POLITECNICO DI MILANO

School of Industrial and Information Engineering
Master of Science in Management Engineering:
Industrial Management

Lean Manufacturing and Industry 4.0: an empirical analysis between Sustaining and Disruptive Change

Supervisor: Prof. Giovanni Miragliotta
Co-supervisor: Eng. Elisa Convertini

Dissertation with discussant of:
Mila Malavasi
ID Number: 863332
Gabriele Schenetti
ID Number: 863352

Academic Year 2016/2017

Innanzitutto grazie al Professor Miragliotta per l'opportunità splendida che ci ha dato di lavorare su un tema così attuale e sfidante, credendo in noi e spronandoci sempre a ragionare usando la nostra ratio. Grazie per averci accompagnati in questo percorso di crescita professionale e personale e per la Conoscenza passataci.

Grazie infinite ad Elisa Convertini per averci presi per mano e supportati (anche sopportati) nella stesura di questo lavoro con pazienza e tenacia. Grazie per la passione che ci hai trasmesso e la cura ai dettagli.

Grazie a tutte le persone che ci hanno aiutato a comporre il nostro modello, mostrandosi sempre disponibili e spendendo tempo prezioso per consigliarci ed ascoltarci. Grazie per l'interesse smisurato e per le critiche costruttive e i complimenti sinceri che ci sono arrivati. In particolare grazie a: Francesco di Pasquale, Federico Bardini, Maurizio Mazzieri, Stefano Cortiglioni, Gaia Ripamonti, Emanuele Mistò, Edoardo Anzani, il professor Luigi Battezzati, Fabio Golinelli, Alberto Moro, Luciano Massone, Vincent Ruelle, Alessando Lacalaprice, Luigi Pellegrini e Gianni Dal Pozzo.

Un grazie particolare anche a tutte le aziende che hanno partecipato alla nostra survey, con un feedback più che tempestivo: ABB Spa, Agrati Group Fastener Solutions, Ansaldo Energia, Asperti Mario, Battezzati Luigi, Beckhoff Automation, Bosch Rexroth Spa, Brembo Spa, Candy Hoover, Castel, Cisco Systems, CNH Industrial, Considi, Dallara, Electrolux, Fiat Chrysler Automobiles, Forgital Italy, Galdi , Gefran Spa, Infor Group Spa, ICS Srl, K.L.A.IN.robotics, Lamborghini, Logital, Montagna Maurizio, Nr di Nisoli srl, Pietro Fiorentini, Poliform Spa, Portioli Staudacher Alberto, Rulli Rulmeca Spa, Same SDF, Sapio, Staufen.Italia, Terzi Sergio, Tesar Spa, Tetrapak, Toyota Material Handling Systems, Whirlpool EMEA.

Mila e Gabriele

Table of Contents

0. EXECUTIVE SUMMARY

Since 2011, when the term *Industrie 4.0* was introduced at the Hannover Messe in Germany, the Fourth Industrial Revolution topic has entered everyday lives, not only as a research theme for University, but especially as an opportunity for industrial businesses, that are trying to grab all the advantages that this transformation could bring.
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 machinery) in the Value Chain" (Politecnico di Milano, 2017). The Fourth Industrial Revolution is based on two main groups of Smart Manufacturing Technologies: Information Technologies (IT) and Operations Technology (OT). The first one is a more cohesive group, which includes Industrial Internet of Things (IIoT), Industrial Analytics and Cloud Manufacturing. The second group is more heterogeneous and it enables a great interconnection between resources used in the operational processes. It includes Advanced Automation, Advanced Human-Machine Interface (HMI) and Additive Manufacturing.

Manufacturing companies are inevitably being hit by this great change; therefore, they are trying to link Industry 4.0 with pre-existent business philosophies. For instance, more and more firms are looking at a potential connection with a deeply-rooted industrial paradigm such as Lean Manufacturing.

The term Lean production appeared for the first time in 1988 in an article of John F. Krafcik, referring to a production system that *do more with less*. It was born as a mere response to the state of the automobile industry in Japan after the World War II. The father of Toyota Production System (TPS) was Taiichi Ohno, which joined together the two pillars of Just in Time and Jidoka in order to increase the efficiency of Toyota Motor Corporation in that period of crisis. However, at the basis of Lean there is a strong philosophy called *Toyota Way*, supported by continuous improvement (Kaizen) and respect for people: as a matter of fact, lean is firstly a way of thinking, not a list of things to do (Shingo, 1989).

