete information, resulting in improvements in terms of employees' decision-making.

Rosin, Forget, Lamouri and Pellerin (2020) showed that technologies from Industry 4.0 benefit Lean practices by deploying different capabilities. Among them, optimization represents the one that mostly supports decision-making. In fact, the optimization capability allows algorithms to analyse both environment and historical data in order to propose better resource utilisation and more efficient results (Porter & Heppelmann, 2014). Thus, Industry 4.0 provides organizations with systems able to review the set of alternatives where the decision-maker can choose the action to take. As a result, different Lean practices – such as Just-In-Time and People and Teamwork – are enhanced and supported (Rosin, Forget, Lamouri, & Pellerin, 2020).

On top of that, it has been noted how IT-enabled information sharing allows a lower information lead-time, resulting in a shorter and more efficient decision-making process (Ghobakhloo & Fathi, 2020). In particular, IoT devices are able to provide autonomous optimized decisions in terms of flow, facilitating the Just-In-Time logic and leading to an improved management of the whole supply chain (Pereira, Dinis-Carvalho, Alves, & Arezes, 2019).

Finally, Haddud and Khare (2020) showed the empowerment of decision-making by studying the impacts of Industry 4.0 on different Lean practices. They demonstrated that Industry 4.0 technologies are able to enhance visual management techniques by providing a smart visualization of the supply chain. This allows to better visualize all the involved processes, operations and activities, leading to an easier decision-making process. At the same time, these new technologies allow to collect and analyse previous risk events, making possible to predict possible future incidents and improving the precision of decisions in terms of risk management. In addition, the authors demonstrated that the data processing capability enabled by Industry 4.0 helps consistently the Just-in-Time logic. In fact, it leads to a more accurate demand forecasting and, consequently, more effective decisions and reactions to marketplace changes. Last but not least, Industry 4.0 technologies allow a more effective information management, providing decision-makers with what they need to take the right actions. In this way, continuous improvement results empowered.

All in all, it is possible to conclude that the synergies between Industry 4.0 technologies and Lean Production practices significantly affect the decision-making process. In particular, they allow to improve the quality and precision of decisions, affecting the processes performance and, therefore, the overall organizational performance.

4.3.4.3 Innovation of Routine Processes

Finally, the last benefit considered is **routine processes innovation**. To be more precise, it means that usual working activities are performed in a renewed way compared to the current performance of a company process.

In fact, Industry 4.0 process innovation strategy always aims at increasing the production process efficiency, reducing waste and lowering marginal production cost, that is in line with Lean principles (Buer, Strandhager, & Chan, 2018). These improvements come with a change in routines and industrial standards, which are well-established and undoubtedly impact the relationship with suppliers. When firms invest in Industry 4.0 technologies, they signal to supplier their intentions to upgrade and ameliorate their internal efficiency and, consequently, improve their operations (De Giovanni & Cariola, 2020).

Moreover, the investments in Industry 4.0 technologies lead to process innovation, with the advantage of using smart tools and the latest technology developments and, also, of making Lean more effective for achieving higher operational and economic performances (De Giovanni & Cariola, 2020).

For instance, Industry 4.0 techniques implementation can enhance flexibility of the production system. This allows to solve the problem of ineffective maintenance that leads to frequent breakdowns which, in turn, leads to loss of productivity (Al-Hyari, Zaid, Arabiyyat, Al-Qwasmeh, & Haffar, 2019). An example is the application of Cloud system and Big Data concept that can be used for monitoring as well as predicting the machine condition (Conti & Orcioni, 2019). Moreover, AR can be also applied for enhancing the maintenance activity where unskilled workers can be connected to a skilled engineer for proper guidance (Masoni, et al., 2017).

In addition, Karkoszka and Honorowicz (2009) said that the proper combination between Kaizen method and operations of the innovative character gives the biggest effects and benefits. Innovations allow following the newest trends and modern technologies, kaizen guarantees the continuity competences and essential standardization. More in details, they develop a case study on which they conclude that: in the Factory of General Motors Manufacturing Poland during the recent years the number of reported kaizen ideas have fluctuated about 14000 per year; it surpasses about keel of thousand the purposes accepted by the leading management. Such a big number of ideas and high percent of implementability confirms the correct functioning of kaizen system, the proper manner of awarding and high involvement of employee in improvement of the personal workplace as well as the whole productive process.

Another important concern in the present industrial scenario is quality (Kumar, Maiti, & Gunasekaran, 2018). Industry 4.0 technologies can aid in enhancing quality parameters such as quality production and services – Lean Principles - in any firm (Foidl & Felderer, 2015). All methods are considered as advanced approaches for scheduling problem (Aytug, Bhattacharyya, Koehler, & Snowdon, 1994). Wireless industrial network technology of Industry 4.0 can help in timely delivery of product. Intelligent quality control system can enhance the product quality as well as process improvement (Vinodh, Antony, Agrawal, & Douglas, 2020).

Lastly, autonomous and collaborative robotics appear having great potential in creating hybrid workplaces where humans and robots work in a collaborative way, promoting People and Teamwork. Moreover, Big Data and Data Analytics are mentioned in some publications as facilitators to problem-solving, as well as promotors of human workers empowerment through mobile information provisioning that actively integrates them in smart manufacturing environment (Pereira, Dinis-Carvalho, Alves, & Arezes, 2019).

4.4 Small and Medium Enterprises

In order to define what a SME is, different countries use different parameters such as size, age, number of employees, annual turnover, sales and asset value of the organization (Yadav, Jain, Mittal, Panwar, & Lyons, The Propagation of Lean Thinking in SMEs, 2019). As a consequence, it doesn’t exist a definitive global definition of Small and

Medium Enterprises (Karlsson & Åhlström, 1997). For instance, a Chinese organization is considered as SME when it has less than 999 employees, while this number drops to 499 in the USA (Alkhoraifa, Rashidb, & McLaughlina, 2019). Nevertheless, since the European Commission has agreed on a description, SMEs located in European countries are associated with the same characteristics. More specifically, organizations are recognized as micro, small or medium according to their number of employees, turnover, and balance sheet total (European Commission, 2020), as shown in table 16. It is noteworthy that these figures don't need to be considered concurrently for a company to be deemed micro, small or medium (Alkhoraifa, Rashidb, & McLaughlina, 2019).

Company Category	Staff Headcount	Turnover	Balance Sheet Total
Medium	< 250	≤ € 50 m	≤ € 43 m
Small	< 50	≤ € 10 m	≤ € 10 m
Micro	< 10	≤ € 2 m	≤ € 2 m

Table 16 - SMEs definition according to European Commission

Besides the figures that allow to classify SMEs as such, the most of these organizations are associated with specific features, which appear very clear in the comparison with large enterprises (LEs). In the first place, SMEs organizational structure is fluid and short, leading to high visibility of top management through few levels (Laufs, Bembom, & Schwens, 2016), as well as quick communication and decision-making (Hudson-Smith & Smith, 2007). In addition, it has been noted the huge impact of top executives' personality on the company's organizational culture (Laufs, Bembom, & Schwens, 2016). In order to be result-oriented and favorable to new change initiatives, a SME needs to be managed by people with this kind of mindset (Pinho, 2007). In this regard, usually SMEs are staffed by young people, who tend to be more keen on trying innovative ideas and taking risks (Alkhoraifa, Rashidb, & McLaughlina, 2019). Nevertheless, it has been proven that SMEs are associated with a lower innovation potential (Antony, 2008), a higher risk aversion and a more short-term orientation (Ates, Garengo, Cocca, & Bititci, 2013) than LEs. In fact, on the one hand the simple organizational structure and the young workforce are likely to be the reasons why SMEs are more adaptable and flexible than LEs; on the other hand, they lead to lack of expertise and limited specialization. These flaws are avoided by LEs' complex structures, characterized by many levels - in which responsibilities and authorities are specifically defined - and empowered by superior communication systems, such as ERP (Yadav, Jain, Mittal, Panwar, & Lyons, The Propagation of Lean Thinking in SMEs, 2019). On top of that, SMEs are likely to have difficulties in obtaining adequate financial support (Ates, Garengo, Cocca, & Bititci, 2013). As a result, they are not able to provide their employees with the learning and training opportunities (Tam & Gray, 2016) necessary for new improvement initiatives to succeed. Conversely, LEs often can afford to carry out in-house training or send their employees to attend external training programs and conferences (Yadav, Jain, Mittal, Panwar, & Lyons, The Propagation of Lean Thinking in SMEs, 2019). Additionally, this lack of innovation and financial backing from governments might jeopardize managers' interest in exploring and introducing new management methods, such as Lean Production (Alkhoraifa, Rashidb, & McLaughlina, 2019). Another important difference lies in the way procedures are carried out. Normally, LEs plan their activities and allocate their resources following standardize and formalized systems and procedures (Yadav, Jain, Mittal, Panwar, & Lyons, The Propagation of Lean Thinking in SMEs, 2019). Conversely, SMEs' operations and activities are not governed by formal rules (O'Reilly, Kumar, & Adam, 2015), resulting in flexibility and quick response to customers' requirements (Towers & Burnes, 2008). However, this lack of systematic procedures might lead to high variability. In terms of relationships along the supply chain, SMEs and LEs manage their networks in a quite different way. While LEs tend to establish long-term relationships with global partners with a large customer base (Yadav, Jain, Mittal, Panwar, & Lyons, The Propagation of Lean Thinking in SMEs, 2019); SMEs are characterized by a few external interactions, close relationships and local markets (Darcy, Hill, McCabe, & McGovern, 2014). In this regard, it has been noted that SMEs' smaller size allows them to be more responsive in modifying their manufacturing process (Floyd & McManus, 2005) and, as a consequence, to be more flexible in addressing the changing needs of customers (Alkhoraifa, Rashidb, & McLaughlina, 2019). Thanks to this flexibility, SMEs have the possibility of presenting personalized services, which can be used as a competitive advantage (Deros, 2014). Conversely, LEs are able to be capital intensive and enjoy economies of scale and often build their success on these elements (Gnanaraj S. M., Devadasan, Murugesh, & Sreenivasa, 2012). All in all, SMEs do not even out LEs in terms of investments possibilities, economies of scale, long-term orientation, risk-taking abilities, and level of organizational structure. On the other side, they result to be more adaptable and responsive in satisfying customer needs, they make decisions in a quicker way and they have more flexible production systems (Yadav, Jain, Mittal, Panwar, & Lyons, The Propagation of Lean Thinking in SMEs, 2019).

SMEs play a crucial role in Europe because they represent 99% of all businesses (European Commission, 2020) and provide 90 million workers with jobs**.** Taking into consideration Italian enterprises, on the basis of the European Commission’s definition, 95.05% of them are micro, 4.86% are small and medium, 0.09% are large. In this context, it is interesting to notice that SMEs are responsible for 41% of Italian revenues and 33% of employment in the private sector (Osservatori Digital Innovation, 2020). In light of these figures, Italian SMEs result to be definitely essential for the country’s economy. For this reason, they are taken into account as subjects of surveys in this dissertation.

4.4.1 Lean Production in SMEs

As mentioned before, SMEs are largely considered as the backbone of the industrial and economic growth of a nation, as well as important contributors in terms of employment (Singh, Garg, & Sharma, 2010). Additionally, they represent significant players in supply chain networks. Nevertheless, due to their structural characteristics, these companies might suffer from long product development lead times, high inventory, poor organizational performance and so on (Chaplin, Heap, & O’Rourke, 2016). Therefore, it is necessary for SMEs to focus on finding effective ways to improve their performance as much as possible. In addition, SMEs are the subjects that struggle the most to maintain their competitiveness because of the high competition in the economic context (Driouach, Zarbane, & Beidouri, 2019). In fact, competitiveness is nowadays influenced by different macro-forces that affect both supply and demand (Alkhoraifa, Rashidb, & McLaughlina, 2019). On the one hand, demand is changing because of the increased number of options available for customers, as well as their ability to better evaluate those options (Bhamu & Sangwan, 2014). On the other hand, supply is influenced by globalization, deregulation of trade, technological advancements and easier accessibility to technology (Harvey, Speier, & Novecevic, 2001). Consequently, companies need to improve their performance by combining a deep understanding of what customers consider as valuable with effective methods to carry out production and operations (Bowersox, Closs, Stank, & Keller, 2000). In this regard, Lean Production practices might come to help: the main aim of this philosophy is to provide companies with a competitive edge by reducing costs and improving productivity and quality. In fact, Lean Production promotes systematic identification and elimination of wastes in order to be highly responsive to customers’ demand (Bhamu & Sangwan, 2014). Lean methods have proven themselves beneficial for all the companies – regardless of their typology, size and industry – that need to increase their competitive advantage, profits and operations efficiency in the market (Alkhoraifa, Rashidb, & McLaughlina, 2019). However, it is worth noticing that even if many studies support the success of Lean practices implementation (Hu, Mason, Williams, & Found, 2015), the majority of them are focused on LEs, completely omitting SMEs (Gnanaraj S. , Devadasan, Murugesh, & Shalij, 2010). On the other side, it is argued that developing studies for SMEs is quite hard because of their poor level of data sharing and closeness (Belhadi, Touriki, & El Fezazi, 2016). Moreover, SMEs tend to integrate and apply Lean practices less than LEs (Rymaszewska, 2014). In light of these considerations, many of the available studies about Lean implementation result to be useless for SMEs because they do not take into account their specific needs and expectations (Dombrowski, Crespo, & Zahn, 2010). In fact, Lean adoption in SMEs faces challenges and barriers which are quite different from the ones of LEs (Ghobadian & Gallear, 1996), and, at the same time, it has different impacts. The main purpose of the following paragraphs is to analyze specific elements characterizing SMEs that make both easier or harder Lean application (i.e. **enabling and inhibiting factors**). Moreover, it is taken into account that set of **critical success factors** (CSFs) that is essential for a successful Lean implementation in SMEs, as well as the main **impacts** of Lean practices in such type of companies. All these elements will be useful to enrich the discussion about the results of the surveys. Finally, the specific **Lean practices** applied by SMEs are introduced.

4.4.1.1 *Lean in SMEs - Enabling and Inhibiting Factors*

There are some specific characteristics of SMEs that make them particularly suitable or, on the other side, unsuitable for the implementation of Lean Production. The former elements are known as enabling factors, while the latter as inhibiting ones. They will be presented in this paragraph by following the framework proposed by Alkhoraifa, Rashidb, & McLaughlina (2019), that classifies both these two typologies of characteristics as related to **supplier relationship**, **intra-SME organization**, **operations**, **resources** or **customer relationship** (see table 17). It is worth mentioning that in the original classification, the category “resources” was called “finance” because it collected financial elements only. With the aim of including more enabling and inhibiting factors, it has been decided to rename it in order to include different typologies of resources.

	Inhibiting	Enabling
Supplier Relationship	− Low negotiation power − Lack of cooperation − Management distrusts business partners	− SMEs are focused on specific business
Intra-SME Organization	− Wrong organizational culture − Lack of management commitment and support − Lack of benefits understanding − Lack of knowledge and skills	− Supportive organizational culture − Private ownership − Ease of communication − Teamwork

	− Lack of employees' involvement − Resistance to change − Backsliding to old methods	− Multi-skilled workforce − Informal relationships − Less bureaucracy and requirements
Operations	− Poor processes and quality control systems	− Flexible production planning
Resources	− Lack of budget, infrastructures, services, time	− Governments' support and grants
Customer Relationship	− Less able to influence demand volatility and variability	− Closeness to customers

Table 17 - Inhibiting and Enabling factors for Lean implementation in SMEs

Starting from **supplier relationship**, SMEs may lack the market power necessary to promote the adoption of Lean within the supplier network (Alkhoraifa, Rashidb, & McLaughlina, 2019). In fact, the usually small volumes produced by SMEs negatively affect their negotiation power towards suppliers (Wilson & Roy, 2009) and, consequently, they struggle in including them into Lean initiatives. In addition, SMEs suffer from a lack of cooperation and involvement with their suppliers (Salaheldin, 2005) and this is supported by Yadav, Jain, Mittal, Panwar and Sharma's (2019) case-studies. At the same time, when the Lean implementation is proposed by SME's partners, a possible barrier is represented by the company's management. In fact, they might distrust business partners and not be keen on being involved on their development projects (Kolosar, 2018). On the positive side, since SMEs are often focused on specific business areas, their suppliers are likely to be quite reliant on them. As a consequence, SMEs might result to be quite influential in the application of Lean practices along the supply chain (Karlsson & Åhlström, 1997).

Intra-SME organization represents the category associated with the most factors, both on the enabling and inhibiting sides. The majority of them revolves around the concept of organizational culture (i.e. rules and behaviors which cover trust, hierarchy, working environment and fellow-feeling), which is considered as essential for Lean implementation (Dora, Kumar, & Gellynck, 2015). In a SME context, the organizational culture reflects the personality and attitude of top executives and it ends up representing a barrier if they are not correctly involved in the project (Yadav, Jain, Mittal, Panwar, & Sharma, 2019). In fact, management commitment represents the key for the successful implementation of any initiative. This is particularly emphasized in SMEs context, where top management is directly involved in daily operations. Hence, the potential lack of management commitment and support is largely recognized as one of the main organizational barriers for Lean implementation (Yadav, Jain, Mittal, Panwar, & Sharma, 2019). In fact, it leads to many additional problems, such as limited access to resources, delays in decision-making processes and inadequate communication (Scherrer-Rathje, Todd, & Patricia, 2009). This might be due to the fact that SMEs leaders' efforts are concentrated on daily operations and, consequently, applying changes to these operations might be difficult. In this case, developing the right organizational culture represents a good remedy because it allows to both improve operations and manage the operational strategic issues related to lean implementation (e.g. backsliding to old methods, human resistance and so on) (Alkhoraifa, Rashidb, & McLaughlina, 2019). Another reason for lack of managers' commitment – that represents an inhibiting factor itself – is their poor understanding of Lean's benefits. In fact, in order to be motivated in pursuing an initiative, people need to have clear the advantages of it and to be able to measure them (Bhasin, 2012). This was clearly confirmed by the case-studies conducted by Yadav, Jain, Mittal, Panwar and Sharma (2019). Moreover, many managers do not spend time on learning new and modern management methods. Thus, they struggle to recognize that applying Lean is not just a cost (Kolosar, 2018). As a consequence, the company suffers a lack of support for training and knowledge development (not only for managers but also for workers), as well as senior managers that are not specialized in the field and that cannot supervise the processes adequately (Chaple, Narkhede, Akarte, & Raut, 2018). In this way, the missing employees' (i.e. managers and workers) knowledge and skills is clearly another barrier for Lean implementation. Another management's mistake that obstacles Lean practices in SMEs is not to involve workers in setting the organizational vision, goals and values. In fact, employees' direct participation improves problem-solving processes, as well as favorites the flow of information and knowledge (Yadav, Jain, Mittal, Panwar, & Sharma, 2019). Even if the most of inhibiting factors are associated with management's actions, there are some wrong behaviors that concern also other types of employees (e.g. shop floor workers). First of all, during Lean implementation, both workers and middle managers provide a resistance to change (Marodin & Saurin, 2015). While the former are concerned about losing their job, the latter are scared of failure. Secondly, employees tend to backslide to old methods because they fear that productivity improvements result in unemployment. In fact, when they face some difficulties or challenges, they find themselves much more comfortable in sticking with traditional old methods (Yadav, Jain, Mittal, Panwar, & Sharma, 2019). As mentioned before, both these problems can be effectively addressed by the development of an organizational culture which is accommodating for Lean (Alkhoraifa, Rashidb, & McLaughlina, 2019). In this regard, it is worth noticing that company's leadership can also represent an enabling factor for Lean implementation as SMEs are likely to be owned privately. Therefore, the owners usually are strongly interested in progressing and maintaining their business: this long-term commitment to survival and profitability might represent the right support for Lean implementation (Bevilacqua, Ciarapica, Ettorre, Mazzuto, & Paciarotti, 2014). Generally speaking, the most enabling factors for Lean practices in SMEs are associated with the simple organizational structure. Firstly, it allows a straight-forward communication process, which is extremely important as communication represents the key for the successful implementation of a strategy (Karlsson & Åhlström, 1997). In fact, it promotes a positive culture of inter-connection, where groups formed by people with different hierarchical positions and different competences are required to work together, leading to high levels of cohesiveness and fast decision-making. This environment is supportive of Lean practices, as teamwork represents one of them (Alkhoraifa, Rashidb, & McLaughlina, 2019). In addition, due to the simple organizational structure, company's employees result to be multi-skilled and cross-functional, as well as they need to take high levels of personal responsibilities. This is another point of strength for the creation of a positive environment for operational initiatives (Yadav, Jain, Mittal, Panwar, & Lyons, 2019). Finally, literature suggests that it might be easy to introduce Lean in SMEs because of the less bureaucracy and traditional requirements, as well as the informal inner relationships (Kolosar, 2018).

In terms of **operational** factors, the main barrier to Lean implementation is identified as the fact that SMEs are likely to have poor processes and quality control systems (Alkhoraifa, Rashidb, & McLaughlina, 2019). On the other side, it has been argued that SMEs' flat structure and simple systems are beneficial to Lean as they allow flexibility to change, as well as dissemination of knowledge (Pearcea, Pons, & Neitzert, 2018). This flexibility in production is promoted also by informal rules on operational planning, which are favorable also for rapid response to the customer, confirming its positive role in Lean implementation (Yadav, Jain, Mittal, Panwar, & Lyons, 2019).

Further inhibiting and enabling factors for Lean implementation in SMEs are associated with the **resources** owned by companies. In fact, the successful implementation of Lean requires an adequate amount of resources (Chaplin, Heap, & O'Rourke, 2016) and the lack of financial, technical and human resources is considered as one of the main barriers. In their literature review, Alkhoraifa, Rashidb and McLaughlina (2019) demonstrated the fact that many authors highlighted often SMEs do not have the budget necessary to apply

Lean practices. As a consequence, they cannot buy the necessary technologies and hire the consultants needed to counterbalance the missing internal expertise. Besides, they lack infrastructures and services necessary to implement Lean, as well as the time needed to educate and train employees. Nevertheless, it has been argued that often governments and other agencies propose specific plans and grants to support SMEs.

Finally, it is worth to analyze those few SMEs' characteristics related to **customer relationship**. On the negative side, SMEs result to be less able to influence demand variability and volatility, as well as to set trends (Rymaszewska, 2014). On the positive side, due to the small size, SMEs are closer to the final customers and, consequently, they can better forecast their needs and requirements (Alkhoraifa, Rashidb, & McLaughlina, 2019). Additionally, they are provided with instantaneous feedbacks from customers (O'Reilly, Kumar, & Adam, 2015). These features, together with the flexible production planning, allow SMEs to be responsive to customer needs, which is essential for an efficient Lean transformation.

It is clear from the above discussion that the characteristics of SMEs can create either a positive or negative environment for Lean implementation. Consequently, they should leverage on their own points of strength and apply some countermeasures to overcome these difficulties.

4.4.1.2 *Lean in SMEs - Critical Success Factors*

The central aim of the present paragraph is to investigate the high-impact factors necessary for Lean implementation in the context of SMEs. These factors are known as CSFs and they are defined as "areas of managerial planning and action that must be practiced to achieve effective quality management in a business unit" (Saraph, Benson, & Schroeder, 1989). In this case, CSFs represent key organizational issues that company's management needs to address to be able to successfully implement lean practices. It is worth noticing that these factors are necessary but not sufficient conditions for success. In other words, their mere presence does not lead to an effective implementation of Lean, but without them it is very difficult to do so. Thus, the general assumption is that these factors need to be present before Lean projects implementation starts (Knol, Slomp, Schoutetena, & Lauchea, 2018). The main CSFs arisen from the literature are seven: **management commitment and leadership**, **organizational culture**, **training of employees, employees' involvement and participation, communication, financial capability** and **supply chain integration**.

Management commitment and leadership is widely recognized as one of the most important CSF for Lean adoption in SMEs. In fact, the main barrier to the successful implementation of an initiative is not technical but human (Mazany, 1995). In light of this, managers are held responsible for educating and motivating all employees to support Lean implementation in every organization's activity. This is possible only if management is highly committed to a long-term vison of added value, which is reached by means of employees' improvement and support. Additionally, high-quality leadership is favorable for the development of adequate skills and knowledge among employees (Panizzolo, Garengo, Sharma, & Gore, 2012).

The topic of management commitment naturally leads to the one of **organizational culture**. In fact, a supportive culture in the organization is necessary for the adoption of Lean in SMEs. As mentioned in the previous paragraph, organizational culture reflects the personality of managers (Yadav, Jain, Mittal, Panwar, & Sharma, 2019), which are required to establish long-term orientation, good teamwork conditions and excellent communication in order to promote Lean adoption (Yadav, Jain, Mittal, Panwar, & Lyons, 2019). In this regard, it has been demonstrated that reducing uncertainty, setting a clear future orientation and adopting an institutional collectivism are key elements to implement successfully an initiative (DeSanctis, Ordieres, Bevilacqua, & Ciarapica, 2018).

Lean transformation requires high levels of expertise and skills (Yadav, Jain, Mittal, Panwar, & Lyons, 2019). As a consequence, **training of employees** represents a CSF as it allows to improve both their soft and technical skills (Dora, Kumar, & Gellynck, 2015). In particular, it has been argued that, rather than diving straight in with Lean tools, it is necessary to start with developing employees' expertise and to keep training them also during Lean implementation (Alkhoraifa, Rashidb, & McLaughlina, 2019).

Besides being trained, employees need also to be engaged: **employees' involvement and participation** represents a central CSF. Panizzolo, Garengo, Sharma and Gore (2012) demonstrated that including employees in quality improvement projects and increasing their independence and accountability is highly advantageous to improve companies' performance. The same authors underlined that the active participation and empowerment of people in the organization is essential to apply some Lean practices, such as Kaizen and 5S. Additionally, employees' empowerment and involvement allow to remove cultural barriers and create a positive environment to support Lean implementation (Yadav, Jain, Mittal, Panwar, & Lyons, 2019).

Another widely recognized CSF is **communication**. In fact, direct communication between management and workforce is the key for JIT successful implementation (Alkhoraifa, Rashidb, & McLaughlina, 2019). At the same time, an efficient communication is necessary between all partners in the value chain, since a lack of it results in poor performance, low quality and sub-optimal production rates (Yadav, Jain, Mittal, Panwar, & Lyons, 2019).

Financial capability represents another critical success factor, as Lean implementation requires investments in training programs and consultancy (Yadav, Jain, Mittal, Panwar, & Lyons, 2019). Unfortunately, SMEs face financial barriers that might obstacle the progress of improvement initiatives (Panizzolo, Garengo, Sharma, & Gore, 2012), also because the financial benefits of Lean are realized after a long period of time. However, it is noteworthy that in literature there is not a common consensus about that. In fact, it has been argued that, if management prioritizes improvements on their agenda, the low financial capability does not affect Lean adoption that much (Dora, Kumar, & Gellynck, 2015).

The last CSF is represented by **supply chain integration**. In particular, it has been demonstrated that the continuous use of Lean in SMEs shows advantageous influences from supplier integration policies, such as information sharing. In light of this, SMEs should foster a supportive Lean environment within their supply chain, in order to involve their partner and empower the improvements projects' results (Alkhoraifa, Rashidb, & McLaughlina, 2019).

4.4.1.3 *Lean in SMEs – Impacts*

Certainly, Lean approach has several influences on those companies that implement it. According to the categorization proposed by Yadav, Jain, Mittal, Panwar and Lyons (2019), the impacts of Lean on SMEs have been classified as **operational**, **financial**, **social** and **environmental** (see table 18). In addition to these categories, the one of **administrative impacts** has been added to provide a clear picture of the influences reported in literature.