0. Executive Summary

Academic publications and reliable practitioners' articles about interactions between Lean Manufacturing and Industry 4.0 were accurately selected and reviewed; as a result, it emerged that there are no frameworks explaining how Lean principles and pillars will be modified in the viewpoint of Industry 4.0, considering the pure essence inherent the two paradigms. Although the two different industrial *languages* of Lean and Industry 4.0 seem to be superficially similar and to sustain each other, going deeply in the analysis some evident inequalities emerge. This gap switches the way of looking at the paradigms from a *sustaining* to a *disruptive* perspective (the terms *sustaining* and *disruptive* have been gathered from Christensen's studies regarding innovation (Christensen, 1997; Christensen et al., 2003)). Therefore, this work was developed by considering this dual viewpoint as a reference for the comparison. Basically, the huge element of originality provided by this dissertation is connected to the definition of a balance between *sustaining* and *disruptive* aspects generated by the introduction of Industry 4.0 paradigm in a Lean environment, going beyond the mere application of advanced technologies. Taking Lean as starting point, on the one hand, Industry 4.0 could be seen as a *sustaining* evolution; in fact, it might improve and complement Lean practices, creating the *true* Lean Smart Enterprise. On the other hand, Industry 4.0 is also called *revolution*, so it can radically change businesses, providing new business and entrepreneurial models, distancing from the traditional Lean paradigm.

The research was carried out by developing a normative model, in which principles and pillars of Lean production were taken as reference points for the comparison towards a digital viewpoint. Regarding principles, the five *actions* presented by Womack et al. (1996) were considered: value, mapping the value stream, continuous flow, pull approach, striving for perfection. Moreover, it was selected the House of Liker (2004) in order to show those interesting pillars and foundations to build the comparison. The attention was focused on Stable and Standardized processes, Visual management, Just in Time, Jidoka and Waste reduction (approach for problem solving), without taking into account *Toyota Way* philosophy and People and Teamwork. As a matter of fact, it was decided to mainly consider *operative* aspects and how the *new* Industry 4.0 ecosystem could interact with an already established Lean ones. In fact, Industry 4.0 paradigm has not already been univocally theorized, so the comparison from a *pure cultural* point of view at a *higher lev*el has been excluded.

The model was built up by joining personal researches together with hints from 9 interviews with experts, presented as brief case studies. The interviewees were taken from people belonging to manufacturing industry, within companies that have already implemented Lean successfully and have already approached Industry 4.0 projects. They are SEW Eurodrive, Galdi S.r.l., Toyota Material Handling Systems, Agrati Group Fastening Systems, Poliform S.P.A., ABB Italia, Brembo and Fiat Chrysler Automobiles N. V. (FCA). Moreover, it was asked the opinion of Luigi Battezzati, Professor of Smart Factory at LIUC – Carlo Cattaneo University. Starting with a conceptual map that illustrates the reasoning inherent the model, this is finally represented by 13 statements that were tested at the end of the research, in order to understand the external level of agreement according to the model. The main idea behind this dissertation is that "Lean in the viewpoint of Industry 4.0 is composed of some principles and pillars which will be modified according to a *sustaining* perspective whereas some others to a *disruptive* one". In the end, 8 statements refer to a *sustaining* perspective, whereas 5 to a *disruptive* one.

For the sake of clarity, the five principles of the model are divided in three *sustaining* and two *disruptive*, which are the ones referring to the concept of value (first principle) and striving for perfection (fifth principle).
The value for the customer is the starting point of the model: collection and sharing of Data and Information from customers through digital technologies (e.g. IT systems and Smart Interconnected Products) will allow companies to have a proactive approach towards customers, aiming at not just *listening* to their requests, but *anticipating* their future trend and needs.
Once defined what is valuable for customer, the focus will be not only on searching obsessively operative activities which create value for the customer, but also on Data Stream, where information opportunely filtered will become value-adding, in order to improve the effectiveness of the decision-making process and fasten it.
Subsequently, these value-adding information must be arranged in a Data Stream Flow: there is not only a physical flow of *pieces*, managed by takt-time logic, but it will be necessary to take into consideration also a flow of data, derived from IT and factory systems, which will create value once managed through a continuous and real-time flow.
Further, *pull everything* is the slogan for the fourth principle: pull production will evolve through Industry 4.0 by the introduction of the concept of *services* enabled by Data Stream, available thanks to Smart Technologies. In other words, according to Industry

4.0, products are always associated to their related services and sold as if they were a *unique entity*. Finally, traditional attitude towards continuous improvement (Kaizen) will be modified introducing radical (and not only incremental) changes since Industry 4.0 aims at transferring internet principles to the industrial world: Digital Factory is built upon the bedrock of CPS (Cyber Physical System) and it will be obtained by introducing *disruptive* innovations.

Regarding Liker's House, for all the five pillars and foundations a *sustaining* view was found, while only for three of them (stable and standardized processes, just in time, jidoka) a *disruptive* viewpoint was depicted.
The topic of standardization will evolve in the concept of interoperability of machines and IT systems: interoperability fosters a better exchange of information, supporting the real-time management of the processes. According to a *disruptive* perspective, standardization of process interfaces, product description and service-orientation (SoA) will be prerequisites for allowing factories to use internet in order to share equipment and infrastructures, enabling MaaS (Manufacturing as a Service).
Human-Machine Interface (HMI) will digitize the traditional Visual Management signals in the factory, by creating a paper-less environment; moreover, it will support workers by making "the whole factory more visible" and by improving the ergonomics of workplace.
Regarding Just in Time pillar, this manufacturing approach could be supported by Cloud Computing, stretching out JIT also to the availability of the needed information, in the right amount and time. It will support a step-forward from JIT production to JIT information. On the contrary, the *disruptive* point of view refers to Additive Manufacturing, designed for small product lots with a high level of customization and complexity, dramatically reducing product lead time. Additive Manufacturing will allow to fasten prototyping, production and maintenance, fostering an innovative logic of just in time production (decreasing inventories at maximum) and one-piece-flow.
The other pillar, Jidoka, will evolve by inserting Co-bots in production line, in which they work in a balanced interaction with individuals, being a fundamental node of the interconnected network; moreover, improving work conditions, productivity, quality of production and safety, without eliminating the need for the presence of workers for team-working. Regarding the *disruptive* viewpoint, the concept of Autonomous Automation will be figured out. Individuals will play the role of supervisor in decision-making process, without the necessity of being necessarily physically present on Gemba for

solving operative problems: as a matter of fact, a lot of process engineers and data scientists will design powerful and robust algorithms in order to allow CPS (Cyber Physical System) to be operationally autonomous.
Finally, Traditional approach of Genchi Genbutsu to discover wastes will be supported by IoT and Tracking devices; they would be more promptly identified and, once fixed, improved.

In order to refine the model, a Beta test was launched to five experts of the field, aiming at receiving feedbacks for perfecting the form and the content of each statement. These sample was composed by FCA, Toyota Material Handling Systems, Luigi Battezzati and also two professors of Politecnico di Milano, Alberto Portioli Staudacher and Sergio Terzi. Once arrived at the final version of the statements, it was sent through a survey (Alpha test) to a wider less restrictive sample of subjects, considering as unique driver an intense knowledge of the theme of Industry 4.0 linked to Lean manufacturing. The components of the sample belong to a huge variety of sectors: from Automotive to Home Appliance, from Energy to Oil & Gas, passing from ICT experts and consultancy companies keen on Lean and Industry 4.0.
38 answers were gathered, obtaining a good level of reliability of 75% (by using the alpha coefficient of Cronbach). For each statement it was computed an Index of Agreement, by assigning scores to each answer, giving higher weight to the answers expressing a level of disagreement. Then, two average indexes were computed, one for the *sustaining* statements, and the other for the *disruptive* ones. As a result, quite high indexes were obtained: the *Average Sustaining Index* gets a score of 60, whereas the *Average Disruptive Index* of 42.
In the end, it is reasonable to conclude that experts were more inclined towards continuity than disruption: the *sustaining* parts of the model were widely accepted, while the *disruptive* parts created more heterogeneity. In fact, for these concepts some subjects agreed, but they were not commonly accepted: sometimes the absence of practical examples could have created ambiguity in understanding the statements; moreover, some scepticism towards a possible enabling technology or a future scenario could emerge; further, the vision towards Industry 4.0, which is considered sometimes an evolution and sometimes a revolution, could have led to this discrepancy.