Operational Impacts	Financial Impacts	Administrative Impacts	Social impacts	Environmental Impacts

− Better delivery time − Higher quality levels − Productivity improvements − Operating costs reduction − Less inventory − Less space occupied − Increased flexibility − Reduced set-up times	− Increased market share − Increased revenues − Increased sales − Increased profit	− Less Administrative procedures − Less administrative costs − Better service level − Less control errors − Higher customer order accuracy	− Better working conditions − Better teamwork − More motivated employees − Less stressed employees − Skilled and versatile employees	− Reduction of wastes − Reduction of pollution − Energy savings

Table 18 - Lean impacts on SMEs

Operational impacts are the ones that arise more clearly after Lean implementation. More specifically, they represent direct consequences of the main goal of Lean: *Muda* reduction. In fact, the significant reduction of wastes is associated with a decrease of lead time and cycle time, which positively affects delivery time as well (Kilpatrick, 2003). Additionally, changes in manufacturing processes and work efficiency lead to higher levels of quality, as well as productivity improvements. Among these improvements, the reduction of productivity time results in the reduction of resources use (e.g. energy, time, machineries and so on) and, consequently, a decrease of operating costs (Driouach, Zarbane, & Beidouri, 2019). In addition, Lean aims at optimizing as much as possible the use of production resources. This is reflected in a reduction of inventory and space occupied (Kilpatrick, 2003). Finally, it has been noted the increase of flexibility at the operational level, as well as the reduction of set-up times (Yadav, Jain, Mittal, Panwar, & Lyons, 2019). The most of these benefits have been confirmed by the case studies conducted by Panizzolo, Garengo, Sharma and Gore (2012), that showed how Lean practices application helped decrease set-up times and obtain better inventory turnover and delivery time.

The operational performance of a firm is reflected in its financial performance. **Financial impacts** are represented by growth of market share, total sales, revenues and, ultimately, profit (Yadav, Jain, Mittal, Panwar, & Lyons, 2019).

As for the **administrative impacts**, the most observed in literature are simplification of administrative processes, reduction of administrative costs, better service level and decrease of control errors (Kilpatrick, 2003). In addition, it has been argued that improvements of delivery time and quality lead to an increase in customer order accuracy (Driouach, Zarbane, & Beidouri, 2019).

Lean Production values a lot the importance of teamwork and people within the organization. The impact of Lean on the **social** performance can be seen in improved working conditions and more efficient teamwork efforts (Yadav, Jain, Mittal, Panwar, & Lyons, 2019). In addition, employees result to be less stressed and more motivated, as well as they are given the possibility to develop new skills and increase their flexibility (Driouach, Zarbane, & Beidouri, 2019).

Finally, Lean Production helps the **environmental** performance through reduction of wastage and pollution, as well as energy savings (Yadav, Jain, Mittal, Panwar, & Lyons, 2019).

4.4.1.4 *Lean Practices implemented in SMEs*

It goes without saying that the benefits on SMEs performance analyzed in the previous paragraph are achievable through the implementation of specific Lean practices. Since Lean approach has been developed in the '90s, many different papers have analyzed which Lean practices have been implemented by SMEs throughout the years. In this regard, Alkhoraifa, Rashidb and McLaughlina (2019) and Yadav, Jain, Mittal, Panwar and Lyons (2019) elaborated two interesting literature reviews and both of them summarize which are the main Lean practices implemented by SMEs, which are reported in table 19.

Lean Practices
Kaizen
Total Production Maintenance
Standardization
5S
Visual Management
Kanban
Value Stream Mapping
SMED

Table 19 - Lean Practices applied in SMEs

While both the studies found evidence on the implementation of Kaizen, Total Production Maintenance, Visual Management, Kanban, Value Stream Mapping and SMED; only Alkhoraifa, Rashidb and McLaughlina (2019) collected papers reporting the use of Standardization and 5S. To date, no research seems to be in place to discover the reasons why some practices are applied by LEs and not by SMEs.

4.4.2 Industry 4.0 in SMEs

In order to stay competitive, SMEs need to continuously achieve productivity improvements in their processes and operations (Nwaiwu, Duduci, Chromjakova, & Otekhile, 2020). In particular, when a company wants to grow successfully, it needs to promptly adapt to the ever-changing environment and understand the impact of different factors on its performance (Ginevičius & Ostapenko, 2015). As a consequence, SMEs have to boost their competitiveness by taking in the influences of technology and automation that, nowadays, characterize the competitive business environment (Türkeș, et al., 2019). In this regard, Industry 4.0 technologies result to be the more innovative and impacting trends. However, only a few SMEs were able to successfully implement process models in line with Industry 4.0 (Nwaiwu, Duduci, Chromjakova, & Otekhile, 2020). The central scope of the following paragraphs is to analyze SMEs' points of strength towards Industry 4.0 technologies' adoption (i.e. **enabling factors**), as well as the main reasons why they might struggle in applying them (i.e. **inhibiting factors**). In addition, the main **CSF** and **impacts** identified in literature are reported. Finally, those **technologies** that are widely implemented in SMEs are analyzed.

4.4.2.1 *Industry 4.0 in SMEs - Enabling and Inhibiting Factors*

Since the business strategy of SMEs is based on flexibility and reactivity, Industry 4.0 technologies result particularly appealing for these companies (Moeuf, Pellerin, Lamouri, Tamayo, & Barbaray, 2018). In spite of the characteristics that make them suitable for technological innovations, some of their features make SMEs struggle quite a lot. For the sake of coherence, these enabling and inhibiting factors have been classified using the same categories proposed in the 2.4.1.1 paragraph, as shown in table 20. Nevertheless, the framework has been adjusted once again by adding the category **other**, that allowed to collect more factors from the literature. Besides, the category **operations** has been deleted because no such factors have been found.

	Inhibiting	Enabling
Supplier Relationship	− SMEs might be dependent on their suppliers	
Intra-SME Organization	− Lack of expertise − Employees' wrong perception of technologies − Organizational behavior − Short-term strategy	− Fast decision making − Few layers of management − Simple and direct communication − High flexibility at all levels − Easy to introduce change and new methods
Resources	− Lack of financial resources − Lack of technical resources − Lack of human resources	
Customer Relationship		− Closeness to customers

Other	− Lack of networking opportunities − Speed of technological improvement	− Speed of technological improvement

Table 20 - Inhibiting and Enabling Factors for Industry 4.0 Technologies adoption in SMEs

Starting from **intra-SME organizational factors**, lack of expertise represents one of the main inhibiting factors as Industry 4.0 uses new technologies and requires many skills. In fact, SMEs result to be less competent in those support functions necessary to implement such technologies (Moeuf, et al., 2020). This might be due to the fact that usually SMEs' employees have daily responsibilities in many different areas and, consequently, they struggle to develop a strong expertise in a particular field (Mittala, Khan, Romero, & Wuest, 2018). At the same time, it is likely that they miss the exposure to mentors, workshops, conferences and so on (McAdam & Reid, 2001). On top of that, it has been demonstrated that Industry 4.0 is wrongly perceived by employees, who see these new technologies as means used to increase surveillance on their work (Moeuf, et al., 2020). Another challenge for Industry 4.0 technologies adoption lies in SMEs' organizational culture, which is often not flexible enough to take into consideration implementation initiatives for innovative technologies. Consequently, SMEs tend to invest less in market research and analyses on Industry 4.0 (Mittala, Khan, Romero, & Wuest, 2018). The last inhibiting factor of the category is the short-term strategy. In fact, a successful digital transformation requires Industry 4.0 projects to be included as part of the corporate strategy (Moeuf, et al., 2020). However, SMEs lack consistent strategies and suitable objectives for technologies implementation (Schmitt, Schmitt, & Engelmann, 2019). On the positive side, it has been argued that Industry 4.0 technologies adoption in SMEs is helped by the fast decision-making, the few layers of management, the simple and direct communication, the high flexibility at all levels, and the easy introduction of changes and new methods (Grube Hansen, Malik, & Bilberg, 2017).

In terms of **resources**, no enabling factors have been identified. On the negative side instead, lack of financial, technical and human resources are widely recognized in literature. In fact, generally speaking, the main obstacles for Industry 4.0 applications are the high investments requirements, the availability of qualified staff and the necessity of technical resources (Schmitt, Schmitt, & Engelmann, 2019). Oftentimes, SMEs face capital constraints due to their small scale that, together with the scarce technical resources, hold them back in terms of research and development (Mittala, Khan, Romero, & Wuest, 2018). In addition, SMEs miss experts who deal extensively with technical innovations of Industry 4.0 because the most of their resources are focused on operational business (Schmitt, Schmitt, & Engelmann, 2019).

As for the company's **relationship with customers and suppliers**, the literature highlights only one factor for each of these two categories. While the closeness to customers is considered an enabling factor for Industry 4.0 applications in SMEs (Grube Hansen, Malik, & Bilberg, 2017), the likely dependence on suppliers represents an inhibiting one (Mittala, Khan, Romero, & Wuest, 2018).

Finally, there are some factors that do not fall into the previous categories, so they have been classified as **other**. Firstly, SMEs tend to miss updates about on-going and innovative research because of their possible lack of networking opportunities, which represents a clear barrier. For the same reason, they struggle to establish alliances with universities and research institutions, leading to a lack of shared knowledge (Mittala, Khan, Romero, & Wuest, 2018). Secondly, it has been observed the misleading nature of technological improvements' speed. On the one hand, it leads to the obsolescence risk of investments on Industry 4.0 technologies, which might be massive for SMEs. On the other hand, this risk is counterbalanced by SMEs' agility and responsiveness that might help them to promptly intervene (Moeuf, et al., 2020)**.**

4.4.2.2 *Industry 4.0 in SMEs - Critical Success Factors*

The present paragraph analyses those factors having a significant influence on the outcomes of Industry 4.0 technologies applications in SMEs. According to the literature, the following CSFs are considered important weapons for Industry 4.0 projects implementations in SMEs: **strong presence of managers, employees' training, continuous improvement strategy, carrying out a study before starting the project, collaborations with academic members, Industry 4.0 technologies' simplification**.

It has been demonstrated that the human resources possessed by a company have a positive influence on its ability to successfully apply Industry 4.0 models (Nwaiwu, Duduci, Chromjakova, & Otekhile, 2020). In particular, the **strong presence of managers** in SMEs represents a CSF as it is up to them to communicate to employees the importance and objectives of Industry 4.0 projects. In addition, they are responsible for the alignment along the short hierarchical line of the company. On the employees' side, it is necessary to potentiate their skills by performing **training programs** that allow to mitigate the lack of expertise (Moeuf, et al., 2020).

It has been argued that developing the right corporate and organizational strategy positively affects the outcomes for achieving an efficient Industry 4.0 technologies implementation (Nwaiwu, Duduci, Chromjakova, & Otekhile, 2020). As an Industry 4.0 project leads to relevant organizational changes, **implementing a continuous improvement strategy** represents a CSF. In fact, this strategy fosters employees' flexibility in using new tools and approaching new environments (Moeuf, et al., 2020).

Finally, the literature identifies some CSFs necessary to successfully approach the Industry 4.0 project itself. First of all, before starting the implementation, it is necessary to **carry out a study** to define the performance target and the needed technologies. On top of that, SMEs need to be supported through the project's steps by **collaborations with academic members,** which is beneficial also in terms of knowledge transfer to employees. Finally, the introduction of Industry 4.0 tools needs to be promoted by **simplifying these tools**. In this way, also the lack of expertise is mitigated (Moeuf, et al., 2020).

4.4.2.3 *Industry 4.0 in SMEs - Impacts*

When companies adopt new technologies, they expect something to change. According to Bayo-Moriones, Billón and Lera-López (2013), SMEs that invest in new technologies are supposed to witness improvements in quality, flexibility, productivity, lead times and costs. In their literature review, Moeuf, Pellerin, Lamouri, Tamayo and Barbaray (2018) explored which of these industrial performance objectives seem to be reached by the adoption of Industry 4.0 technologies in SMEs. They found out that **flexibility**, **productivity** and **lead times** are the fields mostly associated with impovements.

This is due to the fact that Industry 4.0 promotes the synchronizations of flows and production processes along the supply chain. For instance, the use of Cloud Computing platforms allows a more efficient collaboration between supply chain partners, leading to a more responsive reaction to new demand from the market and, consequently, a **higher level of flexibility** (Ren, et al., 2015). At the same time, it allows to shorten design time that, together with the digitization of orders and the conservation of customers' data, allows to reduce the **lead times** (Moeuf, Pellerin, Lamouri, Tamayo, & Barbaray, 2018). Additionally, Ren et al. (2015) demonstrated that the **productivity** of the entire network of partners can be improved by applying algorithms that optimize the production flows on the basis of data collected by IoT devices.

Since reaching such performance objectives requires the use of specific expertise and new investments, it is likely to develop new managerial capacities. In this regard, the levels of managerial capacity achievable through Industry 4.0 result to be **monitoring**, **control** and **optimization** (Mittala, Khan, Romero, & Wuest, 2018).

As for **monitoring,** it has been argued that the use of connected objects allows to better observe production processes and systems (Wang, Törngren, & Onori, 2015). For instance, positioning RFID sensors along the production line leads to map the part flow in real-time and to detect performance inconsistencies, as well as to continually collect data (Denkena, Dengler, Doreth, Krull, & Horton, 2014). RFID demonstrates positive outcomes also in terms of **control:** the e-Kanban system proposed by MacKerron, Kumar, Kumar and Esain (2014) is able to supervise supply processes and send a notification when changes in quantities consumed occur. Generally speaking, Industry 4.0 promotes control – in terms of interaction between employees and systems - through the use of historical data and predefined thresholds (Moeuf, Pellerin, Lamouri, Tamayo, & Barbaray, 2018). Finally, SMEs take advantage of simulation systems to have a clear view of current industrial processes, leading to **optimization** of resources and production processes (Moeuf, Pellerin, Lamouri, Tamayo, & Barbaray, 2018).

The last contribute found in literature in terms of Industry 4.0 opportunities in SMEs is the study carried out by Moeuf et al. (2020). They investigated these impacts by relying on a Delphi study, where a group of experts was required to provide their opinions. All the experts agreed on the possible **competitiveness improvements** of SMEs adopting Industry 4.0 technologies. Furthermore, they identified two additional visions of Industry 4.0: on the one hand, it leads to operational improvements related to cost reduction with the aim of increasing added value; on the other hand, it moves towards business models modifications that implies better added value but also higher costs.

The following table summarizes the Industry 4.0 impacts on SMEs just described.

Industrial Performance Impacts	**Managerial Capacity Impacts**
− More flexibility	− Improvements of monitoring activities
− More productivity	− Better control
− Better lead times	− Optimization of resources and activities
− Improved competitiveness	

Table 21 - Impacts of Industry 4.0 technologies adoption in SMEs

4.4.2.4 *Industry 4.0 Technologies adopted in SMEs*

In the context of SMEs, nowadays, not all the groups of Industry 4.0 technologies seem to be adopted. In particular, there are some technologies - such as Big Data Analysis, Virtual Reality, Collaborative Robots – which are almost not mentioned in literature. On the other side, **Cloud Computing, Internet of Things** and **Simulation** appear to be quite widespread in SMEs (Moeuf, Pellerin, Lamouri, Tamayo, & Barbaray, 2018).

Cloud Computing results to be the most implemented Industry 4.0 practice because of its versatility and compatibility with SMEs' characteristics. In fact, it allows to develop collaboration among partners belonging to the same supply chain, tackling SMEs lack of knowledge that makes hard for them to satisfy complex customers' needs (Fornasiero & Zangiacomi, 2013). Additionally, Cloud Computing platforms provide SMEs with the opportunity of entering new markets and increasing customers' loyalty by offering products and services online (Bonfanti, Del Giudice, & Papa, 2015). These platforms promote also a change of perspective from "what there is" to "what it is achievable" - also known as product servitisation - which is quite in line with SMEs' flexibility (Ren, et al., 2015). Moeuf, Pellerin, Lamouri, Tamayo and Barbaray (2018) highlighted three additional uses of Cloud Computing in SMEs: distributed production, resource optimization and sharing documents.

Internet of Things technologies appear to be extensively employed in SMEs as well. In particular, it has been demonstrated that RFID technology is able to empower the collaborations among SMEs in distributed production networks by providing real-time production feedbacks (Ren, et al., 2015). In addition, RFID is considered useful also to promote the implementation of Lean Manufacturing. In fact, it allows to better manage information flows – providing SMEs with more reliable data – and to identify areas of improvement more quickly than the traditional VSM practice (Denkena, Dengler, Doreth, Krull, & Horton, 2014). Generally speaking, IoT in SMEs is used to acquire data and to evaluate the performance of the production system (Mittala, Khan, Romero, & Wuest, 2018). Besides, Grube Hansen, Malik and Bilberg (2017) noted that SMEs should take advantage of RFID tags in material movement, resource planning and logistics.

Although in a lower extent, also **Simulation** is quite used in SMEs. In fact, it is particularly useful to generate operations schedules on-line (Moeuf, Pellerin, Lamouri, Tamayo, & Barbaray, 2018). For instance, Barenji A, Barenji R, Roudi and Hashemipour (2016) developed a planning simulation software which allows SMEs to take into consideration customers' dynamic demand and production variation at the same time. Moreover, Simulation is used also to play what-if scenarios in order to analyze and modify the current production systems (Moeuf, Pellerin, Lamouri, Tamayo, & Barbaray, 2018). This idea is supported by Grube Hansen, Malik, & Bilberg (2017), who pointed out how experimenting a physical model is much more expensive than creating a virtual one which imitates the characteristics of the real system. In light of this, Simulation supports the decision-making process when it comes to design and improvement of both new and current production systems.

According to the literature, SMEs do not seem to widely use Big Data Analysis. Nevertheless, it has been argued that, as the use of IoT devices and Cloud Computing is becoming more and more widespread, the amount of data collected will increase accordingly. As a consequence, SMEs will need to employ Big Data Analytics in order to exploit it (Moeuf, Pellerin, Lamouri, Tamayo, & Barbaray, 2018). At the same time, Collaborative Robots were recognized as a potential effective solution for repetitive and less ergonomic tasks in SMEs (Grube Hansen, Malik, & Bilberg, 2017).

All in all, it is possible to conclude that SMEs, so far, have been neglecting the most expensive and revolutionary Industry 4.0 technologies; while they have been employing the cheapest and most "traditional" ones (Moeuf, Pellerin, Lamouri, Tamayo, & Barbaray, 2018).

4.4.3 Lean 4.0 in SMEs and Hypotheses formulation

At first glance, Lean Production and Industry 4.0 seem to be two different approaches, as the former is oriented towards an organizational approach and the latter is related to technology. Nevertheless, as extensively explained in 4.3 section, they represent two different paths with the same destination: increasing efficiency and improving productivity. In fact, the digitization of Lean processes is meant to simplify the complexity of production systems, with the final aim of value creation for customers (Hoellthalera, Braunreuthera, & Reinharta, 2018). To date, there is no reason not to perceive Industry 4.0 technologies as supporters of Lean Manufacturing.

In this context, SMEs explicitly declared to be aware of the great potential associated with the combination of Industry 4.0 and Lean Production (Raucha, Dallasega, & Matt, 2017). Nevertheless, not all of them have a clear knowledge and a consolidated experience with traditional Lean practices (Raucha, Dallasega, & Matt, 2017). At the same time, they still face digitization with reluctance and skepticism (Hoellthalera, Braunreuthera, & Reinharta, 2018) because of the insufficient skills of employees, as well as all the inhibiting factors mentioned in section 4.4.2.1 (Raucha, Dallasega, & Matt, 2017). These findings are confirmed by the previous sections of this literature review, which revealed that SMEs seem not to adopt all the Lean practices and Industry 4.0 technologies.

It is worth mentioning that the research on Lean 4.0 in SMEs is still immature. For this reason, literature seems to present only a few papers covering this topic. Some authors – for instance Hoellthalera, Braunreuthera and Reinharta (2018) – focused on creating a methodological support for SMEs to implement a symbiosis of Industry 4.0 and Lean. Others tried to shape assessment models to map the status of Lean and Industry 4.0 which are suitable for the specific characteristics of SMEs. This is the case of Kolla, Minufekr and Plapper (2019). Nevertheless, to date, nobody seems to have investigated which are the practical synergies between Lean practices and Industry 4.0 technologies actually implemented in SMEs. In other words, nobody has tried to fill the matrix developed in section 4.3.3.8 in the context of SMEs and to understand if the main benefits highlighted in section 4.3.4 are also valuable for this typology of company. On the other side, all the efforts seem to be directed towards LEs, as shown in the following table.

Papers	Industry 4.0	Lean Production	Lean 4.0
Large Enterprises	37	43	24
Small and Medium Enterprises	9	12	0

Table 22 - Gap in literature

The identification of these gaps in literature led the authors to formulate the hypotheses guiding the operative part of this dissertation (figure 11):

HP 1: ***The integration between Industry 4.0 technologies and Lean Production practices positively affects SMEs in terms of improvements of the decision-making process.***

HP 2: ***The integration between Industry 4.0 technologies and Lean Production practices positively affects SMEs in terms of improvements of data collection process.***

HP 3: ***The integration between Industry 4.0 technologies and Lean Production practices positively affects SMEs in terms of innovation of routine processes.***

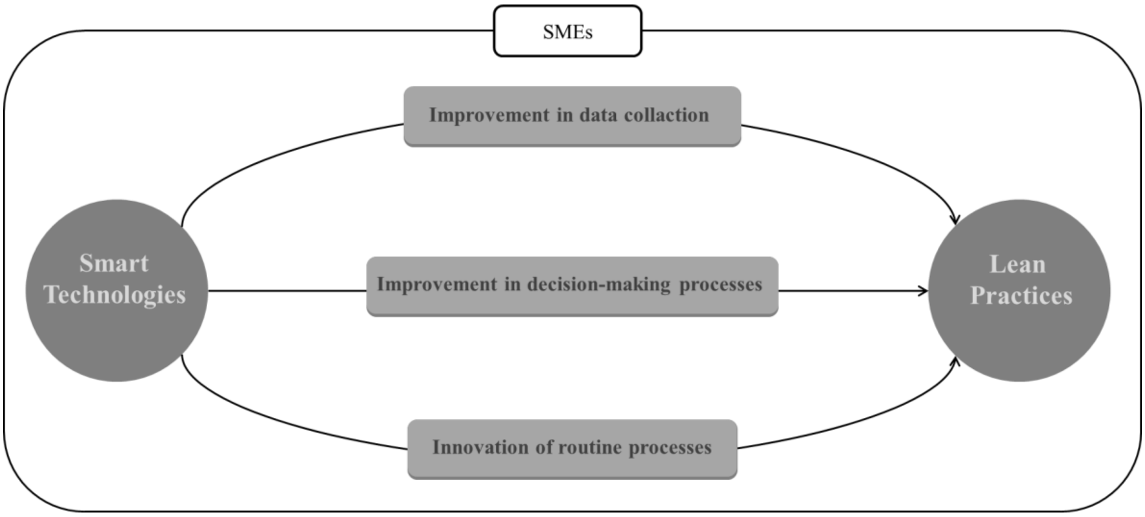

Figure 11 - Benefits of Smart technologies on Lean Practices in SMEs

These hypotheses will be tested throughout the dissertation following the methodology described in the next chapter. It will shed light on the matrix intersections (see section 4.3.3.8) actually present in SMEs that, in turn, will be useful to validate the above-mentioned hypotheses.

5. Methodology

As previously highlighted, the introduction of Lean 4.0 is taking place mainly in large companies. In order to introduce this concept into SMEs as well, it is necessary to define organizational tools able to show which synergies between Lean Production practices and Industry 4.0 technologies are suitable for different companies' size. This is particularly useful because SMEs are characterized by specific projects and investments, which represent a new source of data creation and collection that often is not matched with a strategic idea of how to use this data. In addition, the presence of a high supply chain turbulence context poses companies the need of making rapid decisions in shorter time. Moreover, at present, there is no scientifically founded knowledge on Lean 4.0 practical implementation in SMEs.

As a consequence, the main aim of this dissertation is to understand how the framework proposed in section 4.3.3.8 – which shows the documented synergies between Lean Production practices and Industry 4.0 technologies in LEs – can be applied to SMEs and if the hypotheses formulated in section 4.4.3 is valuable. In this way, managers and academics will be provided with information that helps them to understand the AS-IS situation of the Lean 4.0 application in the small and medium industrial context. In order to do that, all the steps followed for this research development are proposed in this chapter.

This dissertation has been carried out following the stages proposed by Polit and Beck (2004). In fact, the authors' model is used by many researchers to describe the methodology of their pieces of work. More specifically, the five phases are:

1. The **Conceptual phase.** It represents the literature analysis, which is mandatory to identify the research purpose and perform an accurate work.
2. The **Design and Planning phase.** It is necessary to create a proper framework to conduct the overall research, highlighting the tools applied and the stakeholders involved.
3. The **Empirical phase.** It is related to all the activities associated with the collection of data and its preparation for the analysis.
4. The **Analytic phase.** It represents the actual analysis of data, which leads to draw results and meaningful conclusions.

5. The **Dissemination phase.** It lies in the communication of results to an appropriate audience in order to spread the findings and contribute to the literature on the topic.

The way these five phases have been structured for this dissertation is shown in table 23.

Phase of Research	Techniques and Tools	Objective
Conceptual phase	Literature analysis	Scope and problem relevance identification
	Critical thought	Understanding the current situation
	Discussion with professors	Finding gaps in literature and formulating the hypotheses
Design and Planning phase	Nonexperimental research – Qualitative Analysis	Selection of the overall plan for conducting a study
	Sampling Plan composed by approximately 1200 SMEs	Selection of the sample of population for the analysis
	Validation through the use of survey	Definition of the method to collect data and finally validate the research
Empirical phase	Data collection	Collection of data from the sample of population
	Data preparation for the analysis	Preparation of data to get the dataset eventually used for the analysis of results
Analytic phase	Data Analysis	Analysis of data in order to identify relationships and patterns within it
	Results Discussion	Deep analysis and interpretation of the information gathered throughout the survey
Dissemination phase	Dissemination writing	Writing the report, with introduction, model, comparisons, data analysis and conclusions Drafting opened points for discussion: Follow-up

Table 23 – Methodology phases according to Polit and Beck's model *(2004)*

5.1 The Conceptual Phase

The conceptual phase is the starting phase of research and revolves around the intellectual process of turning a research idea into a realistic and appropriate research design. In this dissertation, a deep literature analysis has been performed, together with a curious and critical thought and many discussions about the research ideas with professors. Thanks to these activities, it was possible to define the state-of-the-art about synergies between Lean practices and Industry 4.0 technologies, as well as to identify the main gaps in literature.

More specifically, this analysis started from a general perspective: understanding the state-of-the-art about the relationship between Lean Production and Industry 4.0. This first superficial research highlighted the prevalence of a bi-directional view: Industry 4.0 technologies result to be supporters of Lean philosophy. In light of this, it was natural to start investigating the topic in a more practical way, aiming at understanding how Lean practices are positively affected by the adoption of Industry 4.0 technologies. This literature review phase was not particularly tough, since recently many papers and academic articles have tackled this topic. As a result, it was possible to develop the framework shown in table 15 and formulate the dissertation hypotheses. However, since those papers and studies are addressed to LEs, it was soon realized that the framework is suitable for this typology of companies only. Consequently, the same analysis was performed in the context of SMEs, leading to some interesting findings:

- The two separate topics of Lean Production and Industry 4.0 are widely studied in SMEs;
- The main dimensions of analysis for Lean Production and Industry 4.0 in SMEs are CSFs, inhibiting factors, enabling factors and impacts;
- There seems to be almost no literature describing which Lean practices and Industry 4.0 technologies are actually implemented in SMEs and, above all, how they support one another. In addition, nobody seems to investigate whether Lean 4.0 benefits SMEs in terms of data collection improvement, decision-making improvement and routing processes innovation.

In light of the identified gap, the conceptual phase ended by defining the research purpose: filling out the framework shown in table 15 in the context of SMEs, in order to understand which Lean practices and Industry 4.0 technologies are adopted in SMEs; and testing the hypotheses reported in section 4.4.3, in order to investigate how these companies benefit from this implementation.

As already mentioned in the second chapter, scientific researches and academic conferences have been selected from Scopus, Research Gate, ScienceDirect and Google Scholar. In addition, information and data found on relevant websites have been used, together with reports written by Politecnico di Milano. These sources have been chosen according to their relevance, year of publication and number of citations.

5.2 The Design and Planning Phase

The second phase of Polit and Beck's (2004) model has its main focus on the selection of the research design and procedures. This phase is divided into three main different steps:

1. The first step taken into consideration is **research design**. In particular, it represents the overall plan for conducting a study that aims at optimizing the ability to obtain accurate results and achieve the study purpose (Polit & Beck,

2004). In this case, the typology of research design used is the *non-experimental* one. It is particularly suitable because typically it is adopted to describe a phenomenon, compare characteristics of two or more groups, or examine relationships among variables. In addition, non-experimental designs are often used to develop methodological research or define questionnaires, like the one of this dissertation (Melnyk & Fineout-Overhold, 2003). In fact, this study is performed by means of a survey and the research is divided in two main phases:

I. Firstly, the initial draft of the survey (appendix 1) is validated through a Beta test, in which two trustworthy companies are in charge of providing feedbacks about its structure and readability.
II. Secondly, the Alpha test - corresponding to the actual research - is carried out. In this phase, the definitive survey (appendix 2) is sent to the sample of population in order to collect significant data and feed the research discussion. A more detailed description of this phase is reported in section 5.3 (i.e. Empirical phase), while the following analyses of results is presented in section 5.4 (i.e. Analytic phase).

Irrespective of the Beta test results, the survey (appendix 2) has been structured in three sections. The first one is composed by both multiple choices and open questions, aiming at collecting relevant information about the respondent companies in terms of their specific characteristics. These questions have been shaped by taking a cue from the SMEs classification of Ranke, Aichele, Görzig, Luckert, Siegert and Bauernhansl (2020), as well as from a report developed by Osservatori Digital Innovation (2018). The second section aims at investigating which Lean Production practices and Industry 4.0 technologies are adopted by the respondent companies. Finally, the third one is shaped to understand how Lean Production and Industry 4.0 support each other in terms of data collection, decision-making process and daily activities. The software chosen to develop this survey has been Opinio because of its wide range of features and options.

2. The second step is related to the identification of the **sample of population,** which represents the panel of companies the definitive survey has been sent to. In general, the process of studying population delineation and specifications leads to the identification of characteristics needed for participation. In fact, this is referred

to as inclusion and exclusion criteria, which in turn stipulates for whom results of the study can be generalized (Polit & Beck, 2004).

In this dissertation, the population sample should be composed by SMEs that apply Lean Production practices and Industry 4.0 technologies. In this way, in fact, the validation of the framework and the hypotheses presented in sections 4.3.3.8 and 4.4.3 would result to be quite straight-forward. Unfortunately, no existing database seems to offer the possibility of filtering companies according to such criteria. As a consequence, the population sample for this research has been chosen as follows:

- Any manufacturing company, proven to be either micro, small or medium.
- Any company providing SMEs with services and consultancy.

Since it was not possible to prove that these companies adopt the studied paradigms, it has been decided to collect a great amount of them. In this way, in fact, the probability of spotting "relevant companies" increases. Moreover, the collected companies belong to different sectors: this diversification is fundamental in order to have more accurate and well-distributed results. On top of that, the first question of the survey is able to discriminate those that are useful for this research (i.e. those that apply Lean Production and Industry 4.0 at the same time) and those that don't.

As a result, approximately 1200 companies have been gathered in an Excel file. It is worth mentioning that the collection itself has been performed using different sources:

- **AIDA**, a database containing thousands of Italian companies that can be filtered on different features. Companies found through this database have been collected using the filter "PMI Innovative": it represents a certificate ensuring that the company is a SME which contributes to innovation in Italy.
- **Confindustria,** an organization representing Italian companies. Confindustria's website offers the possibility to find lists of such companies grouped according to their sector. These companies have been analysed one-by-one by the authors, who checked them on LinkedIn to verify their size.

- **Authors' personal connections.** Some companies were already known by the authors, who used their personal connections to get in touch with them.

3. The third and final step of the Design and Planning phase is the **validation,** in terms of how to perform it and who needs to be involved. In the context of a qualitative research, there are different quality criteria that are usually applied to reach validation:
   - **Credibility**: confidence in the truth of interpretations and data provided.
   - **Dependability**: stability of data over time and conditions.
   - **Confirmability**: congruence of interpretation between two or more stakeholders.
   - **Transferability:** extent to which findings can be transferred to other settings or groups.

   In this dissertation, the validation process has been conducted by sending the survey via email to two companies – namely *Company 1* and *Company 2* - which were in charge of providing feedbacks about its structure and content. Generally speaking, the first company represents a manufacturing company that applies Lean Production practices and Industry 4.0 technologies, while the second one is a consulting company highly specialized on these topics. However, a more detailed description of these companies is provided in sections 5.2.1 and 5.2.2.

   As for the validation criteria mentioned before, it is worth noticing that all of them have been met throughout the validation process. In fact, as regards **credibility**, the two selected companies are already known by the researches because of previous collaborations. As a consequence, their judgement is considered trustworthy. In terms of **dependability**, they provided their feedbacks within two weeks. This time span is not enough to observe significant changes in both Lean Production practices and Industry 4.0 technologies. On top of that, the Alpha test process has taken one month to be completed so the results can be considered as stable. **Confirmability** is supported by the number of companies considered that, being more than one, can give congruence of interpretation to the research. Finally, as far as **transferability** is concerned, the companies analysed represent good examples of both a typical SME and a consulting company working directly with SMEs. Consequently, the findings of this validation can be transferred to all the companies of the Alpha test.

In the third step of the Design and Planning phase, the two companies involved in the Beta test have been briefly mentioned. Nevertheless, because of their precious contribution, they deserve a more detailed description. For this reason, sections 5.2.1 and 5.2.2 report a general overview of them, as well as their feedbacks about the survey. In conclusion, section 5.2.3 summarizes the results of the validation process, that led to the creation of the definitive survey version.

5.2.1 Company 1

Company 1 S.r.l. is an engineering company working in the industrial refrigeration sector. According to the survey results, they declare to be a medium (less than 250 employees) family-run enterprise, characterized by a single production site configuration and an internal IT department. Moreover, they claim a spending of 5% of revenues for R&D.

Although Europe represents the main market where they export products, they have been expanding their presence in the last years. In order to support their business overseas, they opened two subsidiaries in China and in USA. The first one allows to serve pacific and oceanic countries such as China, Japan, South Korea, Taiwan, Indonesia, Malesia, Australia and India. The second one, instead, is useful to export products to Canada, USA, Mexico, Brazil, Chile and Argentina. In addition, they export products in Africa, Russia and Middle East as well.

Company 1 has been chosen to test the survey because they worked with Osservatorio Industry 4.0 of Politecnico di Milano (i.e. the sponsor of this dissertation) in the past. This is the reason why the authors already knew that this company is a SME and that they adopt both Lean Production practices and Industry 4.0 technologies. For these reasons, their profile represents the perfect one to verify the survey ability to investigate Lean 4.0 in SMEs.

The feedback provided by *Company 1* has been definitely positive. In fact, they defined the survey as “simple, intuitive and quick”. Nevertheless, the way they filled in the questionnaire allowed to shed light on a problem: even though they employ less than 250 workers, they declared to be a big company because their turnover is higher than 50M. In light of this, it has been decided to change the question related to the company size (see question 3 in appendix 1) by providing respondents with two separate dimensions to define their own size (see questions 4 and 5 in appendix 2).

5.2.2 Company 2

Company 2 is a small enterprise operating in the consulting sector. In filling in the questionnaire, they claimed to be run by a management group, to spend 10% of their revenues in R&D and to have an internal IT department.

Thanks to their long-term and innovative way of working, throughout the years *Company 2* has been able to gain the trust of companies all over Italy and, nowadays, they serve foreign markets as well. In fact, they have been quite precocious in understanding the importance of Lean philosophy and its possible application to all the company's functions. In particular, they support entrepreneurs and managers in organizing their companies in an efficient and effective way by leveraging on three main pillars: development, efficiency and innovation. All these aspects revolve around an innovative way of applying Lean practices, which are renovated to meet the new needs of modern companies. In this renovation process, Industry 4.0 technologies play a crucial role and, consequently, *Company 2* can be considered highly specialized on this topic as well.

In light of *Company 2* description, it is very clear the reason why they have been chosen to run the Beta test. In fact, their high level of expertise made them the perfect candidates to evaluate whether the survey was appropriate or not. The authors had the opportunity of getting in touch with them thanks to the long-term relationship between the company and Osservatorio Industry 4.0 of Politecnico di Milano (i.e. the sponsor of this dissertation).

The feedbacks provided by *Company 2* can be summarized in two main suggestions:

- Firstly, they advised to add a matrix with the aim of studying the relationship between the five Lean principles (see section 4.1) and Industry 4.0 technologies in SMEs. Nevertheless, the goal of this dissertation is more practical: investigating the synergies between Lean practices and Industry 4.0 in SMEs. In light of this, the focus is not on the philosophy behind the practices but on the practices themselves. In addition, there are some principles that, because of their practical nature (e.g. value flow mapping), have been taken into account as practices. As a consequence, the authors decided not to add the aforementioned matrix.

- Secondly, they recommended to add a further dimension of differentiation in the survey first section (i.e. characterization of respondent companies): whether the company's processes are labor intensive or capital intensive. In fact, they explained that Lean Production practices and Industry 4.0 technologies lead to quite different impacts according to the typology of process they are applied on. For this reason, they suggested the aforementioned discrimination that, in the definitive version of the survey (appendix 2), is reported as question 8.

5.2.3 Conclusions: from survey draft to definitive version

To sum up, the Design and Planning phase has been useful to plan the activities and prepare the resources necessary to run them. This phase is divided into three steps. Firstly, in the **research design** step, it has been decided to validate the framework and the hypotheses by means of a survey. Hence, an initial draft of the survey has been shaped taking into consideration different typologies of synergies between Lean Production practices and Industry 4.0 technologies. In the **sample of population** step, a numerous group of companies has been gathered from different sources, taking into account the two main targets of the survey: manufacturing SMEs and consulting/service companies working directly with SMEs. In conclusion, the **validation** process has been extremely useful to test the worth and intelligibility of the survey. In this process, two trustworthy companies – a SME that applies Lean Production practices and Industry 4.0 technologies and a consulting company highly expert on the topics – have been called to express their opinion about the structure and content of the survey. Thanks to their suggestions, the initial draft (appendix 1) has been gradually modified to its definitive version (appendix 2). On the basis of the main adjustments applied to the survey, its first section has been modified as follows:

- The question about the company's size – which initially took into account both revenues and number of employees – has been split into two separate questions.
- A question investigating the nature of company's processes (i.e. labor intensive VS capital intensive) has been added.

This final version of the survey is the one that has been sent to the sample of population – defined as explained in the second step of the Design and Planning phase – in order to test the framework shown in section 4.3.3.8 and validate the hypotheses of section 4.4.3.

5.3 The Empirical phase

According to the model developed by Polit and Beck (2004), the next stage to carry out a successful research is the Empirical phase. More specifically, this phase is more operative and practical compared to the previous two and, indeed, it requires the direct involvement of the authors, as well as of the sample of population. The Empirical phase involves two steps: **data collection** (i.e. all the activities related to the gathering of the needed information to carry out the research) and **data preparation** for the analysis (i.e. all the activities necessary to obtain the final database on which the analysis is performed).

In this dissertation, the two steps associated with the Empirical phase have been performed as follows:

1. The **data collection** step represents the starting point to complete the above-mentioned Alpha test. As mentioned before, during the Design and Planning phase a sample of approximately 1200 companies has been collected and the definitive version of the survey has been drafted. During this first step of the Empirical phase, the survey has been sent to the group of companies in two ways:
    - Most of the companies has been reached via email,
    - A little part of them has received the survey via LinkedIn

   The total number of answers has been 326 out of 1200 companies involved in the sample of population. As a consequence, the answer rate has been around 25% (figure 12), which is considered totally appropriate for the kind of research carried out in this dissertation.

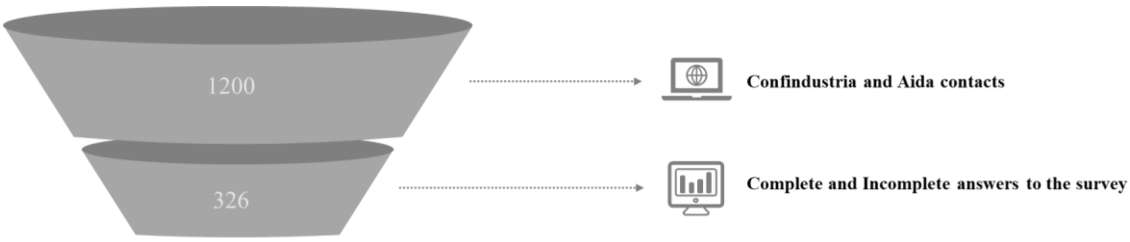

Figure 12 - Partial fuel diagram of data collection process

2. The **data preparation** step has allowed the authors to obtain the dataset used to perform the results analysis described in the Analytic phase (see section 5.4). Starting from the Excel file automatically provided by the software used to create the survey – namely Opinio – some operations have been carried out to clean the initial dataset and obtain a suitable one:

- Firstly, the rows corresponding to incomplete answers have been deleted because they have not been considered as relevant. In particular, 129 rows have been taken off.
- Secondly, the complete rows have been divided according to the answer to the first question (see appendix 2). In fact, only the ones reporting "Yes" as answer would have been relevant for the study. However, in the first part of results analysis, the amount of "no" answers would have been used to draw some considerations about the central topic of this dissertation. In light of this, 114 rows – reporting "no" as first answer – have been saved in a separate Excel sheet in order to be used for the initial part of the analysis, while 83 rows – reporting "yes"– went on with the cleaning process.
- Among the leftovers, all the companies not belonging to the target – shown in the sample of population step of the Design and Planning phase – have been deleted. More specifically, 8 manufacturing companies declared to be big (see appendix 2) and, for this reason, they have been removed from the dataset.

In the end, the resulting dataset was populated by the complete answers of 75 companies, all of them in line with the targets of this research (figure 13). The list of the names and sectors of these companies is reported in appendix 3, where some names have been hidden for privacy reasons.

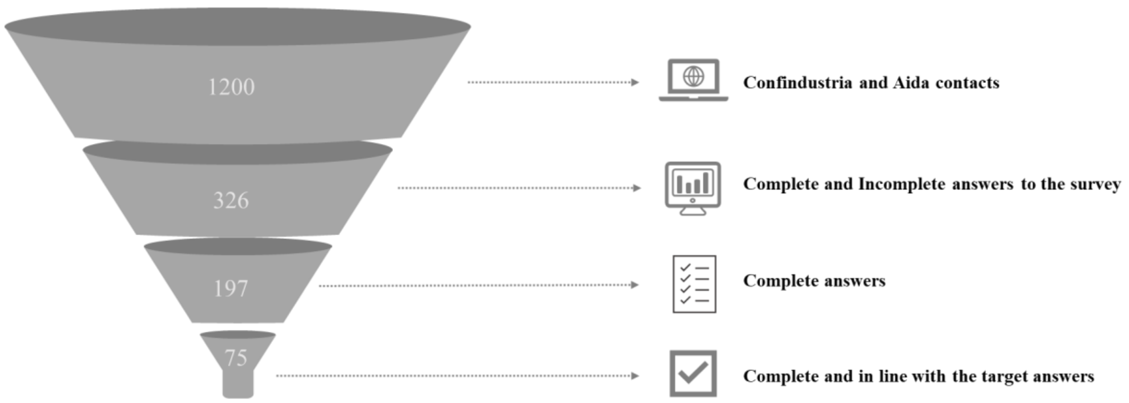

Figure 13 – Complete fuel diagram of data preparation process

In addition to this, it has been necessary to recreate the matrixes corresponding to questions 15, 16, 17, 18 of the survey's definitive version (see appendix 2). In fact, the Excel file provided by Opinio reports, for every row (i.e. for every company), a number of columns which is equal to the amount of intersections of all the matrixes. More specifically, each matrix is characterized by 105 intersections – 7 Smart Technologies on the columns and 15 Lean Practices on the rows. Consequently, each row of the dataset is characterized by 105 x 4 columns referring to the matrixes. Hence, it was necessary to rebuild each matrix and populate it with the results of the survey. In particular, for the first matrix – reporting the intersections between Lean practices and Industry 4.0 technologies – the sum of answers declaring each intersection has been reported. Whereas for the other matrixes – reporting the degree of different benefits associated with those intersections – the mean value of the answers has been reported.

The main result of the Empirical phase has been a dataset reporting all the significant information necessary to properly analyse and discuss the survey's answers (see the Analytic phase), as well as to draw the conclusions shown afterwards in this dissertation.

5.4 The Analytic phase

In all research, the Analytic phase is strictly aligned to the Empirical one. In fact, after data is collected and prepared, it needs to be analyzed in order to identify relationships and patterns within it. In addition, descriptive statistics are used to describe the sample characteristics, enhancing the interpretation of other analyses. Eventually, through a synthesis of these findings, it is possible to either confirm or reject the hypotheses formulated at the end of the Conceptual phase (see section 4.4.3).

In this dissertation, the Analytic phase is associated with a deep analysis and interpretation of the information gathered throughout the Alpha test. More specifically, the answers provided by the 75 companies populating the final dataset – i.e. the result of the data preparation step of the Empirical phase – have been investigated in two steps. The first one represents a careful description of the data and it is associated with questions from 1 to 15:

- Firstly, the 197 complete answers have been analyzed comparing the number of 'yes' and 'no' answers to the first question (appendix 2). This comparison has been made using percentages.
- Secondly, the 75 'yes' answers have been divided taking into account the two typologies of population that have been identified as the questionnaire target: SMEs and companies working directly with SMEs. Separately, these two

typologies of companies have been analyzed by means of tree charts that show – in percentages – how they are distributed on the characteristics investigated in the first section of the survey (see questions 2 – 12, appendix 2).

- Then, an analysis on the application of Lean Practices and Smart technologies in SMEs has been conducted relying on the answers to the 13th and 14th survey's questions. It has been performed by creating two different histograms: one on Lean Production and the other on Industry 4.0. The results of this analysis have been critically examined by comparing them with literature review findings (section 4.4.1.4 and 4.4.2.4).
- Concerning the answers to the 15th question, the framework created in section 4.3.3.8 has been rebuilt and analyzed through a comparison between the different intersections' numbers. In particular, each number represents the amount of companies that have declared to have that combination implemented. In addition, some considerations have been made on what was highlighted in literature during the framework construction.

The second step represents a critical study and interpretation of answers associated with questions 16, 17 and 18. In particular, five different analyses have been conducted and – by taking different perspectives – it has been possible to gather all the data necessary to perform a proper discussion and validate the dissertation hypotheses. The five analyses and their main subjects are described as follows:

- The first analysis revolves around the three benefits. In particular, the Weighted Means associated with each of them – which appear to be very similar among each other – have been broken down in order to understand if those similar results came from equally similar distributions of answers. This has been possible by taking as reference the general Arithmetic Mean among the three benefits.
- The second analysis takes the single Smart Technologies and Lean practices perspectives. For each of them, the Weighted Mean for each benefit has been calculated and the Arithmetic Mean among them has been compared to the general one, leading to some interesting considerations about how SMEs perceive Lean Production and Industry 4.0.
- The third analysis follows the lead of the second one. In fact, the main aim is to analyze the relationships among the different Smart Technologies, trying to identify some general trends along the three benefits. This allows to understand

the way in which SMEs adopt these technologies and the level of benefit they perceive by couples of them.

- Also, the fourth analysis is related to Lean Production practices and Industry 4.0 technologies. More precisely, it has been carried out considering the most relevant intersections of the framework. For each of the three benefits, these intersections have been compared to each other and the outliers have been highlighted, leading to some interesting considerations.
- The last analysis takes a completely different perspective: the one of the two typologies of respondent companies. In particular, it aims at understanding if the two targets – SMEs and companies working directly with them – perceive the benefits associated with Lean Production and Industry 4.0 integration in SMEs in the same way. In order to do so, the distributions of answers for each benefit have been divided according to the two targets and some considerations have been drawn.

In conclusion, the above-mentioned two steps analysis – and all its points – has been essential to develop the dissertation discussions and conclusions. In fact, it has been fundamental for the hypotheses' validation process.

5.5 The Dissemination phase

It goes without saying that, after the Analytic phase, it is necessary to spread the results through a Dissemination phase. In fact, this activity allows to clearly explain the model, draw meaningful conclusions and define the open points of discussion for further research.

In this dissertation, the Dissemination phase has been conducted by writing down the steps followed throughout the research. In particular, this dissertation contains all the fundamental elements for a traditional research report, which are arranged in separate chapters:

- An **Introduction** that provides an overview of the topics and points out the main aims of the research.
- A **Literature Review** that explains the state-of-the-art on the topics and leads to the creation of the framework and the formulation of the hypotheses.
- A description of the **Methodology** carried out to conduct the study needed to validate the framework and test the hypotheses.

- An illustration of the research **Results** together with a **Discussion** of major findings and critical implications in terms of research and/or policy. This chapter should provide a concise and interesting description of the results with key points highlighted (Polit & Beck, 2004).
- A **Conclusion** that wraps up all the following elements, shows the limits of the research and points out suggestions for future research.

6. Results and Discussion

As largely mentioned throughout this dissertation, the main aim of this research is to study the integration of Lean Production practices and Industry 4.0 technologies in SMEs. In particular, it is important to investigate the practical synergies between them and the degree of benefit they provide in terms of data collection improvement, decision-making improvement and routine processes innovation. In other words, this whole study revolves around the intention of either confirming or rejecting the hypotheses formulated in section 4.4.3.

Chapter 5 deeply explains all the phases of Polit and Beck's model (2004), as it represents the methodology followed to investigate the central topic of this dissertation. In particular, it starts form the literature review and formulation of the research hypotheses, going on with the survey creation, adjustment and validation (i.e. Beta test), as well as its submission to the sample of population (i.e. Alpha test). It concludes with the analysis of collected data, which will lead either to the confirmation of rejection of the above-mentioned hypotheses.

The present chapter breaks down the two phases of Polit and Beck's model (2004) which deal the most with the treatment of data: the Empirical phase, which represents data collection and preparation; and the Analytical one, which includes data analysis and interpretation. Differently from chapter 5 - where these phases have been described in an operative way - the findings associated with them are presented in a more descriptive, critical, and detailed way. This critical approach, in the end, will allow to draw meaningful conclusions about the research hypotheses.

More specifically, section 6.1 represents a descriptive chapter, where the main steps of the Empirical phase are reported. The Analytical one, instead, is covered by section 6.2, which presents a critical analysis of the survey results in terms of benefits associated with the integration of Lean Production and Industry 4.0 in SMEs. The introductive parts of sections 6.1 and 6.2 provide a more detailed description of the analyses performed within each of them.

6.1 Results Description

This first section is meant to describe the results associated with the answers provided by respondent companies. In particular, this description will follow the logic used to build the survey. In fact, after a general description of the complete answers (section 6.1.1), section 6.1.2 investigates the distribution of respondent companies over the dimensions proposed in the first survey section. Then, section 6.1.3 analyses what respondent companies have declared in terms of Lean Production practices and Industry 4.0 technologies adoption, as well as their main intersections. In this regard, a brief comparison with the Literature Review has been performed in section 6.1.4. The critical analysis of the benefits section is reported in section 6.2.

6.1.1 Survey Answers

Aiming at obtaining a dataset populated by significant information only, a preliminary step for results' analysis has been to delete all the uncomplete answers. Then, the first step has been to check how many significant answers have been collected. More specifically, the first question of the questionnaire was meant to discriminate the companies belonging to the target from the ones that do not (see appendix 2). In fact, the roughly 1200 companies that received the survey via e-mail have been asked if they apply Lean practices and Industry 4.0 technologies or if they work directly with these types of SMEs.

Considering that the total amount of significant and complete answers has been 197, 114 respondent companies have declared not to be part of the target. In addition, 8 out of the 83 left companies have proved to be big manufacturing companies and, as a consequence, they have not been considered as relevant. In conclusion, 75 companies have provided an answer that can be considered significant. In other words, only the 38.1% of respondent companies have been able to complete the survey in a way that was relevant for the central aim of this dissertation.

In light of this, it is possible to state that - so far - the results have been in line with the expectations. In fact, before starting the survey distribution, the authors expected to receive a lower number of "Yes" compared to the amount of "No". Taking into consideration the target of the survey, indeed, this result is easily predictable:

- On the one hand, the literature review had shown that SMEs adopt a little range of Lean practices and Industry 4.0 technologies. Since many companies that received the e-mail were SMEs, it seems reasonable that most of the sample declared not to apply Lean Production and Industry 4.0.

- On the other hand, since SMEs tend not to implement such practices and technologies, companies that provide them with services or work directly with them are likely not to be involved in this kind of projects.

The final dataset, populated by the above-mentioned 75 significant answers, has been used to conduct different analyses – presented in the following sections – aimed at populating the matrix built in section 4.3.3.8 and testing the hypotheses formulated in section 4.4.3.

6.1.2 Description of Respondents Companies

In order to study a new topic, especially when it comes to the application of some practices within companies, it is necessary to collect data from reliable sources. The reliability of sources strictly depends on the nature of the topic that is meant to be investigated, as well as on the central aim of the research.

This dissertation revolves around the analysis of the practical integration of Lean Production and Industry 4.0 in SMEs and the main benefits these companies obtain from it. In light of this, it goes without saying that the most reliable sources are represented by companies that either apply Lean Production and Industry 4.0 themselves or present high levels of expertise on these topics. More specifically, it has been decided to send the survey to two typologies of target:

- Manufacturing SMEs that apply Lean practices and Industry 4.0 technologies in the first place,
- Other companies - expert on the topics - working directly with SMEs that adopt Lean Production and Industry 4.0, such as companies providing services or consulting firms.

As depicted in figure 14, the former target accounts for 64% (i.e. 48 out of 75) of respondent companies, while the latter is represented by the residual 36% (i.e. 27 out of 75).

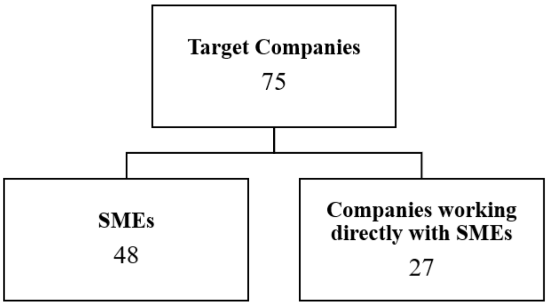

Figure 14 - Distribution of respondent companies

The first section of the survey is meant to collect information about specific characteristics of the respondent companies. In particular, the dimensions identified as significant have been chosen by mixing different sources:

- The SMEs classification provided by Ranke, Aichele, Görzig, Luckert, Siegert and Bauernhansl (2020), developed with the aim of detecting companies' special needs and how these needs can be addressed in a good way. From this paper, the dimensions of *Sector*, *Size, Holder*, *Main Task* and *Percentage of R&D over Revenues* have been chosen.
- A report developed by Osservatori Digital Innovation (2018), that has shed the light on the dimensions of *Market*, *Productive Site Configuration* and *IT Department*.
- Finally, as explained in chapter 4 (see Design and Planning phase, validation step), the dimension of *Process* has been added following the advice of an expert.

Figures 15 and 16 show how the two typologies of respondent companies are distributed according to the above-mentioned dimensions.

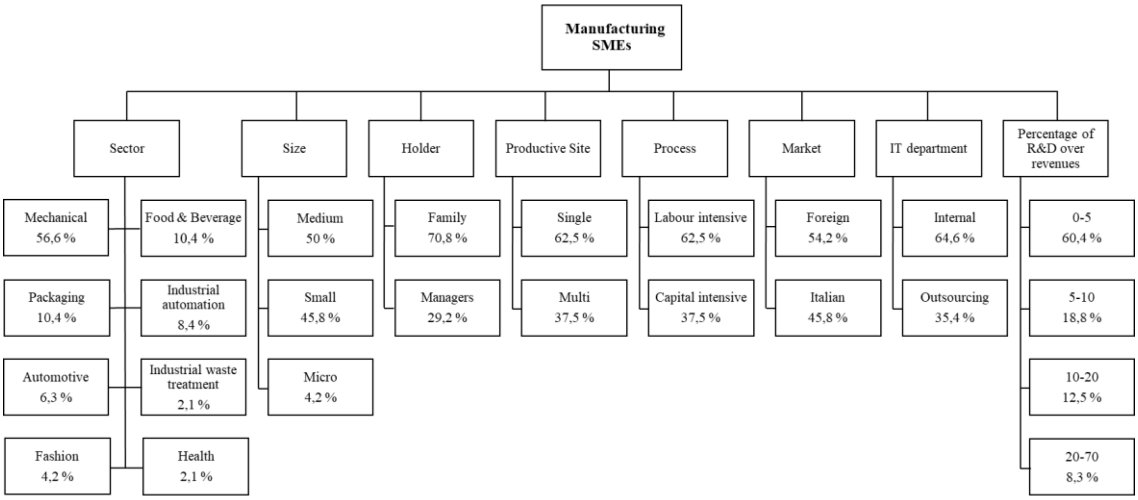

Figure 15 - Distribution of manufacturing SMEs according to the dimensions of analysis

As far as manufacturing SMEs are concerned, the most of them belong to the mechanical industry, followed by food & beverage and packaging. Then, small percentages of other *sectors* are present. As for the *size*, half of the respondent SMEs have declared to be medium, while a very few of them have presented themselves as micro. As expected in small realities, the 70% of the respondent SMEs have stated to be *family-run*. In addition, since SMEs tend to be characterized by a lack of resources in terms of infrastructures and funds (as explained in section 4.4), many of them have claimed to have a single *productive site configuration.* In the same way, being this part of target oriented towards manufacturing SMEs, it was predictable that the most of respondents would declare to conduct labor intensive *processes,* as workforce is an essential element in many production realities. Nevertheless, the presence of capital intensive companies is justified by the fact that they might need very expensive machineries and tools to carry out their activities. In terms of the *market* they serve, respondent companies seem to be quite well-distributed between Italian and foreign markets. Generally speaking, the ratio of *R&D over revenues* tends to be quite low. Once again, this might be due to the lack of financial resources, that pushes SMEs to invest on more urgent activities. At the same time, it is worth noticing that keeping R&D projects under control is not that easy, especially when employees are not enough. Hence, companies prefer to focus their efforts on production activities, that show a more immediate result in term of revenues. Finally, the most of respondents have declared to have an internal *IT department*. This result is in line with the size of companies that, being medium-small, might not need to manage a huge amount of information and, consequently, might be able to do it by themselves. At the same time, the 40% of them have stated to resort to outsourcing. This makes sense because SMEs might not have the competences needed to handle the complexity of an IT department.