To conclude, the main intuition behind this dissertation is shared: it is reasonable to assume a balance between *sustaining* and *disruptive* elements, considering Lean in the viewpoint of Industry 4.0. In this sense, since it is a research, the results obtained can be considered acceptable, paving the way for promising further improvements.

1. INTRODUCTION

1.1 Lean and Industry 4.0: Different Industrial "Languages" in Comparison

Since the beginning of industrialization, technological progresses have led to paradigmatic shifts that have been called *Industrial Revolutions*, all of them mainly characterized by a drastic increase in productivity. The first was triggered by the introduction of the steam power, in the middle of the eighteenth century; the second started conventionally in 1870 with the establishment of electricity, chemical products and crude oil, together with the changing concept of mass production; the third, one century later, referred to the effects provided by the increasing usage of electronics and IT in manufacturing industry; finally, in 2011, the term *Industrie 4.0* was introduced at the Hannover Messe in Germany.

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 machinery) in the Value Chain" (Politecnico di Milano, 2017).

Manufacturing companies are inevitably being hit by this great change; therefore, they are trying to link Industry 4.0 with pre-existent business philosopies. For instance, more and more firms are looking at a potential connection with a deeply-rooted industrial paradigm such as Lean Manufacturing.

The final goal of this dissertation is finding, in theory, potential interactions between the two different industrial *languages* of Lean and Industry 4.0. So, a reasonable question could be: *What type of innovation does Industry 4.0 represent?*

Although they seem to be superficially similar and to sustain each other in this industrial shift, some evident inequalities could emerge, deeply analysing the real essence inherent the two paradigms. This gap could switch the way paradigms should be looked at, from a *sustaining* to a *disruptive* perspective.

1.2 Christensen's Studies about Innovation: Efficiency, Sustaining and Disruptive

The terms *sustaining* and *disruptive* have been gathered from Christensen's studies regarding innovation (Christensen, 1997; Christensen et al., 2003). According to the author of the book "The Innovator's Dilemma" (1997), there are three different types of innovation (Christensen, 2013).

The first are *empowering* or *disruptive* innovations (i.e. ones that dramatically disrupts the current market). Basically, they introduce completely new functionalities, different from what the market is currently offering. This kind of innovation often leads to a redefinition of products or business models, radically changing the concept of value for the customer, eventually displacing the established one. According to Christensen (1997), a disruptive innovation "allows a whole new population of consumers at the bottom of a market access to a product or service that was historically only accessible to consumers with a lot of money or a lot of skill".

In addition, there are *sustaining* innovations. Their function is to replace old products with new ones, slightly improved. In a few words, *sustaining* innovations replace yesterday's products with today's products. They generate the largest part of innovations but "they have a zero-sum effect on jobs and capital" (Christensen, 2013). However, they are really important in the economy, because they keep the margins attractive and the market *vibrant*.

Lastly, the third type of innovations are *efficiency* ones. A clear example could be identified in the Toyota Just-in-Time manufacturing system, because it reduces the cost of making and distributing existing products and services. Traditionally, *efficiency* innovations often allow the same amount of work (or more) to get done using fewer people. These innovations are critical to improve a company's business since they allow to avoid, for instance, capital tied up in inventories. The recognized purpose of *efficiency* innovations is to "do more with less". The interesting aspect is related to the fact that this is the perfect definition for Lean Manufacturing (Womack et al., 1996). Lean is a well-established concept since 20 years around the world. Nowadays, the Fourth Industrial Revolution is arising; anyway, it is not considered an isolated phenomenon, since it often has to be inserted into a well-known and existing framework, such as Lean Manufacturing.

1. Introduction

In the following paragraphs, a deep introduction to the topics of Lean Manufacturing and Industry 4.0 is presented. Later on, a *normative* model is presented which aims at explaining the relationship between these two industrial paradigms, after a systematic review of academic and practitioners' articles about the interaction between these two industrial *languages*. This model provides a detailed analysis in terms of *sustaining* or *disruptive* elements, perfectly in line with the final goal of this dissertation.