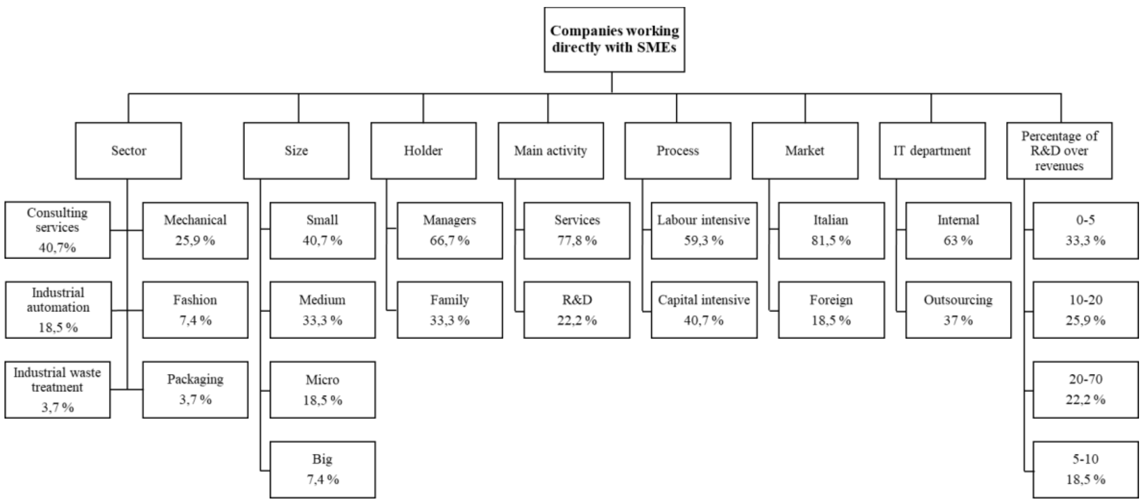

Figure 16- Distribution of other companies according to the dimensions of analysis

As for the second part of the target – namely those companies that work directly with SMEs – the most of them belong to the consulting *sector*. However, there are also fair percentages of companies providing services in mechanical and automation industries, followed by lower amounts operating in other sectors. In terms of *size* and *holder,* the respondent companies are fairly distributed among the different sizes and they are mainly run by managers, especially when it comes to big companies. In addition, while the *main activity* for most of them is the provision of services, only the rough 20% is devoted to R&D. At the same time, the ones characterized by labor intensive *processes* seem to be a bit more than capital intensive ones: this feature depends mostly on the type of service they provide and the sector they belong to. Moreover, the most of respondent companies have declared to serve Italy more than foreign *markets*. This result is particularly interesting as it allows to provide a clear view of Lean 4.0 in Italian SMEs. Generally speaking, the percentage of R&D over revenues is higher in this case compared to the first part of the target. This might be due to the fact that this part of the target is populated by companies completely dedicated to R&D, as well as service providers. However, this percentage is still quite low because the most of them have declared to be either medium or smell. For the same reason, many of them have proved to have an internal IT department.

6.1.3 Lean Practices and Smart Technologies in SMEs

Lean 4.0 section of the survey was meant to investigate different themes:

- Firstly, which Lean practices and Industry 4.0 technologies are separately adopted by SMEs (see questions 13th and 14th in appendix 2).
- Secondly, whether the above-mentioned practices and technologies enhance each other (see question 15th in appendix 2).
- Finally, to which extent those synergies benefit the company in terms of data collection, decision-making and routine processes (see questions 16th, 17th and 18th in appendix 2).

In the current section, an analysis of the answers related to the first and second points will be performed, following the same logic used to build the survey. In particular, in the first stage Lean practices and Smart technologies adopted by SMEs will be examined separately. Then, they will be put together in order to recreate the Lean 4.0 framework proposed in the Literature Review chapter (see section 4.3.3). Section 6.2, instead, will be totally devoted to an analysis of the third point.

Starting from Lean practices, figure 17 shows the results of question 13th. As can be easily seen, Kaizen results to be the most applied practice in SMEs, followed by Kanban and 5S. In between 20 and 30 respondent companies have declared to apply JIT, People and Teamwork, Visual Management and Standardization. Conversely, Heijunka, Andon, Jidoka, SMED, Muda reduction and Poka Yoke turn out to be adopted by less than 10 respondent companies.

Looking at figure 17, it is noteworthy that three out of four foundations principles of House of Lean (Liker, 2004) – Kaizen, Visual Management, Standardization – have turned out to be quite applied by SMEs. Conversely, Heijunka is placed among the least applied practices and this might be due to the production flexibility and informal rules on operational planning characterizing SMEs (Yadav, Jain, Mittal, Panwar, & Lyons, 2019). In addition, the two pillars of the House– JIT and Jidoka – are ranked very differently. This might be due to the fact that Jidoka is strictly related to automatization of processes, which requires specific competences and resources. In fact, the main tools associated with Jidoka – Poka Yoke, Andon, TPM – are not much applied as well. On the opposite side, Kanban – the main practice of JIT – occupies the second place. This might be related also to the fact that it represents one of the most proven Lean practices. Finally, it is worth mentioning the wide adoption of People and Teamwork. In fact, this is completely in line with SMEs' organizational structure, which is short and fluid (Laufs, Bembom, & Schwens, 2016), and their supportive organizational culture, which enhances teamwork and collaboration (Yadav, Jain, Mittal, Panwar, & Sharma, 2019).

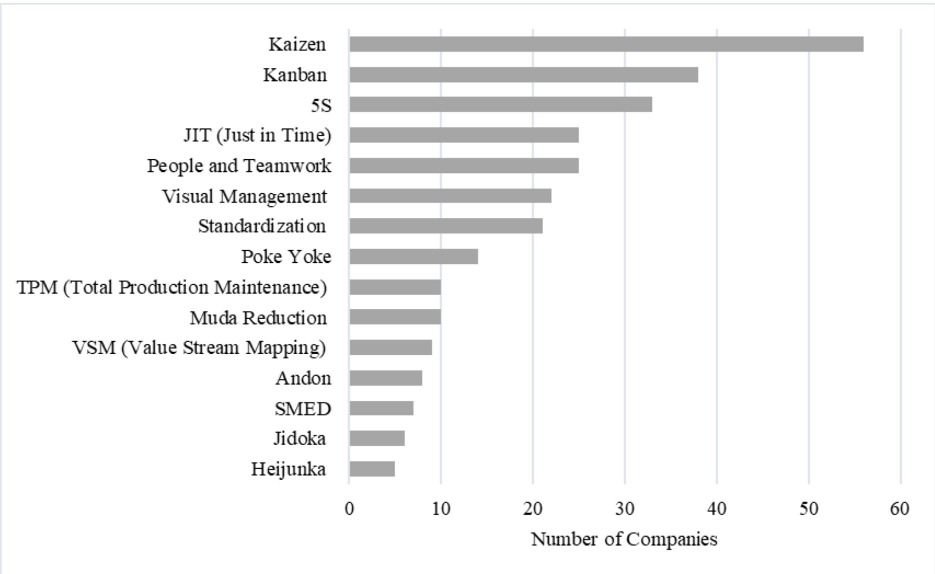

Figure 17 - Lean practices in SMEs

As far as Smart Technologies are concerned, figure 18 shows the results related to question 14th. According to respondent companies, Industrial Analytics and Industrial Internet of Things result to be the most applied technologies; while Additive Manufacturing and Digital Twin/Simulation the least ones. At the same time, in between 30 and 50 respondent companies have declared to adopt Advanced Automation, Cloud Manufacturing, Advanced Human-Machine Interface.

The Literature Review showed that LEs tend to perceive Additive Manufacturing, Digital Twin, Simulation and Advanced Human-Machine Interface as strongly beneficial. However, according to the survey results, SMEs still struggle in realizing their advantageous impact. As for Digital Twin and Simulation, the low adoption might be related to the fact that these technologies are still not completely developed; while SMEs lack of financial resources and specific competences might be the reasons why they are still sceptical in investing in Additive Manufacturing and Advanced Human-Machine Interface. On the other side, Industrial Analytics, Internet of Things and Cloud Manufacturing represent the most consolidated and widespread Smart Technologies. As a consequence, they are quite accessible for companies of any size. However, according to respondent companies, SMEs do not adopt Cloud Manufacturing as much as Industrial Analytics and Internet of Things. Once again, this might be due to SMEs' lack of expertise, as well as to the weak influence they are likely to have towards their supply chain partners.

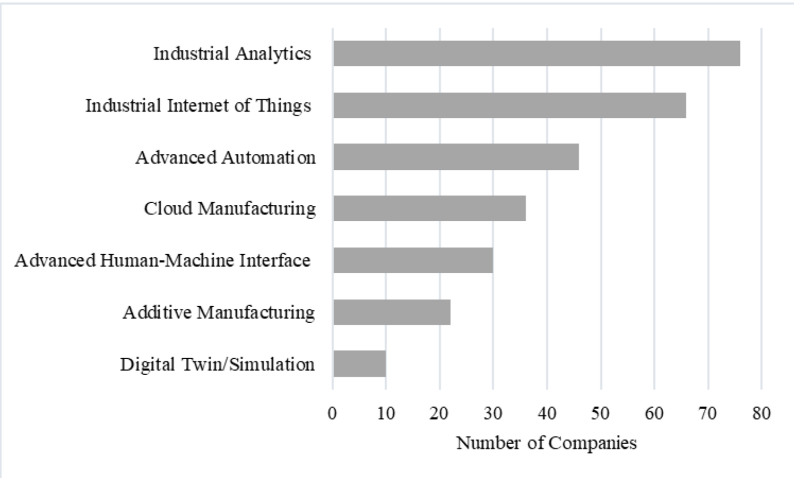

Figure 18 - Smart Technologies in SMEs

The last step of this analysis is related to Lean 4.0. In particular, the framework shown in section 4.3.3.8 has been rebuilt on the basis of the answers to the 15th survey question. This allows to have an idea about which intersections between Lean Production and

Industry 4.0 are implemented in SMEs and which are the most popular ones. Table 24 shows the rebuilt framework. As expected, the most numerous intersections are the ones associated with the most adopted practices and technologies, and vice versa.

Lean 4.0	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen	5	7	6	16	15	7	
Andon		1		3	2	2	
Poke Yoke	2	2	2	2	3	3	
TPM (Total Production Maintenance)		2	1	3	2	1	1
Jidoka		1		2	2	1	
Standardization	3	6	2	4	3	1	2
5S	3	3	3	7	11	5	1
Visual Management	3	3	5	5	3	1	2
Kanban	1	7	4	5	12	7	2
JIT (Just in Time)	1	6	1	5	8	3	1
Muda Reduction		1	1	1	5	2	
VSM (Value Stream Mapping)	1	3	1	2	1		1
Heijunka				1	1		
SMED	1	1		2	3		
People and Teamwork	2	3	4	8	5	3	

Table 24 - Lean 4.0 framework for SMEs

6.1.4 Lean Practices and Smart Technologies in SMEs compared to the Literature Review

This section is meant to make a comparison between the survey results and the literature findings in terms of Lean practices and Smart Technologies adoption. In this way, it is possible to understand whether what has been found in literature reflects reality or not.

Starting form Lean practices, section 4.4.1 of the Literature Review shows that Kaizen, TPM, Standardization, 5S, Visual Management, Kanban, VSM and SMED are the mostly used practices in SMEs, while Heijunka, Andon and Jidoka are not even mentioned (Alkhoraifa, Rashidb and McLaughlina, 2019; Yadav, Jain, Mittal, Panwar and Lyon, 2019). For some of these practices, the results of the questionnaire are in line with the literature:

- Kaizen, Kanban and 5S seem to be the most used practices in SMEs.
- Visual Management and Standardization are widely adopted in SMEs, but not as much as Kanban or Kaizen.
- Heijunka, Andon and Jidoka seem to be the least used practices in SMEs.

On the contrary, according to the 75 respondent companies, SMED, VSM and TPM rank among the least adopted practices. In particular, they have turned out to be applied as much as Muda Reduction and Poka Yoke, which are not mentioned at all by literature.

Finally, People and Teamwork and Just in Time appear to be quite used in SMEs, even if their role is totally underestimated by previous researchers.

As for Smart Technologies, according to the main findings in literature, Cloud Manufacturing, IoT and Simulation are the most widespread in SMEs (Moeuf, Pellerin, Lamouri, Tamayo and Barbary, 2018). However, survey results have revealed that IoT is the only technology confirming the literature considerations. In fact, figure 18 shows that many technologies are more applied than Cloud Manufacturing, while Simulation turns out to be the least adopted. Besides, Additive Manufacturing confirms the literature, as it seems to be not so much used in SMEs. Lastly, the presence of Industrial Analytics, Advanced Human-Machine interface and Advanced Automation in SMEs seems to be totally underestimated by literature and researchers. In fact, Industrial Analytics appears to be the most applied technology, while Advanced Automation results to be even more applied than Cloud Manufacturing.

All in all, the survey results for both Lean Practices and Smart Technologies present some differences from the literature findings. This might be due to different reasons:

- An evolution of SMEs over the last years might have generated different results from the ones found in literature.
- Researchers might not be focusing enough on Lean Production and Industry 4.0 application in SMEs.
- Literature statements might be purely theoretical and not based on empirical studies and research.
- The respondent companies of the survey might not be representative of the overall Italian SMEs market. In fact, the sample of population is represented by 75 companies only.
- The respondent companies might not be completely aware of Lean practices and Smart technologies definitions.

Finally, it is worth comparing the Lean 4.0 framework built on the basis of survey results to the one proposed in the Literature Review chapter. However, it is important to keep in mind that the numbers into the two frameworks are incomparable: the ones in table 15 represent the amount of papers and academic articles that describe that intersection in LEs, while the ones in table 24 represent the number of answers to this dissertation survey. For this reason, the comparison has been performed merely looking at the presence of the intersections within the two frameworks. To avoid any kind of misunderstanding, the cells presenting some evidence have been coloured. In the case of the framework created from the survey answers, only the cells associated with a number higher than 4 have been coloured. In fact, according to the authors, less than four answers is not enough to claim that a certain intersection exists. Tables 25 and 26 report the framework used to perform the following comparison.

As shown by tables 25 and 26, the intersections highlighted in the two frameworks are quite different. In terms of density, it is clear that the second framework is populated by many more coloured cells. This is in line with the expectations because the Literature Review showed that, nowadays, SMEs do not adopt Lean Production practices and Industry 4.0 technologies as LEs do.

Looking at the columns, the first clear evidence is that, differently from LEs, SMEs seem not to apply Digital Twin and Simulation at all. This situation might depend on the fact that these technologies are quite new and, above all, complex. In fact, their implementation require companies a lot of commitment, competences and – last but not least – investments. A similar reasoning might apply for Advanced Human-Machine Interface, which results to be much more adopted by LEs than SMEs.

On the other side, Cloud Manufacturing, Industrial Analytics, Industrial IoT and Advanced Automation are adopted quite in the same way. In fact, these technologies represent the ones that, according to respondent companies, are mostly applied by SMEs. Additionally, most of them represent the technologies that are mostly suitable to be combined with Lean Production practices, as extensively explained in section 4.3.3 of the Literature Review.

In terms of Additive Manufacturing, the images show that this technology seems to be almost not applied by SMEs but, surprisingly, also by LEs. Once again, this might be due to the high costs and competences necessary to implement it. However, Additive Manufacturing – because of its own characteristics – is compatible with just a few Lean Production practices, as shown in section 4.3.3.1 of the Literature Review.

Lean 4.0	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen							
Andon							
Poke Yoke							
TPM (Total Production Maintenance)							
Jidoka							
Standardization							
5S							
Visual Management							
Kanban							
JIT (Just in Time)							
Muda Reduction							
VSM (Value Stream Mapping)							
Heijunka							
SMED							
People and Teamwork							

Table 25 - Lean 4.0 framework for SMEs with colored cells

Lean 4.0	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen							
Andon							
Poke Yoke							
TPM (Total Production Maintenance)							
Jidoka							
Standardization							
5S							
Visual Management							
Kanban							
JIT (Just in Time)							
Muda Reduction							
VSM (Value Stream Mapping)							
Heijunka							
SMED							
People and Teamwork							

Table 26 - Lean 4.0 framework from Literature Review with colored cells

6.2 Discussion of Results

This section is meant to critically discuss the answers to last questions of the survey (see questions 16th, 17th and 18th in appendix 2), used to investigate to which extent the integration between Lean Production practices and Industry 4.0 technologies benefits SMEs in terms of data collection, decision-making and routine processes.

In particular, the following chart (figure 19) shows the line of reasoning followed to perform the analyses presented in 6.2.1, 6.2.2, 6.2.3, 6.2.4 and 6.2.5 sections.

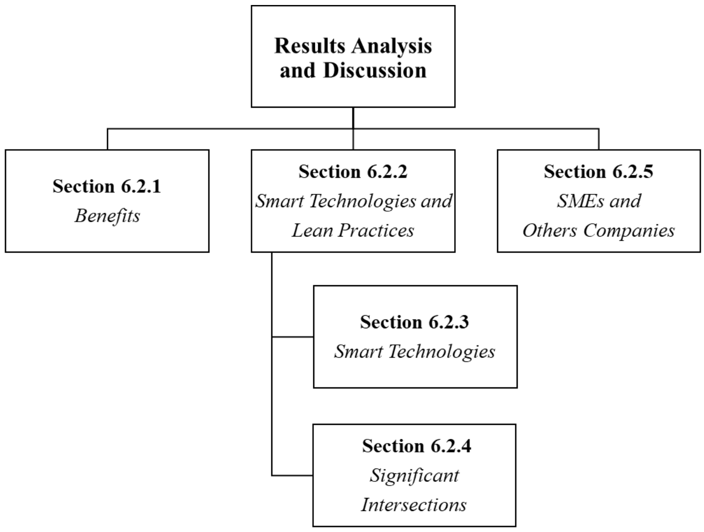

Figure 19 - Results Analysis and Discussion

6.2.1 Benefits Perception

The main aim of this analysis is trying to understand if the respondent companies perceive the three benefits mentioned in the research hypotheses in the same way. For each of the three benefits, the Weighted Mean – weighted on the number of answers for each intersection – has been calculated and the results of this operation, from now on, will be called **Benefit Impacts**. These values provide an indication of "how much" the respondent companies perceive the single processes as getting benefits from Lean Production and Industry 4.0 integration. Then, the Arithmetic Mean between those Benefit Impacts has been calculated (for more details see Appendix 4) and called, from now on, **Total Impact**. Generally speaking, this value allows to understand to what extent the integration between Lean Production and Industry 4.0 is perceived as beneficial by SMEs. These values are reported in table 27.

Benefits (based on 75 respondent companies)	**Benefit's Impact**
Data Collection	3.5
Decision-Making	3.4
Process Innovation	3.5
Total Impact	**3.5**

Table 27 - Means used to perform the analysis

As table 27 shows, the Total Impact is slightly higher than 3, the average number of the scale proposed in the survey (from 1 to 5). This means that, according to the respondent companies, the integration of Industry 4.0 technologies and Lean Production practices benefits SMEs to a certain extent. Additionally, the Benefit Impacts are strongly similar among each other, indicating that respondent companies perceive these benefits quite in the same way.

As the Benefit Impacts appear to be so similar among each other, it might be interesting to investigate if they come from different distributions of answers. In particular, for each benefit, it has been analysed how the values used to calculate the Benefit Impact are distributed with respect to the Total Impact value (i.e. 3.5). In order to do so, it has been necessary to divide those values according to different ranges, which have been chosen looking at the Benefits Boxplots (figure 20). The plot shows that the range of the average values of the three benefits is the one between 3.2 and 3.8, as it is common to all the three benefits.

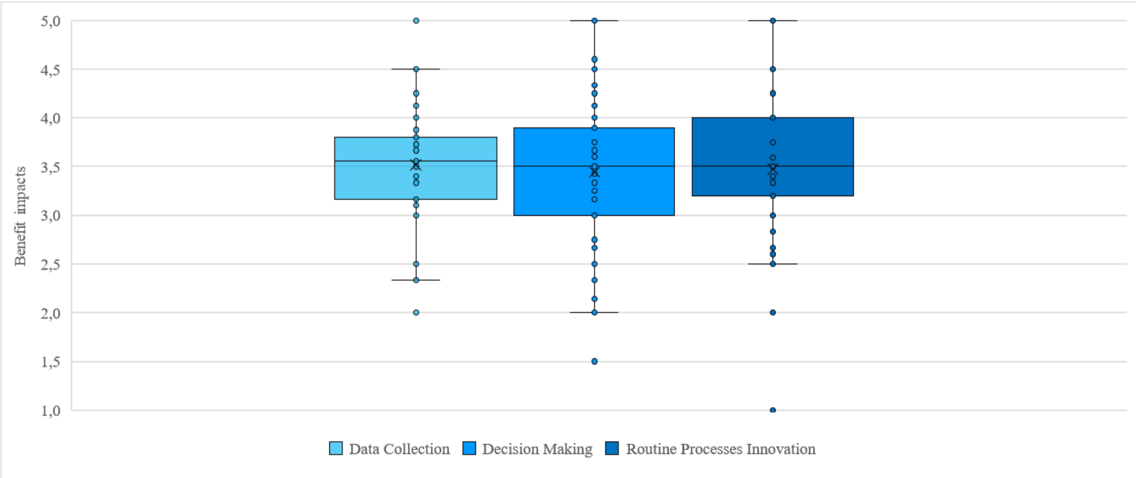

Figure 20 - Benefits Boxplots

This comparison has been performed by looking at tables 28, 29 and 30, where each value has been assigned different colours according to their position with respect to 3.5:

- Yellow if they are in between 3.2 and 3.8. As explained before, this range includes the values closest to the Total Impact.
- Red if they are lower than 3.2. In this case, the values are considered as much lower than the Total Impact.
- Green if they are higher than 3.8. In the same way, these values are considered as much higher than the Total Impact.

Firstly, a separate analysis has been performed for each of the three benefits. Then, a comparison between the three has been conducted with general conclusions and considerations.

Starting from Data Collection, table 28 shows the values distribution for this benefit. Generally speaking, all the three ranges are present in the matrix but with a different distribution for each Smart Technology:

- Advanced Automation and IoT present a prevalence of green spots.
- Cloud Manufacturing and Industrial Analytics present a prevalence of yellow spots.
- Additive Manufacturing, Advanced Human Machine Interface and Digital Twin and Simulation present a prevalence of red spots.

Data Collection	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen							
Andon							
Poke Yoke							
TPM (Total Production Maintenance)							
Jidoka							
Standardization							
5S							
Visual Management							
Kanban							
JIT (Just in Time)							
Muda Reduction							
VSM (Value Stream Mapping)							
Heijunka							
SMED							
People and Teamwork							

Table 28 - Color distribution for Data Collection

Data collection improvement is characterized by a higher amount of yellow values than red and green ones, confirming that the perception of this benefit is in line with the Total Impact value. In fact, the implementation of some Smart Technologies – such as Cloud Manufacturing – naturally leads to simplify the data collection process. However, this simplification takes place when these technologies are coupled with expertise and competences in terms of data analysis and interpretation. If companies lack these features, they might not be able to totally perceive their benefits.

Figure 21 - Distribution of value for Data Collection

Table 29 shows the distribution of answers for decision-making improvement. Smart Technologies present different colours prevalence:

- Industrial Analytics, Advanced Automation and IoT present a prevalence of green spots.
- There is no technology that present a prevalence of yellow spots.
- Cloud Manufacturing, Additive Manufacturing, Advanced Human Machine Interface and Digital Twin and Simulation present a prevalence of red spots.

Decision Making	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen							
Andon							
Poke Yoke							
TPM (Total Production Maintenance)							
Jidoka							
Standardization							
5S							
Visual Management							
Kanban							
JIT (Just in Time)							
Muda Reduction							
VSM (Value Stream Mapping)							
Heijunka							
SMED							
People and Teamwork							

Table 29 - Color distribution for Decision-Making

Decision-making improvement is characterized by way more red values than yellow and green ones. This might be due to the organizational structure of SMEs, that are likely not to have a proper department that makes decisions for the whole company. Normally, the different departments make decisions for themselves. Therefore, it might be difficult to perceive the benefit related to decision making because there is not a centralized view of this process in those companies. Nevertheless, decision-making Benefit Impact is in line with the other ones and this might be explained mathematically. In fact, it is likely that the few companies belonging to the green range have assigned to this benefit a value much higher than 3.8, while the many ones belonging to the red one have declared a value close to 3.2.

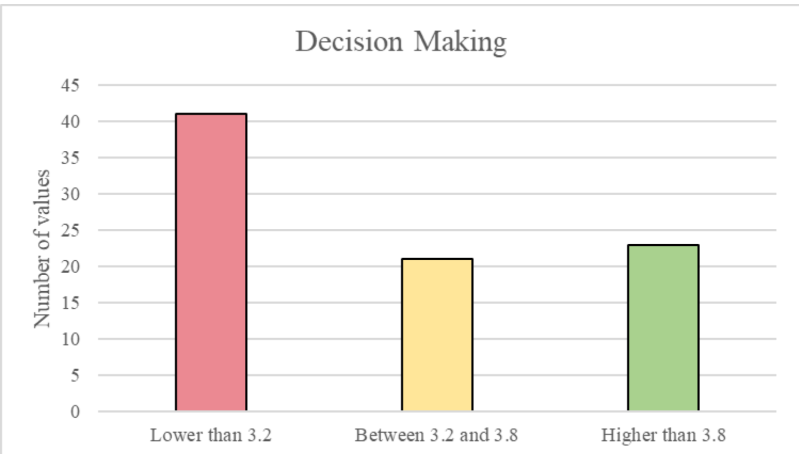

Figure 22 - Distribution of value for Decision Making

As for Routine Processes Innovation, table 30 highlights the distribution of answers for this benefit. More in details, Smart Technologies are characterized by the following dominant colours:

- Green for Industrial Analytics, Advanced Automation and IoT.
- Yellow for Cloud Manufacturing.
- Red for Additive Manufacturing, Advanced Human Machine Interface and Digital Twin and Simulation.

Process Innovation	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen							
Andon							
Poke Yoke							
TPM (Total Production Maintenance)							
Jidoka							
Standardization							
5S							
Visual Management							
Kanban							
JIT (Just in Time)							
Muda Reduction							
VSM (Value Stream Mapping)							
Heijunka							
SMED							
People and Teamwork							

Table 30- Color distribution for Routine Processes Innovation

Routine processes innovation is characterized by more red and green values than yellow ones. This tendency towards either green or red values might depend on the Smart Technology considered. In fact, the introduction of some Industry 4.0 technologies naturally brings changes in SMEs. As a consequence, the employees tend to face changes in their daily activities. For instance, Advanced Automation is able to automatize some manual tasks, allowing workers to focus on more important activities. Even if this is an inner feature of Advanced Automation, it leads to a change in the way people work on a daily basis who will perceive it as an innovation. On the other side, some Smart Technologies do not affect the routine processes, as they refer to data collection, treatment and sharing. This might be the case of Cloud Manufacturing, that does not impact the daily tasks of many employees. However, the amounts of red and green values are quite balanced, reconfirming the fact that this benefit is perceived as much as the other two.

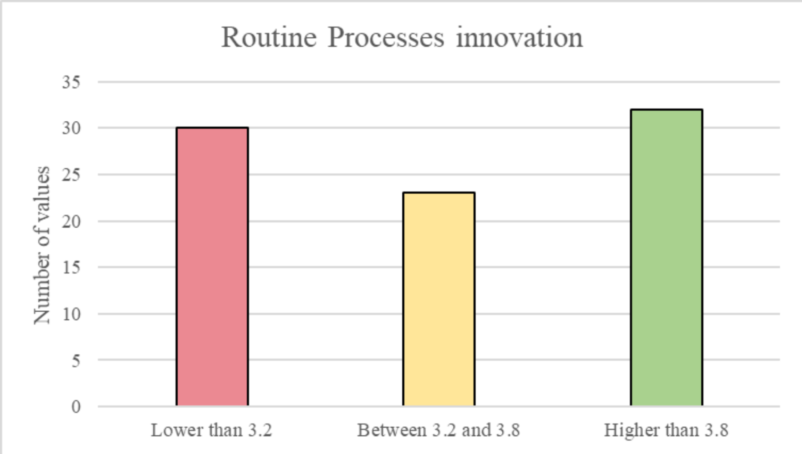

Figure 23 - Distribution of value for Routine Processes Innovation

It is possible to conclude that the similar results obtained in terms of Benefit Impacts come from very different distributions of answers (see figure 24). This might be justified by the different benefits characteristics and by the diverse perception that SMEs have of them after implementing Smart Technologies.

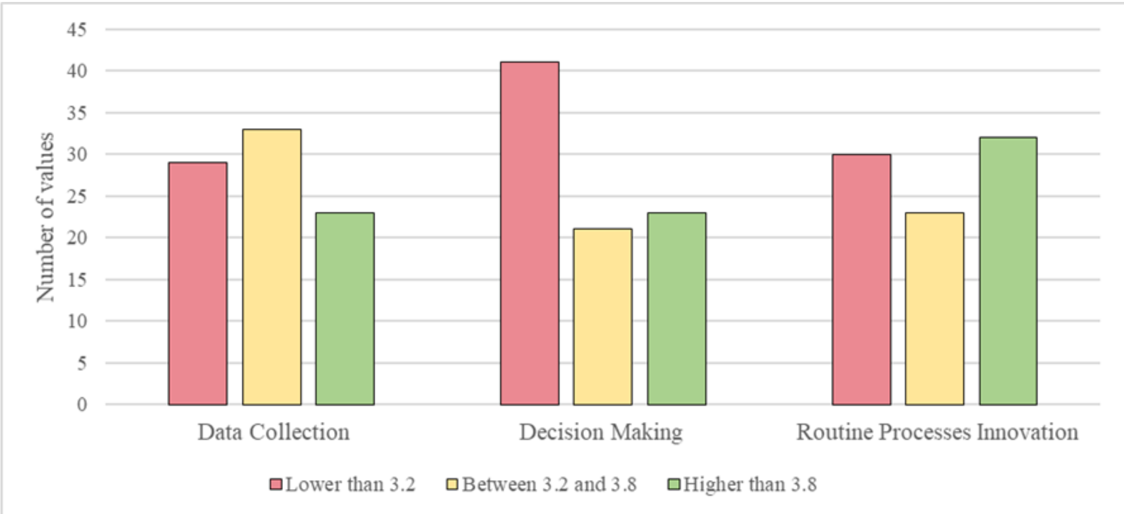

Figure 24 - Summarized color distributions for the three benefits

6.2.2 Analysis on Smart Technologies and Lean Practices

The perspective taken in this analysis is the one of Lean Production practices and Industry 4.0 technologies. In fact, the main aim is twofold:

1) Understanding how beneficial SMEs perceive Industry 4.0 technologies according to the 75 respondent companies.
2) Understanding how SMEs perceive the benefits on Lean Production practices according to the 75 respondent companies.

To do so, for each technology and practice, the Arithmetic Mean among the Weighted Means associated with each benefit has been calculated (tables 31 and 32). This value represents the general benefit perceived on each practice and from each technology. Then, both Industry 4.0 technologies and Lean Production practices have been divided according to the three ranges described in the previous analysis, in order to get a clear understanding of how they are distributed. This division has been graphically represented by coloring the general benefits cells according to the colors related to the three ranges.

Starting from Industry 4.0 technologies, table 31 shows the following evidence:

- **Industrial Internet of Things** is characterized by three Benefit Impacts placed within the yellow range, indicating that this technology is considered strongly beneficial from all the considered points of view. To be more precise, Industrial IoT is considered a bit more beneficial in terms of data collection than decision-making and process innovation, which makes sense considering the nature of IoT devices.
- Also in the case of **Advanced Automation,** all the Benefit Impacts belong to the yellow range, indicating the benefit recognized by respondent companies for this technology. However, while data collection improvement and routine process innovation are positioned close to the upper end, decision-making improvement results to be the furthest one. As mentioned in the previous section, this is probably due to the fact that the nature of Advanced Automation does not fit well in this process.
- Also, **Industrial Analytics** is definitely perceived as beneficial, as its Benefit Impacts are placed within the yellow range. In particular, it is perceived as particularly beneficial for routine process innovation.
- **Cloud Manufacturing** and **Advanced Human-Machine Interface** – which belong to the yellow range – are both characterized by Benefit Impacts which are very balanced among one another. Additionally, both of them are placed close to the range lower end, indicating that SMEs have started recognizing the potential of these technologies.
- **Additive Manufacturing** is characterized by three Benefit Impacts placed in the red range. In particular, while data collection improvement is quite close to the yellow range lower end, decision-making improvement and routine process innovation are much further. This means that SMEs are still struggling in recognizing the benefits associated with this technology.

- Also, **Digital Twin and Simulation** belong to the red range, with three balanced Benefit Impacts which are quite far from red range upper bound. This means that, nowadays, this technology is recognized as less beneficial than others. This might be due to the fact that Digital Twin and Simulation are the least adopted technologies and, as a consequence, SMEs are not able to recognize their benefits in a proper way.

	Industrial IoT	Advanced Automation	Industrial Analytics	Cloud Manufacturing	Advanced HMI	Additive Manufacturing	Digital Twin/Simulation
DC	3.8	3.7	3.5	3.5	3.3	3.3	2.9
DM	3.6	3.5	3.6	3.4	3.3	3.1	2.8
RPI	3.6	3.8	3.7	3.4	3.4	3.0	2.8
	3.7	3.7	3.6	3.4	3.3	3.1	2.8

Table 31 – Impacts per benefit and general impacts of Industry 4.0 technologies

In light of these considerations, it is possible to conclude that:

- There is no technology in the green range, meaning that none of them is perceived as much more beneficial than the others.
- Five out of seven technologies belong to the yellow range, meaning that they are perceived as beneficial quite in the same way. It is noteworthy that these technologies correspond to the most adopted ones by SMEs (see section 6.1.3). As a consequence, they can be considered trustworthy in the way they perceive these technologies as beneficial in their integration with Lean. In addition, the majority of them are IT. This reconfirms the fact that, to date, SMEs are more comfortable dealing with the most proven and accessible Smart Technologies.
- There are two technologies in the red range: **Additive Manufacturing** and **Digital Twin/Simulation**. These technologies represent the least adopted by SMEs and, consequently, it might be hard for them to clearly judge how beneficial they are. This might be related to the complexity – in terms of financial investment and necessity of specific competencies – associated with them. In addition, **Additive Manufacturing** is useful in very specific situations that might not occur in small business. A similar reasoning applies for **Digital Twin/Simulation.** In fact, these technologies are particularly advantageous when companies deal with a high degree of complexity, which might not be the case of SMEs.

As far as Lean practices are concerned, table 32 leads to some interesting considerations:

- Two practices belong to the green range: **Total Production Maintenance** and **Heijunka.** As for TPM, respondent companies have declared to perceive a lower benefit in terms of data collection. Heijunka is characterized by high Benefit

Impacts in terms of decision-making and process innovation, while the one associated with data collection is positioned way lower the green range lower end.

- **Standardization** belongs to the yellow range and the Benefit Impact associated with process innovation is way higher than the other two. The **Visual Management** situation is similar, as its data collection Benefit Impact turns out to be perceived better than the others. Conversely, **People and Teamwork** presents quite balanced Benefits Impacts, exception made for decision-making one which is lower than the others. These three practices are positioned very close to the yellow range upper end.
- **Jidoka,** which belongs to the yellow range, is characterized by quite unbalanced Benefit Impacts. In fact, decision-making Impact is way lower than data collection and process innovation ones.
- **Kaizen, Just in Time**, **Poka Yoke** and **5S** are all placed within the yellow range and characterized by balanced Benefit Impacts.
- **Muda Reduction** and **Kanban** fit the yellow range but they are placed close to its lower end. While Kanban is characterized by balanced Benefits Impacts, Muda Reduction presents a process innovation one which belongs to the red range.
- **Andon** belongs to the red range, but it is characterized by quite unbalanced Benefit Impacts: decision-making and process innovation ones are placed within the red range, while data collection one fits the yellow one. **Value Stream Mapping** presents a very similar situation, with the decision-making Benefit Impact that fits the yellow range.
- **SMED** belongs to the red range and is characterized by really balanced Benefit Impacts.

	TPM	Heijunka	Standardization	Visual Management	People and Teamwork
DC	3.8	3.0	3.6	3.9	3.9
DM	4.2	5.0	3.5	3.6	3.5
RPI	4.1	4.0	3.9	3.7	3.8
	4.0	4.0	3.7	3.7	3.7
	Jidoka	**Kaizen**	**Just in Time**	**Poka Yoke**	**5S**
DC	3.7	3.5	3.5	3.4	3.3
DM	3.2	3.6	3.4	3.3	3.6
RPI	3.8	3.6	3.6	3.4	3.4
	3.6	3.6	3.5	3.4	3.4
	Muda Reduction	**Kanban**	**Andon**	**VSM**	**SMED**
DC	3.4	3.4	3.3	3.2	3.0
DM	2.8	3.2	3.0	3.4	2.7
RPI	3.6	3.2	2.9	2.8	3.0
	3.3	3.3	3.1	3.1	2.9

Table 32 - Lean Production practices Weighted and Arithmetic Means

All in all, it is possible to state that:

- Once again, most of the practices belonging to the yellow range represent the most adopted by SMEs (see section 6.1.3). As a consequence, they can perceive more clearly the benefits on these practices. In addition, these practices include three out of four foundations of the House of Lean (Liker, 2004) (**Standardization, Visual Management, Kaizen**) and its main pillars (**Just in Time**, **Jidoka, People and Teamwork, Muda Reduction**). This indicates that SMEs are perceiving a real benefit on those practices that are fundamental to build an up and running Lean system.
- On the opposite side, the practices belonging to the green and red ranges represent the least adopted ones (see section 6.1.3), making respondent companies' judgement slightly biased. However, some differences should be highlighted. Firstly, the red range is populated by **Andon, VSM** and **SMED.** These practices play a strictly operational role, and their functioning might not be particularly affected by Industry 4.0. In fact, literature tends not to mention them when it comes to Smart Technologies benefits (see section 4.3.4). Secondly, the green range includes **TPM** and **Heijunka**. Literature presents much evidence of the different ways in which Industry 4.0 benefits the Maintenance processes. Hence, according to respondent companies, SMEs definitely appreciate the three benefits on this practice. Conversely, literature tends to neglect Heijunka, also in the context of LEs. As a consequence, to date, there is no consolidated knowledge about the way this practice takes advantage from Smart Technologies. However, according to respondent companies, SMEs perceive these benefits quite a lot.

6.2.3 Relationship Analysis on Smart Technologies

Following the lead of the previous section, this analysis is meant to explore even more Smart Technologies and the relationships between them

Before proceeding with this section's analysis, some considerations are needed. A simplification of the matrix presented in section 2.5 that excludes 3 out of 7 columns and 10 out of 15 rows has been done. The reason for that is related to the number of answers received for each intersection. In fact, for the following analysis only the intersections with more than 7 answers have been taken into consideration to have a minimum amount of responses to be compared.

Semplified Matrix Lean 4.0	Advanced Automation	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing
Kaizen	7	7	15	16
5S		7	11	
Kanban	7		12	7
JIT (Just in Time)			8	
People and Teamwork		8		

Table 33 - Simplified Matrix of Lean 4.0 in SMEs

As a consequence, only Advanced Automation, Industrial Internet of Things, Industrial Analytics and Cloud Manufacturing have been considered as Smart Technologies. As regards Lean practices, the ones that have been taken into consideration are Kaizen, 5S, Kanban, JIT and People and Teamwork as shown in table 33. This simplified framework ensures that a relationship analysis on Smart Technologies can be performed for the significant intersections.

The relationship analysis proposed in the following paragraphs has been performed on the matrix, row by row, respecting the Excel file's configuration. This file is the output that came from Opinio, the survey platform, that contains the respondents answers for all the proposed questions. More in details, matrixes' results have been reported in the Excel file in this form: each intersection is represented by a column, reporting on the rows the 75 respondent companies' answers. However, even if this analysis has been performed row by row, the final considerations has been proposed separately for each benefit and the common findings have been summarized at the end of this section.

In addition, it is important to highlight that this analysis has been performed only for Smart Technologies and not for Lean Practices because the focus of this dissertation is on the benefits that Smart Technologies might bring to SMEs. Therefore, a relationship analysis makes sense only if performed on Industry 4.0.

Moreover, all the considerations reported in the following paragraphs have been pointed out by comparing the four technologies two by two and they have been expressed only if more than three of the considered rows presented the same trend.

More accurately, two typologies of relationship between technologies have been proposed:

- The two considered technologies present correspondent values connection (e.g. the same respondent company has declared the same benefit value for both Cloud manufacturing and IoT). In this case, the graphical representation occurs with a straight line between the two technologies.

- The two considered technologies present a positive relationship. In particular, a positive relationship takes place when two conditions hold true:
  1. Respondent companies that declare to adopt two technologies together assign high benefits values to both of them.
  2. Respondent companies that declare to adopt only one of those two technologies assign lower benefits values to it.

  In particular, a positive relationship is represented with a straight line and a +. In addition, the number of + represents the number of rows that show a positive relation between the two technologies being analysed.

Moreover, it is important to highlight that there is not a case in which both technologies have only low value when they are proposed together by a single company but only cases in which both high and low values correspond (see point 1 of the above list).

The first benefit considered is data collection improvement that, as shown in figure 25, presents both the two typologies of relationship previously mentioned: a positive relation between IoT and Cloud, a positive relation between IoT and Industrial Analytics and a correspondence in values between Advanced Automation and IoT when implemented together.

More in details, IoT connection with both Cloud Manufacturing and Industrial Analytics might be a clear sign of its versatile nature. However, it can be justified also by the fact that all of them are Information Technologies and, as a consequence, this facilitates the positive relation of IoT with the other two Smart technologies. Moreover, the correspondence in value between IoT and Advanced Automation might indicate the possible presence of a relation which SMEs perceive as less strong than the ones between other technologies. Generally speaking, data collection seems to be a benefit mainly related to Information Technology. This does not mean that it is not common for Operations Technologies, but that probably SMEs struggle to perceive its positive impact. In addition, the absence of a connection between Cloud Manufacturing and Industrial Analytics - strongly present in literature - might be due to the low amount of data analysed.

Figure 25 – Relationships for Data Collection

As for the second benefit, decision making improvement, figure 26 sums up all the main considerations: there is a positive relation between Cloud Manufacturing and Industrial Analytics, but also between IoT and Industrial Analytics and between IoT and Advanced Automation; finally, there is a correspondence in values between IoT and Cloud Manufacturing.

The first consideration that is necessary to take into consideration is that IoT presents a relation with all the other three technologies, as in the case of data collection improvement. This is justifiable, as mentioned before, by the versatile nature of IoT. The correspondence in values between IoT and Cloud Manufacturing is probably due to the nature of the data analysed, but in any case, it can be considered a relevant connection. Finally, the positive relation between Cloud Manufacturing and Industrial Analytics is coherent with what found in literature. Generally speaking, even if decision making presents one more connection than data collection, the overall connections are quite the same.

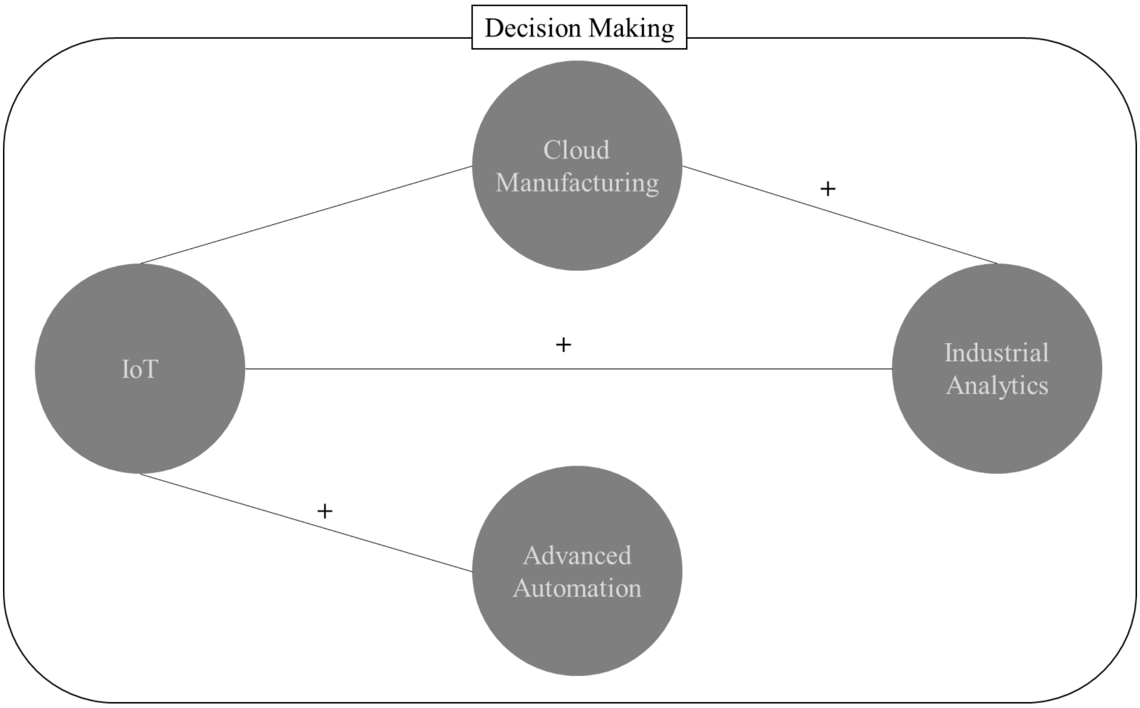

Figure 26 – Relationships for Decision Making

For the last benefit, routine processes innovation, figure 27 shows which relationships are present. In particular, there are positive relationships between IoT and the other three technologies and, also, a positive relation between Cloud Manufacturing and Industrial Analytics.

In this case, compared to the previous benefits, there is no correspondence in value and, in two out of four connections, the relation is really strong because it is present more than once (see the number of + in figure 27). This might mean that SMEs perceive routine processes innovation in a more beneficial way than the other two improvements. This might be due to the fact that introducing a Smart Technology in a SME is already perceived as an innovation in routine processes because of the changes that occur with its implementation. In conclusion, routine processes innovation is the benefit that has shown more easily the relationships between the main Smart Technologies implemented.

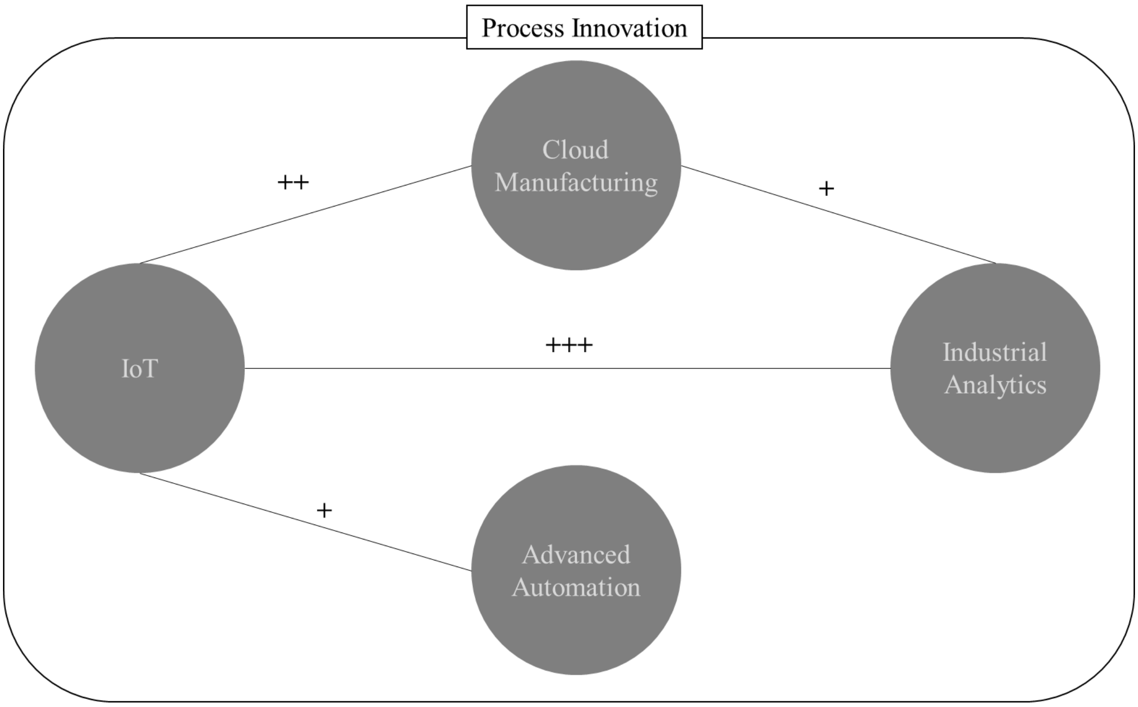

Figure 27 - Relationships for Process Innovation

In conclusion, a summarized representation of the relationships between the different Smart Technologies has been proposed. In fact, figure 28 shows the overall outcome of the relationships analysis. Naturally, not all the possible lines between two technologies have been proposed, but only the ones that are considered the most recurrent: connections that are present in two out of three benefits.

The main considerations that can be declared as common to all the three benefits are:

- The presence of three Information Technologies over only one Operations Technology is an aspect that might justify the higher relation present between the first three technologies excluding, in some way, the last one. However, this does not mean that Advanced Automation is not related to the other technologies. In fact, Information Technologies are more widespread in the SMEs context and, consequently, companies might perceive them as easier to adopt.
- Another important factor is related to the presence of no line between Cloud Manufacturing and Advanced Automation and between Advanced Automation and Industrial Analytics. This is related to the fact that the link between Information technologies and Operations technology is IoT. In fact, Cloud Manufacturing and Industrial Analytics are used, for example, for analysis and storage of data, instead, Advance Automation is used for more practical operations.

- Generally speaking, IoT appears to be positively related to all the other technologies. This might be the consequence of its versatile nature, as previously said, that makes it adaptable to different contexts, as well as different Lean practices.
- Finally, there seems to be no "negative relationships" among the analysed technologies. In other words, it means that there seems to be no case in which respondent companies that declare to adopt two technologies together assign high benefits values to one of them and low values to the other one. This can be the consequence of the exclusion of three out of the seven Smart Technologies considered or the evidence of the positive relation that Smart Technologies have between each other.

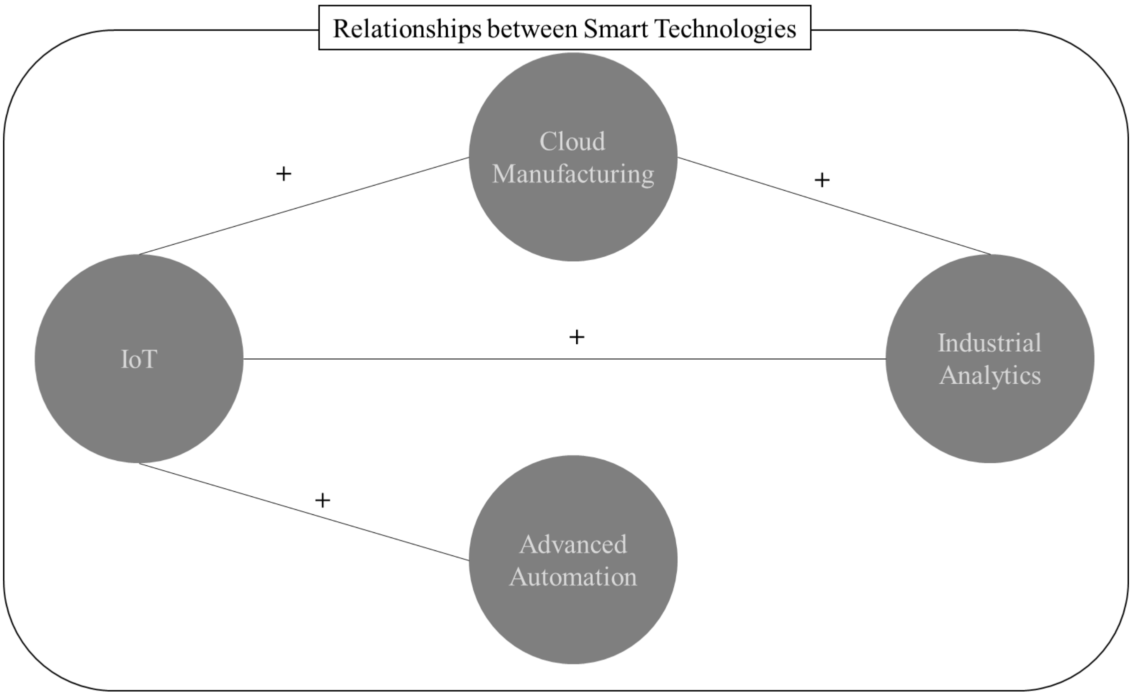

Figure 28 - Relationships between Smart Technologies

6.2.4 Benefits analysis for the Eleven Intersections

This analysis has been performed following the lead of the one in section 6.2.3, as the focus is on the eleven intersections of the simplified framework. However, in this case a framework for each benefit has been created. In addition, the three frameworks (tables 34, 35, 36) are populated by the Arithmetic Means of the benefit values declared by respondent companies for each specific intersection. These values will be named as Impact Levels from now on.

This analysis revolves around a comparison among the Impact Levels associated with the intersections, aiming at understanding if the values of those particular Lean practices and Smart Technologies are different between each other and if there are some outliers. In addition, it has been performed looking at the three benefits separately, aiming at understanding whether the exceptions are consistent along them.

Data Collection	Advanced Automation	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing
Kaizen	3.57	3.75	3.40	3.57
5S		3.57	3.27	
Kanban	3.14		3.75	3.29
JIT (Just in Time)			4.13	
People and Teamwork		3.88		

Table 34 - Simplified Framework of Weighted Means for Data Collection

Decision Making	Advanced Automation	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing
Kaizen	3.29	3.69	3.40	3.29
5S		3.29	3.73	
Kanban	2.14		3.92	3.00
JIT (Just in Time)			4.13	
People and Teamwork		3.75		

Table 35 - Simplified Framework of Weighted Means for Decision Making

Process Innovation	Advanced Automation	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing
Kaizen	3.29	3.75	3.73	3.71
5S		3.43	3.18	
Kanban	2.71		3.67	3.43
JIT (Just in Time)			4.00	
People and Teamwork		3.63		

Table 36 - Simplified Framework of Weighted Means for Routine Processes Innovation

Considering that respondent companies have been asked to evaluate the benefits with a value from 1 to 5, the most common answer has been 3. However, table 34, 35, 36 show that there have been some exceptions (see red and green intersections):

- The intersection between JIT and Industrial Analytics. More accurately, this intersection is perceived as more beneficial than the others from all the three benefits point of view. This might be due to the fact that Industrial Analytics is able to speed up the order processing activity, leading to an enhancement of JIT philosophy.
- The intersection between Kanban and Advanced Automation. In this case, two out of three benefits present Impact Levels values lower than 3. Therefore, this intersection is perceived as less beneficial than others. This might be related to Advanced Automation and Kanban nature, that are characterized by no common elements. In fact, Kanban is mainly applied to improve production schedule and set priorities, while Advanced Automation is aimed at preventing mistakes and time waste by increasing the level of automation of processes.