Therefore, since the model proposed is based on a balance between *sustaining* and *disruptive*, it is worth to explain in which way these two terms regarding innovation were adapted, once retrieved from Christensen's studies. For the purpose of the comparison, *sustaining* means an innovation which simply improves the way in which an existing practice is carried out. So, Industry 4.0 might enhance and complement Lean practices, resulting in higher productivity and efficiency. On the contrary, a disruptive innovation implies a radical change which opens completely new scenarios. In this second case, Industry 4.0 drastically revolutionizes the way in which a certain practice is brought forward, acting as a *game-changer*.

2. LEAN MANUFACTURING

2.1 History of Toyota Production System

Although there were instances of process thinking in manufacturing since the 1450s, the first person that was able to truly integrate an entire production process was Henry Ford. In 1913, he put together consistently interchangeable parts with *standard work* creating the so called *production flow*. Ford was able to turn the inventories of the entire company every few days; however, the problem with this new production system was the inability to provide variety. A famous sentence highlights this issue: "Any customer can have a car (Ford T) painted any colour that he wants so long as it is black" (Ford et al., 1922).
Other carmakers tried to solve that increasing need for variety by investing in larger machines that ran faster. On the one side, they lowered costs per process step, but on the other side they continuously increased throughput times and inventories, except in rare cases where all of the process steps could be linked and automated.
Kiichiro Toyoda, Taiichi Ohno and others Japanese engineers looked at this situation, especially after the World War II. They tried to implement a series of simple *quick-win* improvements to have at the same time continuity in the process flow and a wide variety in product offerings. Therefore, they revisited Ford's original thinking and invented the Toyota Production System (TPS), better known as *Lean Production* (Holweg, 2007).

When people are asked to answer the question *What is a Toyota Production System?*, "80% of them will definitely reply that it is a Kanban-based system, another 15% will associate it to a particular production system, while only the remaining 5% will gather the real core of the question and they will define it as a system to eliminate wastes" (Shingo, 1989).
The term *Lean Production* firstly appeared in 1988 in the article "Triumph of the Lean Production System" by John F. Krafcik, based on his thesis at the MIT Sloan School of Management. In his publication, Krafcik introduced the word aiming at comparing the production systems of Western producers, which he defined *buffered*, with the innovative TPS arisen in Japan after the WWII. The term refers to a production system that "do more with less", which means using the lowest amount of resources in order to obtain the highest level of efficiency and quality. Lean was introduced for the first time in Toyota Motor Manufacturing and it is a methodology that, after having identified the wastes that

do not create value for the customers (*Muda*), aims at eliminating them to increase the productivity of the factory. Nevertheless, Taiichi Ohno, the father of Toyota Production System, wanted to underline that Lean Production was only “a mere response to the state of the automobile industry in Japan after the World War II” (Ohno, 1973): it was the outcome of a trial and error approach for many years, in order to find a way to survive in the mass production competitive environment already established in Europe and America. In fact, the Japanese automobile industry was intensely damaged by the war and Ohno was appointed to improve the productivity of the factory, since efficiency was the primary driver in that period. Despite a trip in United States, initially with the aim of studying Ford’s production process, he was inspired by the logic behind American supermarkets. Once returned in Japan, he put in practice what is today called *Toyota Production System*, by joining the two pillars of Jidoka and Just-in-Time, previously implemented by Sakichi Toyoda (Toyoda Spinning and Weaving Company, 1918) and his son Kiichiro (Toyota Motor Corporation, 1937). He smartly understood that the only way to increase productivity was adapting that system to current Japanese industry, because “mass production could have never worked within those conditions” (Womack et al., 1990).

Practically speaking, TPS is associated to the term *Lean* because it uses less of everything compared to mass production: half of the human effort, half of the space in the factory, half of the investment in tools, half of the hours needed for developing a new product and far less than half of the inventory (Womack et al., 1990). While mass production is based on narrowly skilled professionals for design and unskilled (or at least semi-skilled) workers for production, Lean creates teams of multi-skilled workers at all levels of the organization. Furthermore, instead of buying expensive, single-purpose machines, Lean suggests manual and automated systems able to produce large volumes with large product variety. From an organizational perspective, the passage is from a hierarchical one to a value streams characterized by the right levels of empowerment, which means that the responsibilities must be pushed down the organization (Krafcik, 1988).