In conclusion, this analysis shows the overall distribution of the values along the most relevant intersections and highlights the presence of only two intersections – one green and one red - that do not belong to the most common answer: 3. As mentioned before, this is the consequence of a similar perception of the three benefits irrespective of the different Lean Practices and Smart Technologies.

6.2.5 Comparison Analysis between SMEs and Other Companies answers

The analysis proposed in this section takes a different perspective: the one of the survey targets. In fact, the population of the survey, that was previously considered as a whole, is now split in two parts: SMEs and companies working directly with SMEs – called Other Companies from now on. This analysis is important because it may highlight possible differences between the two typologies of respondent companies.

Firstly, tables 37 and 38 show the subdivision of survey answers between the two targets. Tables have been filled with ‘X’ character and not with the number of answers for each intersection because the focus of this analysis is on the existing interchanges and not on the amount of answers. It goes without saying that the framework of SMEs – associated with 48 answers – presents more complete intersections than the one of Other Companies, associated with 27 out of 75. Besides, these differences in distributions might be related to the fact that Other Companies have been asked to fill in the survey by referring to SMEs they work with and, for sure, it is more difficult to understand the benefits of something that is applied and used by others.

Lean 4.0 SMEs (48)	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen	X	X	X	X	X	X	
Andon		X		X	X	X	
Poke Yoke	X	X	X	X	X	X	
TPM (Total Production Maintenance)		X		X	X		X
Jidoka		X		X	X	X	
Standardization	X	X	X	X	X		X
5S	X	X	X	X	X	X	X
Visual Management	X	X	X	X	X	X	X
Kanban		X	X	X	X	X	X
JIT (Just in Time)	X	X	X	X	X	X	X
Muda Reduction		X	X	X	X	X	
VSM (Value Stream Mapping)		X		X			X
Heijunka				X			
SMED	X	X		X	X		
People and Teamwork	X	X	X	X	X	X	

Table 37 - Lean 4.0 in SMEs - distribution of answers

Lean 4.0 Other Companies (27)	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen	X	X	X	X	X	X	
Andon							
Poke Yoke			X		X		
TPM (Total Production Maintenance)		X	X	X	X	X	
Jidoka					X		
Standardization		X	X				
5S	X	X	X	X	X	X	
Visual Management	X	X	X	X			X
Kanban	X	X	X	X	X	X	X
JIT (Just in Time)		X		X	X	X	
Muda Reduction					X		
VSM (Value Stream Mapping)	X	X	X	X	X		
Heijunka					X		
SMED							
People and Teamwork	X	X	X	X	X	X	

Table 38 - Lean 4.0 in other companies - distribution of answers

An important aspect of this analysis is that it is not focused on the Impact Levels of each intersection but on the comparison between the distribution of those values and the Benefit Impact of each benefit – respectively 3.5, 3.4 and 3.5 for data collection, decision-making and process innovation. Therefore, the following matrices do not contain numbers but colours. More in details, green represents an Impact Level which is definitely higher – more than 3.8 – than the Benefit Impact, yellow means that Impact Level is quite close – in between 3.2 and 3.8 – to the Benefit Impact and red indicates an Impact Level which is quite lower – less than 3.2. Moreover, it is important to say that Digital Twin/Simulation has been excluded from the analysis because there are not enough intersections for other companies to make a proper comparison with SMEs. For this reason, its column is full of 'X' character.

As regards the first benefit, data collection improvement, the main considerations that tables 39 and 40 show are:

- Additive Manufacturing and Advanced Human Machine Interface present a prevalence of red spots in SMEs than in other companies.
- Conversely, Cloud Manufacturing presents a prevalence of red and yellow spots for other companies than for SMEs.
- Advanced Automaton, Industrial Analytics and IoT have most of the values above or similar to the Benefit Impact of data collection for both the two targets. It means that the perception of these technologies by the two targets is quite the same.

In conclusion, data collection is perceived in two different ways for three out of six technologies analysed. In particular, Additive Manufacturing and Advanced Human-Machine Interface are two of the less applied Smart Technologies in SMEs and, consequently, their benefit perception is probably distorted. On the opposite side, in terms of Cloud Manufacturing, it is likely that data collection is perceived in a more beneficial way by SMEs because of its easiness of application and adaptation to different situations and requirements.

Data Collection SMEs	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen							X
Andon							X
Poke Yoke							X
TPM (Total Production Maintenance)							X
Jidoka							X
Standardization							X
5S							X
Visual Management							X
Kanban							X
JIT (Just in Time)							X
Muda Reduction							X
VSM (Value Stream Mapping)							X
Heijunka							X
SMED							X
People and Teamwork							X

Table 39 - Distribution of answers for Data Collection in SMEs

Data Collection Other Companies	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen							X
Andon							X
Poke Yoke							X
TPM (Total Production Maintenance)							X
Jidoka							X
Standardization							X
5S							X
Visual Management							X
Kanban							X
JIT (Just in Time)							X
Muda Reduction							X
VSM (Value Stream Mapping)							X
Heijunka							X
SMED							X
People and Teamwork							X

Table 40 - Distribution of answers for Data Collection in other companies

Secondly, as regards decision making improvement (tables 41, 42), the main considerations are the following:

- Industrial Analytics presents more green and yellow spots for both the two targets.
- Conversely, IoT is characterized by a prevalence of red and yellow spots.
- Additive Manufacturing, Advanced Automation, Advanced Human-Machine Interface and Cloud Manufacturing present a prevalence of red spots for SMEs and, on the contrary, a prevalence of green ones for other companies.

Generally speaking, Industrial Analytics is perceived in a positive way by both the targets, probably because it is a fundamental passage for improvement in decision making processes. Conversely, the perception of IoT benefits appears to be quite unclear in terms of decision making. Moreover, all the other technologies are characterized by a general trend in which SMEs have declared lower values than other companies.

Decision Making SMEs	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen							X
Andon							X
Poke Yoke							X
TPM (Total Production Maintenance)							X
Jidoka							X
Standardization							X
5S							X
Visual Management							X
Kanban							X
JIT (Just in Time)							X
Muda Reduction							X
VSM (Value Stream Mapping)							X
Heijunka							X
SMED							X
People and Teamwork							X

Table 41 - Distribution of answers of Decision Making in SMEs

Decision Making Other Companies	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen							X
Andon							X
Poke Yoke							X
TPM (Total Production Maintenance)							X
Jidoka							X
Standardization							X
5S							X
Visual Management							X
Kanban							X
JIT (Just in Time)							X
Muda Reduction							X
VSM (Value Stream Mapping)							X
Heijunka							X
SMED							X
People and Teamwork							X

Table 42- Distribution of answers of Decision Making in other companies

Finally, as regards routine processes innovation (table 43,44), the main findings are:

- IoT presents a prevalence of red and yellow spots, indicating that both the two targets perceive it in a more negative way.
- Industrial Analytics and Advanced Automation, instead, are mainly characterized by yellow and green spots.
- Additive Manufacturing, Advanced Human-Machine Interface and Cloud Manufacturing appear to be perceived negatively by SMEs and positively by other companies.

In conclusion, routine processes innovation is perceived in a different way for each Smart Technology, as happens for the previous two benefits. In this case, IoT might be perceived in a negative way by the two targets because it is not something that is easy to be seen applied in a company due to its abstract nature. In fact, Process Innovation is something that is usually easy to be seen in a company when implemented. Moreover, Industrial Analytics and Advanced Automation are, contrary to IoT, two technologies that are quite used for Process Innovation procedures. Finally, the other technologies follow the usual trend common for the two targets in which SMEs perceive Smart Technologies in a worse way than other companies. This happens probably because it is easier to understand the benefit of something if it is applied in their own company rather than in clients' ones.

Process Innovation SMEs	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen							X
Andon							X
Poke Yoke							X
TPM (Total Production Maintenance)							X
Jidoka							X
Standardization							X
5S							X
Visual Management							X
Kanban							X
JIT (Just in Time)							X
Muda Reduction							X
VSM (Value Stream Mapping)							X
Heijunka							X
SMED							X
People and Teamwork							X

Table 43 - Distribution of answers of Process Innovation in SMEs

Process Innovation Other Companies	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen							X
Andon							X
Poke Yoke							X
TPM (Total Production Maintenance)							X
Jidoka							X
Standardization							X
5S							X
Visual Management							X
Kanban							X
JIT (Just in Time)							X
Muda Reduction							X
VSM (Value Stream Mapping)							X
Heijunka							X
SMED							X
People and Teamwork							X

Table 44 - Distribution of answers of Process Innovation in other companies

Finally, table 45 is meant to summarize SMEs perception of the three benefits and table 46 other companies' perception. Looking at the two tables, it is possible to draw some general considerations on the analysis performed in this section:

- Digital Twin/Simulation cannot be analysed and compared because of the limited number of intersections (only two) for Other Companies.
- IoT and Cloud Manufacturing are the only technologies associated with the same trend for the two targets, even if it is reversed. This means that the percentages of green, yellow and red spots are similar along the benefits, so – on average – the overall value for these technologies is close to the general Total Impact (i.e. 3.5). This might be the consequence of IoT and Cloud Manufacturing nature, as they are easily applicable to many different scenarios.
- Finally, the other four technologies might be divided in two groups:
    1. Advanced Automation and Industrial Analytics are characterized by a major presence of green and yellow spots, meaning that both the two targets perceive them as positive from all the benefits points of view.

2. Additive Manufacturing and Advanced Human-Machine Interface present a different distribution of green and red spots between the two targets. In particular, other companies are associated with only green spots, while the opposite happens for SMEs. The main justification of that might be the difficulty of these technologies' implementation in SMEs. In particular, their beneficial aspect appears not to be perceived so much by the SMEs using them, but only by the other companies that are offering to SMEs that specific technology implementation.

	SMEs						
	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/ Simulation
Data Collection Improvement							X
Decision-Making Improvement							X
Routine Processes Innovation							X

Table 45 - Distribution of answers in SMEs

	Others Companies						
	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/ Simulation
Data Collection Improvement							X
Decision-Making Improvement							X
Routine Processes Innovation							X

Table 46 - Distribution of answers in other companies

In conclusion, this analysis highlights the fact that the perception of the three benefits by the two targets is not the same for all the technologies. This suggests that, changing the perspective of the analysis, it is possible to obtain some revolutionary insights. Consequently, it is necessary to deepen into Lean 4.0 main benefits through different points of observation.

7. Conclusions

Innovation is the key to be competitive and successful in the market nowadays. Although the concept of innovation is often associated with products and services offered by companies, it is important to point out that the ability to innovate consolidated production and organizational processes sometimes represents the best way to turn up profits and customer service. While this concept appears to be quite well-understood and implemented in big companies, SMEs still struggle a bit in taking in the benefits associated with some innovations.

In this regard, it has been widely demonstrated that LEs have been renewing the way they conduct operations for many years. In particular, they have been able to integrate the most cutting-edge technologies available on the market – namely, Smart technologies – with the most well-functioning and consolidated production system ever invented, Lean Production. Among the several benefits they recognize from this integration, the most cited ones in literature seem to be data collection improvement, decision-making improvement, and innovation of routine processes.

As mentioned before, an extensive Literature Review revealed that SMEs tend to be quite neglected and underestimated when it comes to this kind of analysis. In fact, studying the integration between Lean Production and Industry 4.0 is much easier in big companies, as they tend to have standardized and consolidated processes, as well as financial resources necessary to adopt the latest technologies. Nevertheless, SMEs are fundamental for the economic growth of both developed and developing countries all over the world. For this reason, it is important to understand – practically speaking – which level of integration between Lean Production and Industry 4.0 characterizes them.

In light of this, the research carried out in this dissertation has been aimed at analyzing the practical integration of Lean Production practices and Industry 4.0 technologies in SMEs. More specifically, an empirical analysis has been performed to investigate the main benefits associated with this integration (i.e. data collection improvement, decision-making improvement and routine processes innovation). In other words, the whole study revolves around the validation process of the three hypotheses reported in section 4.4.3.

This final chapter aims at summarizing the findings that have brought to conclude the **hypotheses validation process** (section 7.1), the **limits** related to the analysis performed throughout this dissertation (section 7.2) and the **suggestions for future research** that might be useful to investigate this topic even more (section 7.3).

7.1 Hypotheses Validation

The Literature Review chapter (i.e. chapter 4) has concluded with the identification of a clear gap in literature, that has led to the formulation of the following three hypotheses:

HP 1: ***The integration between Industry 4.0 technologies and Lean Production practices positively affects SMEs in terms of improvements of the decision-making process.***

HP 2: ***The integration between Industry 4.0 technologies and Lean Production practices positively affects SMEs in terms of improvements of data collection process.***

HP 3: ***The integration between Industry 4.0 technologies and Lean Production practices positively affects SMEs in terms of innovation of routine processes.***

In turn, these hypotheses have guided the analysis throughout the whole dissertation. In fact, the entire process - from survey structuring to the last analysis performed - has been aimed at either confirming or rejecting them. In particular, data collected through the survey has been analyzed and interpreted in different ways, as reported in chapter 6. These critical analyses have allowed to look at the same data from different points of view, leading to many interesting insights:

- The first analysis has shown that SMEs seem to perceive the three benefits in the same way, even if the distribution of answers is quite different.
- The second one has demonstrated that Information Technologies are perceived as more beneficial than Operational ones. Additionally, considering the House of Lean, SMEs seem to perceive the benefits on foundations and concepts representing the pillars more than on other practices.
- The third analysis has proved that some relationships exist in the way SMEs adopt Industry 4.0 technologies and in the benefits that they perceive from them.
- The fourth analysis has highlighted the most relevant intersections between Lean Production practices and Industry 4.0 technologies and has demonstrated that not all the intersections are perceived in the same way.

- The last analysis has allowed to point out that the two targets of the survey – SMEs and companies working directly with them – present quite a different perception of the three benefits.

In light of all the findings and discussions associated with these analyses – which are based only on the answers to the survey – it is possible to conclude that the three research hypotheses are **confirmed**. In particular, considering the Benefit's Impact, it is possible to state that:

- HP1: the integration between Industry 4.0 technologies and Lean Production practices benefits SMEs in terms of data collection improvement to an extent that can be ranked as 3.5 out of 5.
- HP2: the integration between Industry 4.0 technologies and Lean Production practices benefits SMEs in terms of decision-making improvement to an extent that can be ranked as 3.4 out of 5.
- HP3: the integration between Industry 4.0 technologies and Lean Production practices benefits SMEs in terms of routine processes innovation to an extent that can be ranked as 3.5 out of 5.

Generally speaking, taking into consideration the general Total Impact among the three benefits, SMEs seem to recognize an improvement in data collection, decision making and an innovation of processes associated with the integration of Industry 4.0 and Lean Production to a certain extent, which can be ranked as 3.5 out of 5.

However, it is important to point out two considerations. First of all, it is worth noticing that the above-mentioned statements have been drawn on the only basis of the answers to the survey. In other words, they are based only on the opinions provided by the 75 respondent companies. In addition, the validation of the three hypotheses has been performed considering the overall framework and not the specific intersections. In fact, this detailed analysis is impossible to be conducted with the few amount of data collected. In support to this, the three hypotheses have been formulated considering a generic point of view on Lean 4.0 in SMEs.

7.2 Limits and Criticalities

Although this research seems to be the first that fills in the above-mentioned gap in literature, as any other research, it comes with some criticalities. In particular, the main **limits** associated with this dissertation are listed as follows:

First of all, the survey submission has allowed to collect 75 answers that, considering the typology of analysis conducted, represents a fair amount. Nevertheless, as shortly mentioned at the end of the previous section, it is not enough to draw conclusions that can be generalized. This is likely to be the reason why the considerations related to the analysis performed in section 6.2.5 appear to be quite weak. In fact, that analysis has been based on the division of the 75 respondent companies by the two targets, reducing even more the number of answers used to obtain the reported insights. At the same time, the low number of data probably has led to the fact that the characteristics investigated in the first section of the survey (see questions 1-12, appendix 2) resulted to be not relevant. In fact, initially the authors had tried to investigate if there was a relation between those characteristics and the benefits of Industry 4.0 and Lean Production integration, but this analysis had proved to be a failure. In light of this, it would be interesting to collect more answers. In this way, it would be possible to test the results of the analysis performed in section 6.2.5 which, at the current state, cannot be considered as completely reliable. At the same time, it would be possible to investigate once again the respondent companies' characteristics, trying to understand if this produces some interesting findings. For instance, the same analysis on the benefits might be performed by dividing companies on the basis of sectors they belong to. However, if this was not the case, it would be necessary to look for new characteristics and study how the answers are distributed according to them.

The second criticality lies in the fact that, unfortunately, there was no database able to filter on the application of Lean Production and Industry 4.0. For this reason, it has been necessary to choose the sample of population by looking at other criteria, such as the dimension, the level of innovation and so on. As a consequence, it is likely that many of the 1200 companies included in the sample of population were not appropriate at all, as they might not have implemented Lean Production and Industry 4.0. At the same time, it is equally likely that many useful companies have not been contacted. In light of this limit, the idea suggested in the previous point – i.e. collecting more answers – would be enhanced by the need of sending the survey to appropriate companies from the very beginning. In this way, the effort put in the answer collection would be definitely optimized.

7.3 Suggestions for Future Research

Starting from the results obtained in this dissertation, many **open points of discussion** and **suggestions for future research** might be investigated:

First of all, the same qualitative research might be performed in order to study different benefits, such as outcomes quality improvement or increased customer satisfaction. In fact, improvement in data collection, improvement in decision-making and innovation of routine processes have been investigated as they represent the most stressed benefits in literature. However, this does not mean that they are the only advantages SMEs can take from Lean Production and Industry 4.0 integration.

Secondly, the collected answers should be investigated to check if there have been similar companies who have declared different levels of benefit. If this was the case, it should be necessary to tackle them by case-studies, performing interviews to the correspondent companies. In this way, indeed, it would be possible to understand the reasons behind their answers.

This suggestion follows the lead of the previous one. In fact, it might be interesting to relate the respondent companies answers to the reasons why they provided those answers. In this case, the aim would be to understand which enabling and inhibiting factors, as well as critical success factors, stand behind SMEs' perception of Lean 4.0 benefits. In particular, these features have been extensively shown in section 4.4 of Literature Review.

Furthermore, it would be interesting to address the same benefits investigated in this dissertation – i.e. data collection improvement, decision-making improvement and routine process innovation – following a quantitative approach. In this way, it would be possible to analyze the effects of Lean 4.0 benefits on the final corporate goals, such as profit increase or productivity growth.

Finally, after collecting more answers, it would be interesting to enhance the analysis conducted in section 6.2.4 by studying in a detailed way each specific intersection. In this way, it would be possible to investigate the benefits that specific combinations between Lean Production practices and Industry 4.0 technologies bring to SMEs. In this dissertation, indeed, the aim has been to analyze the benefits associated with Lean 4.0 as a whole. Consequently, the intersections have been used just as means to draw general conclusions, but their single contributions have been neglected.

References

Advance Civilization. (2011, April). *Advance Automation*. Tratto da adciv.org: http://adciv.org/Advanced_automation

Al-Hyari, K., Zaid, M., Arabiyyat, O., Al-Qwasmeh, L., & Haffar, M. (2019). The applications of Kaizen methods in project settings: applied study in Jordan. *The TQM Journal, Vol. 31, N°5,* 831-849.

Alkhoraifa, A., Rashidb, H., & McLaughlina, P. (2019). Lean implementation in small and medium enterprises: Literature review. *Operations Research Perspectives*.

Al-Tarawneh, H. (2012). The Main Factors beyond Decision Making. *Journal of Management Research*.

Alves, G., Roßmann, J., & Wischnewski, R. (2009). A Discrete-Event-Simulation Approach for Logistic Systems with Real Time Resource Routing and VR Integration. *International Journal of Computer and Information Engineering 3* , 821–826.

Antony, J. (2008). Reflective Practice: Can Six Sigma Be Effectively Implemented in SMEs? *International Journal of Productivity and Performance Management, Vol. 57 (5)* , 420–423.

Ates, A. P., Garengo, P., Cocca, P., & Bititci, U. (2013). The Development of SME Managerial Practice for Effective Performance Management. *Journal of Small Business and Enterprise Development, Vol. 20 (1),* 28–54.

Aytug, H., Bhattacharyya, S., Koehler, G., & Snowdon, J. (1994). A review of machine learning in scheduling. *IEEE Transactions on Engineering Management, Vol. 41 No. 2,* 165-171.

Azambuja, M. T. (2013). Enabling lean supply with a cloud computing platform - An exploratory case study. *21st Annual Conference of the International Group for Lean Construction*, 815-824.

Barenji, A. V., Barenji, R. V., Roudi, D., & Hashemipour, M. (2016). A Dynamic Multi-Agent-Based Scheduling Approach for SMEs. *The International Journal of Advanced Manufacturing Technology, Vol. 89* , 3123–3137.

Bauters, K., Cottyn, J., Claeys, D., Slembrouck, M., Veelaert, P., & Landeghem, H. v. (2018). Automated work cycle classification and performance measurement for manual work stations. *Robot. Comput. Integr. Manuf., vol. 51,*, 139–157.

Bayo-Moriones, A., Billón, M., & Lera-López, F. (2013). Perceived Performance Effects of ICT in Manufacturing SMEs. *Industrial Management & Data Systems, Vol. 113* , 117–135.

Belhadi, A., Touriki, F., & El Fezazi, S. (2016). A framework for effective implementation of lean production in small and medium-sized enterprises. *Journal of Industrial Engineering and Management, Vol. 9 (3)* , 786-810.

Bevilacqua, M., Ciarapica, F., Ettorre, N., Mazzuto, G., & Paciarotti, C. (2014). Total quality control through value stream mapping: a case study of small medium enterprises. *International Journal of Integrated Supply Management*, 94.

Bhamu, J., & Sangwan, K. (2014). Lean manufacturing: literature review and research issues. *International Journal of Operations and Production Management, Vol. 34 (7),* 876-940.

Bhasin, S. (2012). Prominent obstacles to lean Management. *International Journal of Productivity and Performance, Vol. 61 (4)* , 403-425.

Bicheno, J., & Holweg, M. (2016). The Lean Toolbox: a handbook for lean transformation . *Production and Inventory Control, Systems and Industrial Engineering Books (5th edition).*

Bonfanti, A., Del Giudice, M., & Papa, A. (2015). Italian Craft Firms Between Digital Manufacturing, Open Innovation, and Servitization. *Journal of the Knowledge Economy* , 1–14.

Boudella, M. E., Sahin, E., & Dallery, Y. (2018). itting Optimisation in Just-in-Time Mixed-Model Assembly Lines: AssigningParts to Pickers in a Hybrid Robot–Operator Kitting System. *International Journal of Production Research*, 5475–5494.

Bowersox, D., Closs, D., Stank, T., & Keller, S. (2000). How Supply Chain Competency Leads to Business Success. *Supply Chain Management Review, Vol. 4 (4)*, 70-78.

Brown, K. A., & Mitchell, T. R. (1991). A comparison of just-in-time and batch manufacturing: the role of performance obstacles . *Academy of Management Journal, Vol. 34 (4)*, 906-917.

Buer, S.-V., Strandhager, J. O., & Chan, F. T. (2018). The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda. *International Journal of Production Research*, 2924-2940.

Chaple, A., Narkhede, B., Akarte, M., & Raut, R. (2018). Modeling the lean barriers for successful lean implementation: TISM approach. *International Journal of Lean Six Sigma*.

Chaplin, L., Heap, J., & O'Rourke, S. T. (2016). Could 'Lean Lite' be the Cost Effective Solution to Applying Lean Manufacturing in Developing Economies? *International Journal of Productivity and Performance Management, Vol. 65 (1)*, 126–136.

Colotla, I., Bland, D., & Knizek, C. (2018). *Avoiding the Hidden Hazards of Industry 4.0*. Tratto da Boston Consulting Group: https://www.bcg.com/it-it/publications/2018/avoiding-hidden-hazards-industry-4.0

Conti, M., & Orcioni, S. (2019). Cloud-based sustainable management of electrical and electronic equipment from production to end-of-life. *International Journal of Quality and Reliability Management, Vol. 36 No. 1*, 98-119.

Coolfire. (2019, April). *What is the difference between IT and OT?* Tratto da Coolfire: https://www.coolfiresolutions.com/blog/difference-between-it-ot/#:~:text=In%20short%2C%20IT%20deals%20with,used%20to%20carry%20them%20out.

Cristalli, C., Foehr, M., Jäger, T., Leitao, P., Paone, N., Castellini, P., . . . Schjolberg, I. (2013). Integration of Process and Quality Control Using Multi-Agent Technology. *IEEE International Symposium on Industrial Electronics*, 1-6.

Dallasega, P., Rojas, R. A., Rauch, E., & Matt, D. T. (2017). Simulation Based Validation of Supply Chain Effects through ICT enabled Real-time-capability in ETO Production Planning. *Procedia Manuf., vol. 11*, 846–853.

Darcy, C., Hill, J., McCabe, T. J., & McGovern, P. (2014). A consideration of Organisational Sustainability in the SME Context. *European Journal of Training and Development, Vol. 38 (5)*, 398–414.

Davies, R., Coole, T., & Smith, A. (2017). Review of Socio-Technical Considerations to Ensure Successful Implementation of Industry4.0. *Procedia Manufacturing*, 1288–1295 .

De Giovanni, P., & Cariola, A. (2020). Process innovation through industry 4.0 technologies, lean practices and green supply chains. *Research in Transportation Economics*.

Denkena, B., Dengler, B., Doreth, K., Krull, C., & Horton, G. (2014). Interpretation and Optimization of Material Flow Via System Behavior Reconstruction. *Production Engineering, Vol. 8*, 659–668.

Deros, B. (2014). Critical success factors for implementing lean manufacturing in Malaysian automotive industry. *Research Journal of Applied Sciences, Engineering and Technology, Vol. 8 (10)*, 1191–1200.

DeSanctis, I., Ordieres, M., Bevilacqua, M., & Ciarapica, F. (2018). The moderating effects of of corporate and national factors on lean projects barriers: a cross-national study. *Production Planning and Control, Vol. 29 (12)*, 972–291.

Diab, W. W., Harper, K. E., Lin, S.-W., & Sobel, W. (2017). Industrial Analytics: The Engine Driving the IIoT Revolution. *Industrial internel - Consortium*, 19.

Ding, K., & Jiang, P. (2017). RFID-based production data analysis in an IoT-enabled smart job-shop. *IEEE/CAA Journal of Automatica Sinica*, 1-11.

Dombrowski, U., Crespo, I., & Zahn, T. (2010). Adaptive configuration of a lean production system in small and medium-sized enterprises. *Production Engineering, Vol. 4 (4)*, 341-348.

Dombrowskia, U., Wullbrandta, J., & Fochler, S. (2019). Center of Excellence for Lean Enterprise 4.0. *Procedia Manufacturing 31*, 66-71.

Dora, M., Kumar, M., & Gellynck, X. (2015). Determinants and barriers of lean implementation in food-processing SMEs – a multiple case analysis. *Production Planning and Control, Vol. 27 (1)*, 1-23.

Downs, R. (2005). Using resistive touch screens for human/machine interface. *Analog Applications Journal*, 5-10.

Driouach, L., Zarbane, K., & Beidouri, Z. (2019). Literature Review od Lean Manufacturing in Small and Medium Enterprises. *International Journal of Technology, Vol. 10 (5)*, 930-941.

Dudek-Burlikowska, M., & Szewieczek, D. (2009). The Poka-Yoke method as an improving quality tool of operations in the process. *Journal of Achivements in Materials and Manufacturing Engineering, Vol. 36 (1)*, 95-102.

Durakbasa, M. N., J. M. Bauer, L. K., & Bas, a. G. (2016). Novel developments in adavanced manufacturing and Multi Functional Intelligent Factories (MFIF) towards production in the future - Challenges of autonomation in industry 4.0.

Eleftheriadis, R. J., & Myklebust, a. O. (2016). A Guideline of Quality Steps towards Zero Defect Manufacturing in Industry. *Proceedingsof the International Conference on Industrial Engineering and Operations Management*, 332–340.

Elwood S.A. (2008). *Encyclopedia of Information Technology Curriculum Integration.* Texas A&M University - Corpus Christi, USA: Publishing house Lawrence A. Tomei.