Lean Manufacturing has two main purposes: customer satisfaction and profitability. Everything has to provide necessarily *value* for the final customer, which is the reason why it is essential to understand what the customer actually wants and what is willing to pay for. A Lean organization understands customer value and focuses its key processes to continuously increase it through a perfect value creation process that has zero (or at

least minimum) wastes. From a practical point of view, Lean could be defined as "a journey to add value". By eliminating wastes along the entire value stream (instead of isolated points), Lean creates lower need of human effort, space, capital and time to make products. By reducing wastes and defects, "companies are able to respond to changing customer desires with high variety, high quality, low cost and with very fast throughput times" (Lean Enterprise Institute).
Moreover, even if the traditional view of profit is based on the equation "selling price is equal to profit plus costs", Taiichi Ohno explained that this view is not the best one. He started to look at profit as selling price minus costs (Ohno, 1973). According to his point of view, the selling price is the price that the customer is willing to pay for the perceived value of the product. Therefore, the profit is strictly related to cost reduction. Once clarified this passage, according to Lean perspective, it is clear that the best way to increase profitability is to reduce costs as much as possible.

In addition, the linchpin of Lean thinking is represented by the continuous research and elimination of non-value adding activities, namely those activities for which the customer is not willing to pay. It is possible to remove waste from many steps of the manufacturing processes: from how the initial product is developed, how the compliance to the design is assured, how to operate a completed facility (Melton, 2005).
Waste removal in itself is not the focus of any initiative towards a Lean implementation but it is surely a *must-have* to achieve. Ohno highlighted seven types of wastes, the so-called *Muda*, connected to a wasting of time, money or also resources: movement of products, inventory, physical motion of a person, waiting, over-production, over-processing and defects (Liker, 1996).

Table 2.1: Seven Types of Wastes (Muda) (Liker, 1996)

Type of Wastes	**Description**
Handling	Movement of products from a location to another or between operations
Inventory	Stock of finished goods and the work in progress (also raw materials)
Motion	Physical movement of a person while he/she is conducting an operation
Waiting	Waiting time for a product or for a machine to finish
Over-production	Producing more than what the customer asks for
Over-processing	Making operations more than what the customer requires
Defects	Reworked or rejected products due to some process errors

Moreover, not only *Muda* are critical, but also *Mura* and *Muri* must be considered. *Mura* is the waste of unevenness, which drives *Muda*: if a company fails in smoothing the

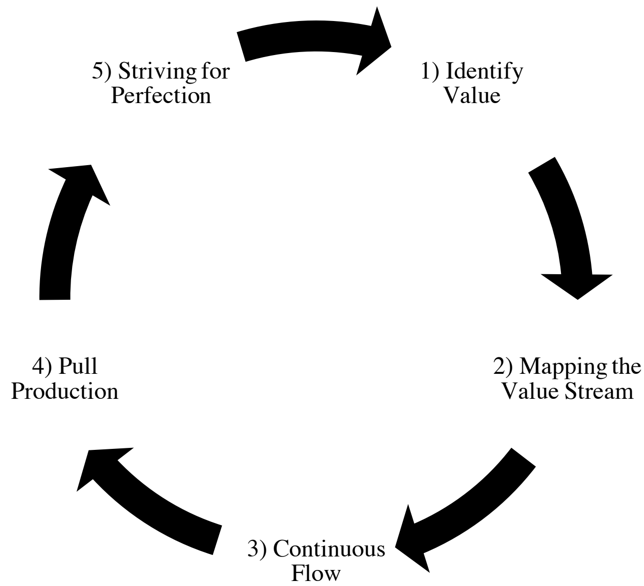
demand, this leads to variation and fluctuation which creates inventories and other wastes. Instead, *Muri* creates over-burden, namely an unnecessary stress given to the employees and the processes: they are caused by *Mura* (fluctuation of the demand), lack of training, failures in the production system or wrong tools (Womack, 2007).
By preventing and reducing wastes, Lean techniques allow an organization to reach many benefits: an improved quality performance due to fewer defects and pieces reworked both in house and at customer, fewer process breakdown, more involved, empowered and satisfied employees, improved supplier relationships, lower levels of inventory and, consequently, a greater level of stock turnover with less space required. The latter is a key factor for Lean that reduces the possibility of obsolescence and allows to release cash back to use into the business according to the general principle that "cash is king" (Gardner et al., 1994).

Nevertheless, Lean is not possible to implement overnight. As a matter of fact, it requires that the whole organization is committed and involved. A curious research conducted in U.S.A in 2007 and published in 2009 in the Journal of Operations Management (Anand et al., 2009) shows that among the 70% of American manufacturing companies which tried to apply lean practices, the 74% of them declared their total dissatisfaction because the results were not tangible. Moreover, matching the term Lean with Japanese companies is not always correct. In fact, even if Toyota is the symbol of the Japanese industry, only 20% of Japanese manufacturers had successfully implemented lean (Goldratt, 1990). This is coherent with the concept of change management and the idea that, first of all, a strong philosophy and a robust culture must support the usage of Lean tools. No matter the country or the industrial context, the success of *Lean Thinking* and therefore Lean implementation is built on the engagement of people and the orientation towards change of any level of the organization. The philosophy must successfully identify the value for the client, before the wastes (Womack et al., 1996). The improvements towards efficiency, possibly able to dismiss jobs, make people more reluctant to changes and more willing to prevent the implementation (Jadhav et al., 2014).
However, even if illustrated, the huge *high-level* topic of people and change management will not be debated in comparison to the Industry 4.0 ecosystem. The work behind the dissertation focused the attention more on *operative* tools and practices of Lean, together with the way in which they are sustained (and continuously improved) or disrupted in the new world of Industry 4.0.

2.2 Lean Principles

Following Lean methodology, the systematic elimination of these three sources of inefficiencies (*Muda*, *Mura* and *Muri*) is only possible through five *actions*, called *principles* by Womack and Jones, which are the reference points for process re-organization. The first action is the definition of value as perceived by the customer. The second action aims at identifying the value stream for each product. The third principle states that it is necessary to make a continuous product flow through the remaining value-added steps. The fourth action aspires to a flow which is pulled by the customer, where continuous flow is possible. The last principle aims at striving for perfection (Womack et al., 1996). These *actions* must be performed *ad infinitum*, every day, like a cycle for the continuous improvement.

Figure 2.1: Five cycling *actions* for Lean implementation (Lean Enterprise Institute, 2016)



2.2.1 Value

The identification of the value is the starting point in the process of waste elimination. The value is defined by the customer and it represents what he or she is actually willing to pay for; first of all, it is essential to define exactly what is valuable for the customer.

The great difference from the past is that the producer has not to force what is more convenient for the factory but must understand and listen to the customer. In this sense, organization use some tools like Brainstorming or Quality Function Deployment (QFD), in order to seek out the value-adding steps to make them as efficient and free of wastes as possible. In other words, it is possible to end up making no-value adding processes in a more efficient way just looking for wastes (Rother et al., 2003). Generally, the customer does not want to pay for reworking, transporting or waiting time (and other sources of wastes, cf. Liker, 1996).

The idea at the basis of the first *principle* could be summarized in the slogan *"customer first"* (Walker, 1990): the mission and the final objective of Lean is listening to the client in order to understand what he or she really wants and needs.

2.2.2 Mapping the Value Stream

Once having defined what is valuable for the client, the second action consists in *mapping the Value Stream*: it is constituted by all those interconnected activities necessary to transform the raw materials into finished product, producing value for the customer (Lovelle, 2001). The analysis of the value flow shows three different possible activities: value-adding activities, necessary non-value adding activities, which needs to be maintained (or at least minimized or optimized), and non-value adding activities which creates waste, and so must be eliminated. Another important aspect of the value stream is that it is analysed from the point of view of the whole product, without looking at individual departments (Howell, 2013). In order to map it, Lean thinking suggests for instance the visual tool of value stream map, which considers the current and the future state of the flow (Grewal, 2008).
This second *action* aims at understanding, within the process, what effectively adds value for the customer, what he or she is willing to pay for, in order to identify the process time and eliminate all the non-value-adding activities.

2.2.3 Continuous Flow

Once eliminated those activities that do not create value, the remaining activities must be arranged in a flow: the process has to be carried out without obstacles and interferences. The ideal flow is what is called *one-piece flow*, even if many times it is not feasible due to machine set-ups and the necessity to flow multiple products streams through individual

machines or cells. Generally, this flow is achieved using some tools from Kanban to small machines and cell design. Everything that stops the flow is a waste, so it has to be identified in order to be removed; it is necessary that the process can proceed without constraints (Krafcik, 1988).
Furthermore, each piece has to follow the *takt-time*, which is the expected production rate in order to deliver the product to the customer, or in other words the production pace in order to satisfy the customer request (Myerson, 2012). It is calculated through the ratio between total available time to deliver a product and the volume of product to be delivered (demand).