European Commission. (2020). *Structural Business Statistics and Global Business Activities*. Tratto da https://ec.europa.eu/eurostat/web/structural-business-statistics/structural-business-statistics/sme#:~:text=SMEs%20are%20defined%20by%20the,Recommendation%20of%206%20May%202003).

Feldmann, C., & Gorj, A. (2017). 3D-Druck und Lean Production: Schlanke Produktionssyst eme mit additiver Ferti gung. *Springer Fachmedien*.

Ferro, R., Ordóñez, R. E., & Anholon, R. (2017). Analysis of the integration between operations management manufacturing tools with discrete event simulation. *Prod. Eng., vol. 11, no. 4–5*, 467–476.

Fescioglu-Unver, N., Choi, S., Sheen, D., & Kumara, S. (2015). RFID in production and service systems: Technology, applications and issues. *Information Systems Frontiers, vol. 17, no. 6*, 1369–1380.

Feteke, M., & Hulvej, J. (2013). “Humanizing” Takt Time and Productivity in the Labor-intensive Manufacturing System . *Active Citizenship by Knowledge, Management & Innovation, Zadar, International Conference 2013*, 191-199.

Floyd, D., & McManus, J. (2005). The role of SMEs in improving the competitive position of the European Union. *European Business Review, Vol. 17 (2)*, 144–150.

Foidl, H., & Felderer, M. (2015). Research challenges of Industry 4.0 for quality management. *International Conference on Enterprise Resource Planning Systems, Springer, Cham*, 121-137.

Fornasiero, R., & Zangiacomi, A. (2013). A Structured Approach for Customised Production in SME Collaborative Networks. *International Journal of Production Research, Vol. 51*, 2110–2122.

Ghobadian, A., & Gallear, D. (1996). Total quality management in SMEs. *Omega, Vol. 24 (1)*, 83-106.

Ghobakhloo, M., & Fathi, M. (2020). Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing. *Journal of Manufacturing Technology Management*, 1-30.

Ginevičius, R., & Ostapenko, A. (2015). A quantitative evaluation of the company environment for the formation of its effective expansion strategy. *Intelektine Ekonomika, Vol. 9 (2)*.

Gnanaraj, S. M., Devadasan, S. R., Murugesh, R., & Sreenivasa, C. G. (2012). Sensitisation of SMEs towards the Implementation of Lean Six Sigma – An Initialisation in a Cylinder Frames Manufacturing Indian SME. *Production Planning & Control, Vol. 23 (8)*, 599–608.

Gnanaraj, S., Devadasan, S., Murugesh, R., & Shalij, P. (2010). DOLADMAICS: a model for implementing Lean Six Sigma in contemporary SMEs. *International Journal of Services and Operation Management, Vol. 7 (4)*, 440.

Grube Hansen, D., Malik, A. A., & Bilberg, A. (2017). Generic Challenges And Automation Solutions In Manufacturing Smes. *Proceedings of the 28th DAAAM International Symposium*, (p. 1161-1169).

Gurumurthy, A., & Kodali, R. (2011). Design of lean manufacturing systems using value stream mapping with simulation: A case study . *Journal of Manufacturing Technology Management, Vol. 22 (4)*, 444-473.

Haddud, & Khare. (2020). Digitalizing supply chains potential benefits and impact on lean operation. *International Journal of Lean SixSigma*.

Haghirian, P. (2010). *Understanding Japanese Management Practices.* New York: Business Expert Press.

Harald Bauer, F. B. (2019). Integration of Industrie 4.0 in Lean Manufacturing Learning Factories . *Science Direct*, 147-152.

Harvey, M., Speier, C., & Novecevic, M. (2001). A theory-based framework for strategic global human resource staffing policies and practices. *International Journal Human Resource Management, Vol. 12 (6)*, 898-915.

Hoellthalera, G., Braunreuthera, S., & Reinharta, G. (2018). Digital lean production – An approach to identify potentials for the migration to a digitalized production system in SMEs from a lean perspective. *11th CIRP Conference on Intelligent Computation in Manufacturing Engineering, Vol. 67* , p. 522 – 527.

Hu, Q., Mason, R., Williams, S., & Found, P. (2015). Lean implementation within SMEs: a literature review. *Journal of Manufacturing Technology Management, Vol. 26 (7)*, 980-1012.

Hudson-Smith, M., & Smith, D. (2007). Implementing Strategically Aligned Performance Measurement in Small Firms. *International Journal of Production Economics, Vol. 106 (2)*, 393–408.

Hüttmeir, A., De Treville, S., Van Ackere, A., & Prenninger, J. (2009). Trading off between heijunka and just-in-sequence. *International Journal of Production Economics, Vol. 118 (2)*, 501–507.

Imai, M. (1986). *Kaizen: The Key's to Japan's Success.* New York: McGraw-Hill.

Inductive Automation. (2018, August). *What is HMI?* Tratto da Inductive Automation: https://www.inductiveautomation.com/resources/article/what-is-hmi#:~:text=HMI%20Defined,context%20of%20an%20industrial%20process.

J. Pfeffer et al. (2015). Towards collaborative plant control using a distributed information and interaction space. *IEEE International Conference on Emerging Technologies and Factory Automation ETFA.*

Jayaram, A. (2016). Lean six sigma approach for global supply chain management using industry 4.0 and IIoT. *Proceedings of the 2016 2nd International Conference on Contemporary Computing and Informatics*, 89-94.

Kamar, A. N., & Kie, C. J. (2018). Using Discrete Event Simulation to Evaluate the Performance of Lean Manufacturing Implementation: A Case Study of an Electronic Manufacturer Company. *International Conference on Industrial Engineering and Operations Management*, 426.

Karkoszka, T., & Honorowicz, J. (2009). Kaizen philosophy a manner of continuous. *Journal of Achievements in Materials and Manufacturing Engineerings - Vol. 5*.

Karlsson, C., & Åhlström, P. (1997). A lean and global smaller firm? *International Journal of Operations & Production Management, Vol. 17 (10)*, 940-952.

Kieviet, A. (2016). Digitalisierung der Wertschöpfung: Auswirkung auf das Lean Management. *Erfolgsfaktor Lean Management 2.0: Wettbewerbsfähige Verschlankung auf nachhaltige und kundenorientierte Weise, H. Künzel, Ed. Berlin/Heidelberg, Germany*, 41-59.

Kilpatrick, J. (2003). Lean Principles . *Utah Manufacturing*, 1–5.

Knol, W., Slomp, J., Schoutetena, R., & Lauchea, K. (2018). Implementing lean practices in manufacturing SMEs: testing 'critical success factors' using Necessary Condition Analysis. *International Journal of Production Research, Vol. 56 (11)*, 3955-3973.

Koch, C., Neges, M., Koenig, M., & Abramovici, M. (2014). Performance Study on Natural Marker Detection for Augmented Reality Supported Facility Maintenance. *Australasian Journal of Construction Economics and Buil ding - Conference Series, vol. 2, no. 1*, 23-34.

Kolberg, D., & Zühlke, D. (2015). Lean Automation Enabled by Industry 4.0 Technologies. *IFAC-PapersOnLine48 (3)*, 1870–1875.

Kolberg, D., Knobloch, J., & Zühlke, a. D. (2017). Towards a lean automation interface for workstations. *Int. J. Prod. Res., vol. 55, no. 10*, 2845–2856.

Kolla, S., Minufekr, M., & Plapper, P. (2019). Deriving essential components of leand and industry 4.0 assessment model for manufacturing SMEs. *52nd CIRP Conference on Manufacturing Systems*, (p. 753-758).

Kolosar, L. (2018). Opportunities Of Lean Thinking In Improving The Competitiveness Of The Hungarian Sme Sector. *Management and Production Engineering Review, Vol. 9 (2)* , 26–41.

Krafcik, J. F. (1988). Triumph of the Lean Production System. *MIT Sloan Management Review, Vol. 30 (1)*, 41-52.

Kumar, C. S., & Panneerselvam, R. (2007). Literature review of JIT – KANBAN system. *International Journal of Advanced Manufacturing Technology*.

Kumar, P., Maiti, J., & Gunasekaran, A. (2018). Impact of quality management systems on firm performance. *International Journal of Quality and Reliability Management, Vol. 35 No. 5*, 1034-1059.

L. Kassner et al. (2017). The stuttgart IT architecture for manufacturing an architecture for the data-driven factory. *Lect. Notes Bus. Inf. Process., vol. 291*, 53–80.

Lacour, F. (2012). Modellbildung für die physikbasierte Virtuelle Inbetriebnahme materialflussintensi ver Produktionsanlagen. *Herbert Utz Verlag*.

Laufs, K., Bembom, M., & Schwens, C. (2016). CEO Characteristics and SME Foreign Market Entry Mode Choice. *Interation Marketing Review, Vol. 33 (2)*, 246–275.

Lean, B. (1996). *Liker J. K.;*. New York: Free Press.

Lettau, U. (2013). Condition Monitoring für die Akustikprüfung. *Fertigungs- und Maschinenautomation, vol. 5*.

Liker, J. K. (1996). *Becoming Lean.* New York: Free Press.

Liker, J. K. (2004). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer.* New York: McGraw-Hill.

Liker, J. K., & Meier, D. (2006). *The Toyota Way Fieldbook: A Practical Guide for Implementing Toyota's 4Ps.* New York: McGraw-Hill.

Longo, F., Nicoletti, L., & Padovano, A. (2017). Smart Operators in Industry 4.0: A Human-Centered Approach to Enhance Operators'Capabilities and Competencies Within the New Smart Factory Context. *Computers and Industrial Engineering 113*, 144-159.

Lovelle, J. (2001). Mapping the value stream. *Institute of Industrial Engineers Solutions, Vol. 33 (2)*, 26-33.

Lu, S., & Yue, H. (2011). Real-time data driven visual simulation of process manufacturing: A case study. *Chinese Control and Decision Conference*, 1806–1809.

Lugert, A., Völker, K., & Winkler, H. (2018). Dynamization of Value Stream Management by technical and managerial approach. *Procedia CIRP vol.72*, 701–706.

Lutz, M., Verbeek, C., & Schlegel, a. C. (2016). Towards a robot fleet for intra-logistic tasks: Combining freerobot navigation with multi-robot coordination at bottlenecks,. *IEEE International Conference on Emerging Technologies and Factory Automation, ETFA.*

M. F. Abreu et al. (2017). Collaborative Process Mapping to Improve Work Instructions and Standardized Work. *Adv. Intell. Syst. Comput., vol. 569*, 257-266.

Ma, J., Wang, Q., & Zhao, Z. (2017). SLAE–CPS: Smart Lean Automation Engine Enabled by Cyber-Physical Systems Technologies. *Sensors 17* , 1-22.

Macchi, M. (2017, March). *Lean manufacturing, tutti i progressi possibili grazie a Industria 4.0*. Tratto da Agenda Digitale : https://www.agendadigitale.eu/industry-4-0/macchi-miragliotta-terzi-portioli-industria-4-0-e-lean-manufacturing-paradigmi-in-antitesi-o-sinergici/

MacKerron, G., Kumar, M., Kumar, V., & Esain, A. (2014). Supplier Replenishment Policy Using E-Kanban: A Framework for Successful Implementation. *Production Planning & Control, Vol. 25*, 161–175.

Maguire, K. (2017). Lean and IT - working together? An Exploratory Study of the Potential Conflicts Between Lean Thinking and the use of Information Technology in Organizations Today. In K. Maguire, *Understanding the Lean Enterprises* (p. 31-60). Springer.

Marks, M. A., Sabella, M. J., Burke, C. S., & Zaccaro, S. J. (2002). The Impact of Cross- Training on Team Effectiveness . *Journal of Applied Psychology, Vol. 87 (1)*, 3-13.

Marodin, G., & Saurin, T. (2015). Managing barriers to lean production implementation: context matters. *International Journal of Production Research, Vol. 53 (13)*, 3947-3962.

Masoni, R., Ferrise, F., Bordegoni, M., Gattullo, M., Uva, A., Fiorentino, M., & Di Donato, M. (2017). Supporting remote maintenance in Industry 4.0 through augmented reality. *Procedia Manufacturing, Vol. 11*, 1296-1302.

Mayr, A., Weigelt, M., Kuhl, A., Grimm, S., Erll, A., Potze, M., & a. J. (2018). Lean 4.0 - A Conceptual Conjunctionof Lean Management and Industry 4.0. *51st CIRP Conference on Manufacturing Systems, Procedia CIRP72*, 622–628.

Mazany, P. (1995). A case study. *International Journal of Operations and Production Management, Vol. 15 (9)*, 271–288.

McAdam, R., & Reid, R. (2001). SME and Large Organization Perceptions of Knowlegde Management: comparisons and contrasts. *Journal of Knowledge Management, Vol. 5 (3)*, 231-241.

Melnyk, B. M., & Fineout-Overhold, E. (2003). Evidence-based practice in nursing and healthcare: A guide to best practice. *Lippincott Williams & Wilkins*.

Michalska, J., & Szewieczek, D. (2007). The 5S methodology as a tool for improving the organisation. *Journal of Achievements in Materials and Manufacturing Engineering, Vol. 24 (2)*, 211-214.

Michels, J. (2016). Praxisbeispiel: Intelligente Feldgeräte und selbstkorrigierende Fertigung. *Industrie 4.0 im internationalen Kontext*, 162-166.

Miragliotta, G., Sianesi, A., Convertini, E., & Distante, R. (2018). Data driven management in Industry 4.0: a method to measure Data Productivity. *Science Direct* , 19-24.

Mittala, S., Khan, M., Romero, D., & Wuest, T. (2018). A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). *Journal of Manufacturing Systems, Vol. 49*, 194-214.

Moeuf, A., Lamouri, S., Pellerin, R., Tamayo, S., Valencia, E., & Eburdy, R. (2020). Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. *International Journal of Production Research, Vol. 58 (5)*, 1384-1400.

Moeuf, A., Pellerin, R., Lamouri, S., Tamayo, S., & Barbaray, R. (2018). The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research, Vol. 56 (3)* , 1118–1136.

Monden, Y. (1983). Toyota Production System: Practical Approach to Management. *Norcross, Industrial Engineering and Management Press*.

Monden, Y. (1993). Toyota Production System: An Integrated Approach to Just-In-Time. *Norcross, Industrial Engineering and Management Press, Institute of Industrial Engineers (2nd Edition)*.

Mrugalska, B., & Wyrwicka, M. K. (2017). Towards Lean Production in Industry 4.0. *Procedia Engineering, vol. 182*, 466–473.

Myerson, P. (2012). *Lean Supply Chain and Logistics Management.* New York: McGraw- Hill Professional.

N., S., & Milenovic, D. (2018). Data-driven Digital Twin Approach for Process Optimization: An Industry Use Case. *IEEE International Conference on Big Data*, 4202–4211.

Nåfors, D., Bärring, M., Estienne, M., Johansson, B., & Wahlström, a. M. (2018). Supporting Discrete Event Simulation with 3D Laser Scanning and Value Stream Mapping: Benefits and Drawbacks. *Procedia CIRP*, 1536–1541.

Negahban, A., & Smith, J. (2014). Simulation for manufacturing system design and operation: Literature review and analysis. *Journal of Manufacturing Systems*, 241-261.

Neges, M., Koch, C., Koenig, M., & Abramovici, M. (2017). Combining visual natural markers and IMU for improved AR based indoor navigation. *Advanced Engineering Informatics, vol. 31*, 18–31.

Nwaiwu, F., Duduci, M., Chromjakova, F., & Otekhile, C. F. (2020). Industry 4.0 Concepts Within The Czech Sme Manufacturing Sector: An Empirical Assessment Of Critical Success Factors. *Business: Theory and Practice, Vol. 21 (1)* , 58–70.

O'Reilly, S., Kumar, A., & Adam, F. (2015). The Role of Hierarchical Production Planning in Food Manufacturing SMEs. *International Journal of Operations & Production Management, Vol. 35 (10)*, 1362–1385.

Ogu, E. C., Benita, A., & Uduakobong, E.-E. (2018). Cognisant computing and 'lean' practices: Interactions with 21st century businesses and implications. *Int. J. Bus. Inf. Syst., vol. 27, no. 2*, 264–275.

Ohno T. (1973). *The "Bible" of the Toyota Production System.* Manuscript by Taiichi Ohno.

Osservatori Digital Innovation. (2018). *PMI e Industria 4.0.* Politecnico di Milano.

Osservatori Digital Innovation. (2020). *Guida alle PMI - Piccole e Medie Imprese*. Tratto da https://blog.osservatori.net/pmi-significato-numeri-innovazione#:~:text=La%20Commissione%20Europea%20definisce%20infatti,i%2043%20milioni%20di%20euro.

Palmarini, R., Erkoyuncu, J., Roy, R., & Torabmostaedi, H. (2018). A systematic review of augmented reality applications in maintenance. *Robotics and Computer-Integrated Manufacturing, vol. 49*, 215–228.

Panizzolo, R., Garengo, P., Sharma, M., & Gore, A. (2012). Lean manufacturing in developing countries: evidence from Indian SMEs. *Production Planning and Control, Vol. 23 (10–11)*, 769–88.

Parry, G. C., & Turner, C. E. (2006). Application of lean visual process management tools. *Production Planning & Control, Vol. 17 (1)*, 77-86.

Pascal, D. (2002). *Lean Production Simplified: A Plain Language Guide to the World's most Powerful Production System.* New York: Productivity Press.

Pautsch, P. G. (2014). Praxisbu ch Lean Management: Der Weg zur operativen Excellence. *2nd ed. München, Germany: Hanser*.

Pearcea, A., Pons, D., & Neitzert, T. (2018). Implementing lean - Outcomes from SME case studies. *Operations Research Perspectives*, 94-104.

Pereira, A. C., Dinis-Carvalho, J., Alves, A. C., & Arezes, P. (2019). How Industry 4.0 Can Enhance Lean Practices . *Scopus*.

Pettersen, J. (2009). Defining lean production: some conceptual and practical issues. *The QTM Journal, Vol. 21(2)*, 127-142.

Pinho, J. C. (2007). The Impact of Ownership. *International Marketing Review, Vol. 24 (6)* , 715–734.

Polit, D. F., & Beck, C. T. (2004). Nursing research: Appraising evidence for nursing practice. *7th Edition*.

Politecnico di Milano. (2016, Gennaio 19). *Industria 4.0, le 6 tecnologie abilitanti secondo il Politecnico di Milano*. Tratto da Network Digital 360: https://www.digital4.biz/supply-chain/industria-40-politecnico-milano-sei-tecnologie-abilitanti/

Politecnico di Milano. (2017). Report Osservatorio. *Osservatorio Industria 4.0*.

Politecnico di Milano School of Management. (2018). PMI e Industria 4.0. *Osservatorio Digitale 4.0*, 55.

Poppendieck, M. (2002). Principles of Lean Thinking. *In OOPSLA Onward!*

Porter, M. E., & Heppelmann, J. E. (2014). How Smart, Connected Products Are Transforming Competition. *Harvard Business Review*, 64-88.

Pötters, P., Kloeckner, I., & Leyendecke, B. (2017). Gamification in der Montage. *ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, vol. 112, no. 3*, 163–167.

Prinza, C., Kreggenfelda, N., & Kuhlenkötter, B. (2018). Lean meets Industrie 4.0 – a practical approach to interlink the method world and cyber-physical world. *Advanced Engineering Education & Training for Manufacturing Innovation* , 21-26.

Raghunathan, V. (2019, May 13). *Digital Twins vs Simulation: Three Key Differences*. Tratto da Enterpreneur.com: https://www.entrepreneur.com/article/333645#:~:text=Simulations%20are%20typically%20used%20for,garage%20for%20a%20regular%20service.

Rammelmeier, T., Galka, S., & Günther, W. (2017). Fehlervermeidung in der Kommissionierung. *Logistics Journal Proceedings*, 1-8.

Ranke, D., Aichele, A., Görzig, D., Luckert, M., Siegert, J., & Bauernhansl, T. (2020). Analysis of SMEs as a target group for research institute services. *International Conference on Industry 4.0 and Smart Manufacturing, Vol. 42*, 356–361.

Rauch, E., Dallasega, P., & Matt, D. T. (2016). The Way from Lean Product Development (LPD) to Smart Product Development (SPD). *Procedia {CIRP}, vol.50*, 26–31.

Raucha, E., Dallasega, P., & Matt, D. (2017). Critical Factors for Introducing Lean Product Development to Small and Medium sized Enterprises in Italy. *27th CIRP Design, Vol. 60,* p. 362 – 367.

Ren, L., Zhang, L., Tao, F., Zhao, C., Chai, X., & Zhao, X. (2015). Cloud Manufacturing: From Concept to Practice. *Enterprise Information Systems , Vol. 9*, 186–209.

Rosin, F., Forget, P., Lamouri, S., & Pellerin, R. (2020). Impacts of Industry 4.0 technologies on Leanprinciples. *International Journal of Production Research*, 1644-1661.

Rossini, M., Costa, F., Portioli Staudacher, A., & Tortorella, G. (2019). Industry 4.0 and Lean Production: an empirical study. *Science Direct*, 42-47.

Rother, M., & Shook, J. (2003). *Learning to See: Value-Stream Mapping to Create Value and Eliminate Muda.* Cambridge: The Lean Enterprise Institute.

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, a. M. (2015). ndustry 4.0: The Future of Productivity and Growth in manufacturing industries. *Boston Consulting Group*.

Ruttimann, 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*, 485.

Rymaszewska, A. (2014). The challenges of lean manufacturing implementation in SMEs. *Benchmarking: An International Journal, Vol. 21 (6)*, 987-1002.

S. Benbelkacem et al. (2011). Augmented Reality Platform for Collaborative E-Maintenance Systems. *Augmented Reality - So me Emerging Application Areas, A. Y. C. Nee, Ed. London, UK: InTech*.

Saez, M., Maturana, F. P., Barton, K., & Tilbury, D. M. (2018). Real-Time Manufacturing Machine and System Performance Monitoring Using Internet of Things. *IEEE Transactions on Automation Science and Engineering 15* , 1735–1748.

Sagi, S. G. (2015). "Ringi System" The Decision Making Process in Japanese Management Systems: An Overview. *International Journal of Management and Humanities, Vol. 1 (7)*, 10-11.

Salaheldin, S. (2005). JIT implementation in Egyptian manufacturing firms: some empirical evidence. *International Journal of Operations and Production Management, Vol. 25 (4)*, 354-370.

Sanders, A., Elangeswaran, C., & Wulfsberg, J. (2016). Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing. *Journal Industrial Engineering Management*.

Sanders, A., Subramanian, K., Redlich, T., & Wulfsberg, J. (2017). Industry 4.0 and Lean Management–Synergy or Contradiction? In A. Sanders, K. Subramanian, T. Redlich, & J. Wulfsberg, *IFIP International Conference on Advances in Production Management Systems* (p. 341-349). Springer.

Saraph, J. V., Benson, P., & Schroeder, R. (1989). An Instrument for Measuring the Critical Factors of Quality Management. *Decision Sciences, Vol. 20 (4)*, 810–829.

Scherrer-Rathje, M., Todd, A., & Patricia, D. (2009). Lean, take two! Reflections from the second attempt at lean implementation. *Business Horizons, Vol. 52 (1)*, 79-88.

Schmitt, P., Schmitt, J., & Engelmann, B. (2019). Evaluation of proceedings for SMEs to conduct I4.0 projects. *7th CIRP Global Web Conference: "Towards shifted production value stream patterns through inference of data, models, and technology"*, (p. 257–263).

School of Management Politecnico di Milano. (2019). *Internet of Things*. Tratto da osservatori.net - digital innovation: https://blog.osservatori.net/it_it/cos-e-internet-of-things#iot-significato

Shingo, S. (1989). *A Study of the Toyota Production System: From an Industrial Engineering Viewpoint.* New York: Productivity Press.

Silva et al., F. (2018). Cloud computing environments for simulation of adaptable standardized work and electronic work instructions in industry 4.0. *16th International Industrial Simulation Conference*, 49-53.

Singh, B., Garg, S. K., & Sharma, S. K. (2010). Development of Index for Measuring Leanness: Study of an Indian Auto Component Industry. *Measuring Business Excellence, Vol. 14 (2)*, 46–53.

Sony, M. (2018). Industry 4.0 and Lean Management: A Proposed Integration Model and Research Propositions. *Production & Manufacturing Research 6*, 416–432.

Sperman, M. L., & Zazanis, M. (1992). Push and pull production systems: issues and comparisons. *Operations Research, Vol. 40 (3)*, 521-532.

Stojanovic, N., Dinic, M., & Stojanovic, L. (2015). Big Data Process Analytics for Continuous Process Improvement in Manufacturing. *IEEE International Conference on Big Data*, 1398–1407.

T. Meudt et al. (2016). Value stream mapping 4.0: Holistic examination of value stream and information logistics in production. *Zeitschrift fuer Wirtschaftlichen Fabrikbetr vol.111*, 319–323.

T., C., & Lin Y., -C. (2017). asibility Evaluation and Optimization of a Smart Manufacturing System Based on 3D Printing: A Review," . *Int. J. Intell. Syst., vol. 32, no. 4,*, 394-413.

Tam, S., & Gray, D. (2016). The Practice of Employee Learning in SME Workplaces. *Journal of Small Business and Enterprise Development, Vol. 23 (3)*, 671–690.

Tamás, P., Illés, B., & Dobos, P. (2016). Waste reduction possibilities for manufacturing systems in the. *20th Innovative Manufacturing Engineering and Energy Conference.*

Tao, F., Cheng, J., Cheng, Y., Gu, S., Zheng, T., & Yang, H. (2017). SDMSim: A Manufacturing Service Supply Demand Matching Simula-tor Under Cloud Environment. *Robotics and Computer-Integrated Manufacturing 45*, 34-46.

Towers, N., & Burnes, B. (2008). A Composite Framework of Supply Chain Management and Enterprise Planning for Small and Medium-Sized Manufacturing Enterprises. *Supply Chain Management: An International Journal, Vol. 13 (5)*, 349–355.

(2003). *Toyota Motor Corporation.* Environmental & Social Report.

Türkeş, M. C., Oncioiu, I., Aslam, H. D., Marin-Pantelescu, A., Topor, D. I., & Căpuşneanu, S. (2019). Drivers and barriers in using industry 4.0: a perspective of SMEs in Romania. *Processes, Vol. 7 (3).*

Tyagi, S., & Vadrevu, a. S. (2015). Immersive Virtual Reality to Vindicate the Application of Value Stream Mapping in an US-Based SME. *International Journal of Advanced Manufacturing Technology 81*, 1259–1272.

Uriarte, A., Ng, H., & Moris, M. (2018). Supporting the Lean Journey with simulation and optimization in teh context of Industry 4.0. *8th Swedish Production Symposium, SPS 2018.*

Vinodh, S., Antony, J., Agrawal, R., & Douglas, J. A. (2020). Integration of continuous improvement strategies with Industry 4.0: a systematic review and agenda for further research . *CI strategies with Industry 4.0*.

Wagner, T., Herrmann, C., & Thiede, S. (2017). Industry 4.0 impacts on lean production systems. In T. Wagner, C. Herrmann, & S. Thiede, *Industry 4.0 impacts on lean production systems* (p. 125-131). Procedia CIRP.

Walker, D. (1990). Customer first: A strategy for quality service. In *Handbook for Management* (p. Chapter 10). Edited by Lock D., Brookfield, The Gower.

Wang, B., Zhao, J., Wan, Z., Ma, J., Li, H., & Ma, J. (2016). Lean Intelligent Production System and Value Stream Practice. *3rd International Conference on Economics and Management*, 442-447.

Wang, L., Törngren, M., & Onori, M. (2015). Current Status and Advancement of Cyber-Physical Systems in Manufacturing. *Journal of Manufacturing System, Vol. 37* , 517–527.

Wilmott, P. (1994). Total Productive Maintenance – The Western Way. Oxford, Butterworth-Heinemann.

Wilson, M., & Roy, R. (2009). Enabling lean procurement: a consolidation model for small and medium-sized enterprises. *Journal of Manufacturing Technology Managagement, Vol. 20 (6)*, 817–833.

Wireman, T. (2004). Total Production Maintenance. New York: Industrial Press Inc.

Womack, J. (2007). *Respect for People*. e-mail to the Lean community, available at bptrends.com.

Womack, J., & Jones, D. (1996). *Lean Thinking: Banish Waste and Create Wealth in Your Corporation.* New York, Free Press.

Xu, Y., & Chen, M. (2017). An Internet of Things based framework to enhance just-in-time manufacturing. *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*

Yadav, V., Jain, R., Mittal, M., Panwar, A., & Lyons, A. (2019). The Propagation of Lean Thinking in SMEs. *Production Planning & Control*, 854-865.

Yadav, V., Jain, R., Mittal, M., Panwar, A., & Sharma, M. (2019). An appraisal on barriers to implement lean in SMEs. *Journal of Manufacturing Technology Management, Vol. 30 (1)*, 195-212.

Zhong, R. Y., Lan, S., Xu, C., Dai, Q., & Huang, G. Q. (2015). Visualization of RFID-Enabled Shopfloor Logistics Big Data in Cloud. *International Journal of Advanced Manufacturing Technology*, 5-16.

Zhuang, C., Liu, J., & Xiong, a. H. (2018). Digital Twin-Based Smart Production Management and Control Framework for the Complex Product Assembly Shop-Floor. *International Journal of Advanced Manufacturing Technology 96* , 1149–1163.

Zywicki, K., Rewers, P., & Bozek, M. (2017). Data Analysis in Production Levelling Methodology. *Recent Advances i n Information Syst ems and Technologies,* , 460-468.

Appendix 1

This appendix is meant to show the *Word* format of survey initial draft, which has been used for the Beta test (i.e. survey validation process). As the two companies involved in the validation process were Italians, the survey has been delivered in Italian.

Lean 4.0

L'erogazione del seguente questionario e la rispettiva racconta dati hanno lo scopo di comprendere come le tecnologie dell'Industry 4.0 supportino le pratiche Lean all'interno delle piccole-medie imprese Italiane.

NOTA: Il presente questionario non può essere utilizzato o riprodotto, anche parzialmente, senza una preventiva autorizzazione da parte del Politecnico di Milano.

Tutti i dati forniti rimarranno all'interno del gruppo di Ricerca e non verranno divulgati se non in forma di elaborazioni statistiche e/o di dati aggregati. Per visualizzare l'informativa privacy è possibile cliccare qui: https://www.osservatori.net/it_it/privacy-policy/

1. **Nella vostra azienda (o in altre realtà con cui siete venuti in contatto) vengono applicate pratiche Lean e tecnologie dell'Industry 4.0?**
    - Si
    - No (grazie per la vostra partecipazione, il questionario termina qui)
2. **Inserisci il nome dell'azienda e il settore in cui opera**
3. **Qual è la dimensione dell'azienda?**
    - Micro (< 10 impiegati, < 2 M tournover)
    - Piccola (< 50 impiegati, < 10 M tournover)
    - Media (< 250 impiegati, < 50 M tournover)
    - Grande (> 250 impiegati, > 50 M tournover)
4. **L'azienda può essere definita a conduzione:**
    - Familiare
    - Manageriale
5. **Quel' è la principale attività dell'azienda?**
    - Produzione
    - Ricerca e Sviluppo (in questo caso le domande successive alla 9 possono essere compilate facendo riferimento alla vostra stessa azienda oppure a dei vostri clienti/realtà con cui siate venuti a contatto)
    - Servizi (in questo caso le domande successive alla 9 possono essere compilate facendo riferimento alla vostra stessa azienda oppure a dei vostri clienti/realtà con cui siate venuti a contatto)
6. **Qual è la percentuale dedicata a ricerca e sviluppo del fatturato totale?**
7. **Qual è il vostro mercato prevalente?**
    - Italiano
    - Estero

8. Quale tipo di configurazione di sito produttivo avere? (se siete un'azienda di ricerca e sviluppo o servizi rispondete N/A)

- Singolo (un solo stabilimento)
- Multiplo (più di uno stabilimento)
- N/A

9. Il dipartimento IT della vostra azienda è:

- In outsourcing (solo core management interno e il resto delle attività e risorse è esterno)
- Interno (management e capacità operativa interna, ricorso all'esterno solo per servizi di tipo IaaS, commodity, servizi specializzati e urgenze)

10. Quali delle seguenti pratiche Lean sono applicate nella vostra azienda (o nelle realtà di PMI con cui siete venuti a contatto)?

- ☐ Kaizen
- ☐ Andon
- ☐ Poke Yoke
- ☐ TPM (Total Production Maintenance)
- ☐ Jidoka
- ☐ Standardization
- ☐ 5S
- ☐ Visual Management
- ☐ Kanban
- ☐ JIT (Just in Time)
- ☐ Muda Reduction
- ☐ VSM (Value Stream Mapping)
- ☐ Heijunka
- ☐ SMED
- ☐ People and Teamwork

11. Quali delle seguenti pratiche Lean sono applicate nella vostra azienda (o nelle realtà di PMI con cui siete venuti a contatto)?

- ☐ Industrial Internet of Things
- ☐ Digital Twin/Simulation
- ☐ Cloud Manufacturing
- ☐ Industrial Analytics
- ☐ Advanced Automation
- ☐ Advanced Human-Machine Interface
- ☐ Additive Manufacturing

12. Metti una x nei riquadri in corrispondenza dei quali la tecnologia presenti in colonna è a supporto delle pratiche Lean in riga, all'interno della vostra azienda (o nelle realtà di PMI con cui siete venuti a contatto).

Lean 4.0	Industrial IoT	Digital Twin/Simulation	Cloud Manufacturing	Industrial Analytics	Advanced Automation	Advanced HMI	Additive Manufacturing
Kaisen	☐	☐	☐	☐	☐	☐	☐
Andon	☐	☐	☐	☐	☐	☐	☐
Poka Yoke	☐	☐	☐	☐	☐	☐	☐

TPM	□	□	□	□	□	□	□
Jidoka	□	□	□	□	□	□	□
Standardization	□	□	□	□	□	□	□
5S	□	□	□	□	□	□	□
Visual Management	□	□	□	□	□	□	□
Kanban	□	□	□	□	□	□	□
JIT	□	□	□	□	□	□	□
Muda Reduction	□	□	□	□	□	□	□
VSM	□	□	□	□	□	□	□
Heijunka	□	□	□	□	□	□	□
SMED	□	□	□	□	□	□	□
People and Teamwork	□	□	□	□	□	□	□

13. **In corrispondenza di ogni incrocio dichiarato alla domanda 12, esprimi con una valutazione da 1 (molto poco) a 5 (completamente), quanto è migliorata la raccolta dati (in termini di velocità di informazioni, elaborazione di informazioni, velocità e qualità dei dati) nella vostra azienda/nella realtà di PMI con cui siete venuti in contatto.**

Lean 4.0	Industrial IoT	Digital Twin/Simulation	Cloud Manufacturing	Industrial Analytics	Advanced Automation	Advanced HMI	Additive Manufacturing
Kaisen	□	□	□	□	□	□	□
Andon	□	□	□	□	□	□	□
Poka Yoke	□	□	□	□	□	□	□
TPM	□	□	□	□	□	□	□
Jidoka	□	□	□	□	□	□	□
Standardization	□	□	□	□	□	□	□
5S	□	□	□	□	□	□	□
Visual Management	□	□	□	□	□	□	□
Kanban	□	□	□	□	□	□	□
JIT	□	□	□	□	□	□	□
Muda Reduction	□	□	□	□	□	□	□
VSM	□	□	□	□	□	□	□
Heijunka	□	□	□	□	□	□	□
SMED	□	□	□	□	□	□	□
People and Teamwork	□	□	□	□	□	□	□

14. **In corrispondenza di ogni incrocio dichiarato alla domanda 12, esprimi con una valutazione da 1 (molto poco) a 5 (completamente), quanto è migliorato il processo decisione (in termini di velocità, correttezza e qualità del processo) nella vostra azienda/nella realtà di PMI con cui siete venuti in contatto.**

Lean 4.0	Industrial IoT	Digital Twin/Simulation	Cloud Manufacturing	Industrial Analytics	Advanced Automation	Advanced HMI	Additive Manufacturing
Kaisen	□	□	□	□	□	□	□
Andon	□	□	□	□	□	□	□
Poka Yoke	□	□	□	□	□	□	□
TPM	□	□	□	□	□	□	□
Jidoka	□	□	□	□	□	□	□
Standardisation	□	□	□	□	□	□	□
5S	□	□	□	□	□	□	□
Visual Management	□	□	□	□	□	□	□
Kanban	□	□	□	□	□	□	□
JIT	□	□	□	□	□	□	□
Muda Reduction	□	□	□	□	□	□	□
VSM	□	□	□	□	□	□	□
Heijunka	□	□	□	□	□	□	□
SMED	□	□	□	□	□	□	□
People and Teamwork	□	□	□	□	□	□	□

15. **In corrispondenza di ogni incrocio dichiarato alla domanda 12, esprimi con una valutazione da 1 (molto poco) a 5 (completamente), quanto si sono innovati i processi di routine (implementazione dei processi in modo nuovo/diverso) nella vostra azienda/nella realtà di PMI con cui siete venuti in contatto.**

Lean 4.0	Industrial IoT	Digital Twin/Simulation	Cloud Manufacturing	Industrial Analytics	Advanced Automation	Advanced HMI	Additive Manufacturing
Kaisen	□	□	□	□	□	□	□
Andon	□	□	□	□	□	□	□
Poka Yoke	□	□	□	□	□	□	□
TPM	□	□	□	□	□	□	□
Jidoka	□	□	□	□	□	□	□
Standardization	□	□	□	□	□	□	□
5S	□	□	□	□	□	□	□
Visual Management	□	□	□	□	□	□	□
Kanban	□	□	□	□	□	□	□
JIT	□	□	□	□	□	□	□
Muda Reduction	□	□	□	□	□	□	□
VSM	□	□	□	□	□	□	□
Heijunka	□	□	□	□	□	□	□
SMED	□	□	□	□	□	□	□
People and Teamwork	□	□	□	□	□	□	□

Appendix 2

This appendix is meant to show the *Word* format of survey definitive version, which has been used for the Alpha test (i.e. final results collection). As all the companies belonging to the sample of population were Italians, also in this case, the survey has been delivered in Italian.

Lean 4.0

L'erogazione del seguente questionario e la rispettiva racconta dati hanno lo scopo di comprendere come le tecnologie dell'Industry 4.0 supportino le pratiche Lean all'interno delle piccole-medie imprese Italiane.

NOTA: Il presente questionario non può essere utilizzato o riprodotto, anche parzialmente, senza una preventiva autorizzazione da parte del Politecnico di Milano.

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1. **Nella vostra azienda (o in altre realtà con cui siete venuti in contatto) vengono applicate pratiche Lean e tecnologie dell'Industry 4.0?**
   - Si
   - No (grazie per la vostra partecipazione, il questionario termina qui)
2. **Inserisci il nome dell'azienda e il settore in cui opera**
3. **Acconsenti alla pubblicazione del nome e del settore della tua azienda all'interno della nostra tesi?**
   - Si
   - No
4. **In base al numero di dipendenti, qual è la dimensione dell'azienda?**
   - Micro (< 10 impiegati)
   - Piccola (< 50 impiegati)
   - Media (< 250 impiegati)
   - Grande (> 250 impiegati)
5. **In base al fatturato, qual è la dimensione dell'azienda?**
   - Micro (< 2 M tournover)
   - Piccola (< 10 M tournover)
   - Media (< 50 M tournover)
   - Grande (> 50 M tournover)
6. **L'azienda può essere definita a conduzione:**
   - Familiare
   - Manageriale
7. **Quel' è la principale attività dell'azienda?**
   - Produzione

- Ricerca e Sviluppo (in questo caso le domande successive alla 9 possono essere compilate facendo riferimento alla vostra stessa azienda oppure a dei vostri clienti/realtà con cui siate venuti a contatto)
- Servizi (in questo caso le domande successive alla 9 possono essere compilate facendo riferimento alla vostra stessa azienda oppure a dei vostri clienti/realtà con cui siate venuti a contatto)

8. I processi nella vostra azienda possono essere definiti:

- Capital Intensive
- Labour Intensive

9. Qual è la percentuale dedicata a ricerca e sviluppo del fatturato totale?

10. Qual è il vostro mercato prevalente?

- Italiano
- Estero

11. Quale tipo di configurazione di sito produttivo avere? (se siete un'azienda di ricerca e sviluppo o servizi rispondete N/A)

- Singolo (un solo stabilimento)
- Multiplo (più di uno stabilimento)
- N/A

12. Il dipartimento IT della vostra azienda è:

- In outsourcing (solo core management interno e il resto delle attività e risorse è esterno)
- Interno (management e capacità operativa interna, ricorso all'esterno solo per servizi di tipo IaaS, commodity, servizi specializzati e urgenze)

13. Quali delle seguenti pratiche Lean sono applicate nella vostra azienda (o nelle realtà di PMI con cui siete venuti a contatto)?

- ☐ Kaizen
- ☐ Andon
- ☐ Poke Yoke
- ☐ TPM (Total Production Maintenance)
- ☐ Jidoka
- ☐ Standardization
- ☐ 5S
- ☐ Visual Management
- ☐ Kanban
- ☐ JIT (Just in Time)
- ☐ Muda Reduction
- ☐ VSM (Value Stream Mapping)
- ☐ Heijunka
- ☐ SMED
- ☐ People and Teamwork

14. Quali delle seguenti pratiche Lean sono applicate nella vostra azienda (o nelle realtà di PMI con cui siete venuti a contatto)?

- ☐ Industrial Internet of Things
- ☐ Digital Twin/Simulation

- ☐ Cloud Manufacturing
- ☐ Industrial Analytics
- ☐ Advanced Automation
- ☐ Advanced Human-Machine Interface
- ☐ Additive Manufacturing

15. Metti una x nei riquadri in corrispondenza dei quali la tecnologia presenti in colonna è a supporto delle pratiche Lean in riga, all'interno della vostra azienda (o nelle realtà di PMI con cui siete venuti a contatto).

Lean 4.0	Industrial IoT	Digital Twin/Simulation	Cloud Manufacturing	Industrial Analytics	Advanced Automation	Advanced HMI	Additive Manufacturing
Kaisen	☐	☐	☐	☐	☐	☐	☐
Andon	☐	☐	☐	☐	☐	☐	☐
Poka Yoke	☐	☐	☐	☐	☐	☐	☐
TPM	☐	☐	☐	☐	☐	☐	☐
Jidoka	☐	☐	☐	☐	☐	☐	☐
Standardization	☐	☐	☐	☐	☐	☐	☐
5S	☐	☐	☐	☐	☐	☐	☐
Visual Management	☐	☐	☐	☐	☐	☐	☐
Kanban	☐	☐	☐	☐	☐	☐	☐
JIT	☐	☐	☐	☐	☐	☐	☐
Muda Reduction	☐	☐	☐	☐	☐	☐	☐
VSM	☐	☐	☐	☐	☐	☐	☐
Heijunka	☐	☐	☐	☐	☐	☐	☐
SMED	☐	☐	☐	☐	☐	☐	☐
People and Teamwork	☐	☐	☐	☐	☐	☐	☐

16. In corrispondenza di ogni incrocio dichiarato alla domanda 12, esprimi con una valutazione da 1 (molto poco) a 5 (completamente), quanto è migliorata la raccolta dati (in termini di velocità di informazioni, elaborazione di informazioni, velocità e qualità dei dati) nella vostra azienda/nella realtà di PMI con cui siete venuti in contatto.

Lean 4.0	Industrial IoT	Digital Twin/Simulation	Cloud Manufacturing	Industrial Analytics	Advanced Automation	Advanced HMI	Additive Manufacturing
Kaisen	☐	☐	☐	☐	☐	☐	☐
Andon	☐	☐	☐	☐	☐	☐	☐
Poka Yoke	☐	☐	☐	☐	☐	☐	☐
TPM	☐	☐	☐	☐	☐	☐	☐
Jidoka	☐	☐	☐	☐	☐	☐	☐
Standardization	☐	☐	☐	☐	☐	☐	☐
5S	☐	☐	☐	☐	☐	☐	☐
Visual Management	☐	☐	☐	☐	☐	☐	☐

Kanban	☐	☐	☐	☐	☐	☐	☐
JIT	☐	☐	☐	☐	☐	☐	☐
Muda Reduction	☐	☐	☐	☐	☐	☐	☐
VSM	☐	☐	☐	☐	☐	☐	☐
Heijunka	☐	☐	☐	☐	☐	☐	☐
SMED	☐	☐	☐	☐	☐	☐	☐
People and Teamwork	☐	☐	☐	☐	☐	☐	☐

17. **In corrispondenza di ogni incrocio dichiarato alla domanda 12, esprimi con una valutazione da 1 (molto poco) a 5 (completamente), quanto è migliorato il processo decisione (in termini di velocità, correttezza e qualità del processo) nella vostra azienda/nella realtà di PMI con cui siete venuti in contatto.**

Lean 4.0	Industrial IoT	Digital Twin/Simulation	Cloud Manufacturing	Industrial Analytics	Advanced Automation	Advanced HMI	Additive Manufacturing
Kaisen	☐	☐	☐	☐	☐	☐	☐
Andon	☐	☐	☐	☐	☐	☐	☐
Poka Yoke	☐	☐	☐	☐	☐	☐	☐
TPM	☐	☐	☐	☐	☐	☐	☐
Jidoka	☐	☐	☐	☐	☐	☐	☐
Standardization	☐	☐	☐	☐	☐	☐	☐
5S	☐	☐	☐	☐	☐	☐	☐
Visual Management	☐	☐	☐	☐	☐	☐	☐
Kanban	☐	☐	☐	☐	☐	☐	☐
JIT	☐	☐	☐	☐	☐	☐	☐
Muda Reduction	☐	☐	☐	☐	☐	☐	☐
VSM	☐	☐	☐	☐	☐	☐	☐
Heijunka	☐	☐	☐	☐	☐	☐	☐
SMED	☐	☐	☐	☐	☐	☐	☐
People and Teamwork	☐	☐	☐	☐	☐	☐	☐

18. **In corrispondenza di ogni incrocio dichiarato alla domanda 12, esprimi con una valutazione da 1 (molto poco) a 5 (completamente), quanto si sono innovati i processi di routine (implementazione dei processi in modo nuovo/diverso) nella vostra azienda/nella realtà di PMI con cui siete venuti in contatto.**

Lean 4.0	Industrial IoT	Digital Twin/Simulation	Cloud Manufacturing	Industrial Analytics	Advanced Automation	Advanced HMI	Additive Manufacturing
Kaisen	☐	☐	☐	☐	☐	☐	☐
Andon	☐	☐	☐	☐	☐	☐	☐
Poka Yoke	☐	☐	☐	☐	☐	☐	☐
TPM	☐	☐	☐	☐	☐	☐	☐
Jidoka	☐	☐	☐	☐	☐	☐	☐

Standardization	□	□	□	□	□	□	□
5S	□	□	□	□	□	□	□
Visual Management	□	□	□	□	□	□	□
Kanban	□	□	□	□	□	□	□
JIT	□	□	□	□	□	□	□
Muda Reduction	□	□	□	□	□	□	□
VSM	□	□	□	□	□	□	□
Heijunka	□	□	□	□	□	□	□
SMED	□	□	□	□	□	□	□
People and Teamwork	□	□	□	□	□	□	□

Appendix 3

The following table reports names and sectors of all the companies that have answered to the survey. For privacy reasons, some of them have not given the consent to publish their names. These companies have been reported as "XXX", while the sectors they belong to has been reported normally.

Number	**Name**	**Sector**
1	*XXX*	*Mechanical*
2	*Nuovo S.r.l.*	*Industrial waste treatment*
3	*XXX*	*Music industry*
4	*XXX*	*Industrial Refrigeration*
5	*XXX*	*Packaging*
6	*A.M. STAMPI S.r.l.*	*Food and Beverages*
7	*ADDA Ondulati S.p.A.*	*Packaging*
8	*Alberto Sassi S.p.A.*	*Mechanical*
9	*ALean Productionhamac*	*Mechanical*
10	*Axcent System Engineering S.r.l.*	*Electric engines*
11	*Baltur S.p.A.*	*Mechanical*
12	*C.F.R. S.r.l.*	*Electric engines*
13	*CAMImpianti S.r.l.*	*Mechanical*
14	*Cartotecnica Moreschini*	*Packaging*
15	*Castel S.r.l.*	*Industrial Refrigeration*
16	*Cimprogetti S.r.l.*	*Mechanical*
17	*Civitanavi Systems*	*Defense and Space*
18	*XXX*	*Defense and Space*
19	*CO-CAR*	*Mechanical*
20	*Compomac S.p.A.*	*Mechanical*
21	*Conceria Nuvolari*	*Fashion*
22	*Cosberg*	*Industrial automation*
23	*XXX*	*Packaging*
24	*Eurmeccanica*	*Industrial automation*
25	*Fatigroup*	*Mechanical*
26	*XXX*	*Consulting services*
27	*Formbags S.p.A.*	*Packaging*
28	*GL Locatelli S.r.l.*	*Civil Engineering*
29	*Kawa Studio*	*Consulting services*
30	*La Manuelita S.r.l.*	*Fashion*
31	*Lesepidado S.r.l.*	*Food and Beverages*
32	*Matteiplast S.r.l.*	*Packaging*
33	*Meccanica Couplings S.r.l.*	*Mechanical*
34	*XXX*	*Automotive*
35	*Michael Page*	*Consulting services*

36	*Minerva Omega group*	*Food and Beverages*
37	*Nanoprom Chemicals S.r.l.*	*Nanotechnologies*
38	*Plastod S.p.A.*	*Health*
39	*SIMEL S.p.A.*	*Electric engines*
40	*Sinteris Industria Prodotti Sinterizzati S.p.A.*	*Mechanical*
41	*SSE Oil & Gas*	*Oil & Gas*
42	*Sync Lab*	*Consulting services*
43	*Tecnomatic S.p.A.*	*Automotive*
44	*Uqido*	*Consulting services*
45	*Vaccari Mauro*	*Mechanical*
46	*Valle Fiorita S.r.l.*	*Food and Beverages*
47	*VARVEL S.p.A.*	*Mechanical*
48	*Water Energy S.r.l.*	*Industrial waste treatment*
49	*Zenith Automazione S.r.l.*	*Industrial Automation*
50	*Zucchetti S.p.A.*	*Consulting services*
51	*Tramec S.r.l.*	*Industrial Automation*
52	*XXX*	*Information technology*
53	*Rold S.r.l.*	*Mechanical*
54	*XXX*	*Mechanical*
55	*Romagnani Stampi S.r.l*	*Automotive*
56	*Eurix S.r.l.*	*Software*
57	*Eletrosystem S.r.l.*	*Automation*
58	*XXX*	*Fashion*
59	*Dress Coders S.r.l.*	*Fashion*
60	*Autebo S.p.A.*	*Mechanical*
61	*Gait S.r.l.*	*Mechanical*
62	*I-Tech S.r.l.*	*Automation*
63	*Eurotec S.r.l.*	*Mechanical*
64	*XXX*	*Mechanical*
65	*A.M. Stampi S.r.l.*	*Mechanical*
66	*Biopapà*	*Food and Beverages*
67	*Sariv S.r.l.*	*Mechanical*
68	*Instituto Stampa S.r.l.*	*Mechanical*
69	*Caron A&D*	*Mechanical*
70	*XXX*	*Oil & Gas*
71	*XXX*	*Consulting services*
72	*XXX*	*Consulting services*
73	*XXX*	*Mechanical*
74	*XXX*	*Automation*
75	*YOUCO*	*Telecommunication*

Appendix 4

This appendix is meant to show how **Weighted Means** and **general Arithmetic Mean** used in section 6.2.1 have been calculated. In addition, it suggests also how the Weighted Means per technology/practice used in section 6.2.2 have been obtained.

More specifically, table 24 (see chapter 6, section 6.1.3) shows the number of respondent companies that have declared to apply each specific intersection, that is the number of answers per intersection. Tables 47, 48 and 49 correspond to the three benefits and they are populated by the Arithmetic Means of the levels of benefit respondent companies have declared for each specific intersection.

For each benefit, the **Weighted Mean** has been calculated as follows: the numbers contained within the same cell in table 24 and 47, 48, 49 have been multiplied; then, all the results have been summed. Then, this sum has been divided by the total amount of answers (i.e. sum of all intersections' answers), that is 286. The **general Arithmetic Mean** represents the Arithmetic Mean between the three Weighted Means. To be more precise:

$$\textbf{WM}_{\text{benefit}} = \frac{\sum_{j=1}^{105} x_j \cdot y_j}{\sum_{j=1}^{105} x_j}$$

$$\textbf{General AM} = \frac{\boldsymbol{WM}_{Data\ Collection} + \boldsymbol{WM}_{Decision-Making} + \boldsymbol{WM}_{Process\ Innovation}}{3}$$

Where *j = 1, …, 105* represent the cells, *x* represents the number in table 24, *y* represents the number in tables 47, 48, 49.

In addition, tables 47, 48 and 49 provide a suggestion of how the **Weighted Means** shown in section 6.2.2 have been calculated: basically, the same formula shown for the benefits has been applied by row and by column.

Decision Making	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen	4.6	3.4	3.5	3.6	3.4	3.3	
Andon		3.0		3.7	2.3	2.5	
Poke Yoke	2.0	4.5	3.0	2.5	4.0	3.3	
TPM (Total Production Maintenance)		5.0	3.0	4.0	4.5	4.0	4.0
Jidoka		3.0		4.0	2.5	3.0	
Standardization	3.0	4.0	3.0	3.0	4.0	3.0	4.0
5S	3.5	4.3	3.5	3.3	3.7	3.6	3.0
Visual Management	3.0	4.0	3.5	4.3	3.7	5.0	2.0
Kanban	3.0	2.1	2.8	4.0	3.9	3.0	2.5
JIT (Just in Time)	2.0	3.2	2.0	3.6	4.1	2.7	2.0
Muda Reduction		3.0	3.0	2.0	2.0	5.0	
VSM (Value Stream Mapping)	2.0	4.5	2.0	3.5	4.0		2.0
Heijunka				5.0	5.0		
SMED	3.0	3.0		2.7	2.5		
People and Teamwork	1.5	3.3	4.0	3.6	3.8	3.8	

Table 47 - Arithmetic Means for Data Collection

Decision Making	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen	4.6	3.4	3.5	3.6	3.4	3.3	
Andon		3.0		3.7	2.3	2.5	
Poke Yoke	2.0	4.5	3.0	2.5	4.0	3.3	
TPM (Total Production Maintenance)		5.0	3.0	4.0	4.5	4.0	4.0
Jidoka		3.0		4.0	2.5	3.0	
Standardization	3.0	4.0	3.0	3.0	4.0	3.0	4.0
5S	3.5	4.3	3.5	3.3	3.7	3.6	3.0
Visual Management	3.0	4.0	3.5	4.3	3.7	5.0	2.0
Kanban	3.0	2.1	2.8	4.0	3.9	3.0	2.5
JIT (Just in Time)	2.0	3.2	2.0	3.6	4.1	2.7	2.0
Muda Reduction		3.0	3.0	2.0	2.0	5.0	
VSM (Value Stream Mapping)	2.0	4.5	2.0	3.5	4.0		2.0
Heijunka				5.0	5.0		
SMED	3.0	3.0		2.7	2.5		
People and Teamwork	1.5	3.3	4.0	3.6	3.8	3.8	

Table 48 - Arithmetic Means for Decision Making

Process Innovation	Additive Manufacturing	Advanced Automation	Advanced Human-Machine Interface	Industrial Internet of Things	Industrial Analytics	Cloud Manufacturing	Digital Twin/Simulation
Kaizen	3.4	3.5	3.6	3.6	3.8	3.4	
Andon		4.0		3.0	2.7	2.5	
Poke Yoke	2.0	3.0	4.0	4.0	4.0	3.3	
TPM (Total Production Maintenance)		4.0	4.0	4.5	4.5	4.0	2.0
Jidoka		5.0		5.0	2.5	3.0	
Standardization	3.0	4.3	3.5	3.3	5.0	5.0	4.0
5S	3.5	4.0	3.0	3.4	3.1	3.8	3.0
Visual Management	3.0	4.0	3.8	4.3	3.7	5.0	2.0
Kanban	2.0	2.8	3.0	3.4	3.6	3.3	2.5
JIT (Just in Time)	2.0	4.0	2.0	3.6	4.0	3.3	3.0
Muda Reduction		5.0	3.0	4.0	3.5	3.0	
VSM (Value Stream Mapping)	1.0	3.5	1.0	3.0	4.0		3.0
Heijunka				4.0	4.0		
SMED	3.0	3.0		3.0	3.0		
People and Teamwork	4.5	4.5	4.0	3.5	4.0	2.6	

Table 49 - Arithmetic Means for Process Innovation