2.2.4 Pull Production

The fourth *principle* is the most critical and it is connected to the way production is organized and conducted. As a matter of fact, inventory is one of the main wastes and it must be eliminated. Thinking about the traditional metaphor of the boat, inventory hides the most of the problems within an organization and causes many other wastes (Gupta et al., 2014). Ideally, a system should produce only when the customer makes the order: the production must be pulled by the actual market demand (Spearman et al., 1992). Pull production is achieved using Kanban and supermarkets. Kanban is a simple and visible tool that allow to replenish the requested component, of course *called* by the external demand. In the workplace only a minimum stock level is left, and before its depletion, an instruction on the Kanban-card carried out by the operator assures a *just-in-time* replenishment. Just-in-Time means that, in order to ensure a flowing pull production and realize the right product, it is necessary to have right pieces, at the right place, at the right time. Through these tools, customer orders can be quickly satisfied at the moment and the components are manufactured from standard ones or taken from a small stock, that is successively replenished in the same way in which shelves in a supermarket are refilled when customers buy products (Kumar et al., 2007).
Of course, a pull production needs a high degree of visibility over the process, in order to be reactive when a product is required; in other terms, higher visibility support a more effective just-in-time production (Myerson, 2012).

2.2.5 Striving for Perfection

By reaching the first four *actions* the prevention of a huge amount of wastes within the organization processes is possible. Nevertheless, the fifth *principle* is more connected to the aspiration of this philosophy and the daily attitude which triggers its practical application. Lean focuses its attention on the final aim of pursuing a continuous perfection through caring about the daily operations: the focus must be put on the daily journey and not on the destination. Being better than the competitors is not enough because the main aim is to deliver value to the customers, by achieving *zero* wastes.

This strong ambition could be interpreted by the term *Kaizen*; it is composed of two Japanese words: *Kai*, which means change, and *Zen*, namely perfection, which together are translated in continuous improvement (Bhuiyan et al., 2005). Kaizen is more an attitude than just a process for getting improvements. Practically speaking, it is the attitude of each member of the organisation, who must be driven by the aspiration of improving every-day performances, through a never-ending cycle towards perfection. A collaborative and participative approach has to be established, in order to involve actively each actor in the continuous improvement process, by using in the field his or her competences, experiences, abilities and skills in the field. It is a behaviour focused on what *must* be done instead of what *could* be done.
The vision of continuous improvement is connected to a step-by-step, day-by-day enhancement, through little but continuous initiatives. In order to better explain this concept, this sentence may be useful "it is better the 50% immediately, rather than 100% never" (Bonfiglioli, 2001). This concept is strongly in contrast with the purely Western idea of innovation and revolution. Nevertheless, Kaizen alone is not useful to pursue the ambitious objectives of Lean: what is needed is also *Kakushin* (discontinuous improvement) and *Kaikaku* (revolutionary or radical change). In fact, every enterprise needs both approaches (radical and incremental) to pursue perfection (Yamamoto, 2010; Gåsvaer et al., 2012).

Typically, managers have the necessity to *learn to see*: to see the value stream, to see the continuous flow of value, to see value being pulled by the customer. It is possible to assume that the final form of seeing is to bring perfection into a clear view: in this way, the objective of improvement is visible and concrete to the whole enterprise. In turn, no

picture of perfection can be impeccable. Perfection, in a lean perspective, is like *infinity*. Reaching it is actually impossible, but the effort to do so inspires and provides a direction essential to make progress along the path. The difference between organizations that have done a lot and others that have accomplished little or nothing relies on the setting of “specific timetables to accomplish seemingly impossible tasks and then routinely met or exceed them” (Womack et al., 1996).
Kaizen needs a strong engineering during the planning phase and a high level of control over the process (like in Deming Cycle). Kaizen cycle goes through different steps: starting from the standardization of activities and processes, it measures them (in term of time and resources consumed), it evaluates all the possible improvement plans and innovates only when the process is saturated, which is standardized and implemented. Of course, this cycle is repeated *ad infinitum*.

2.3 House of Lean

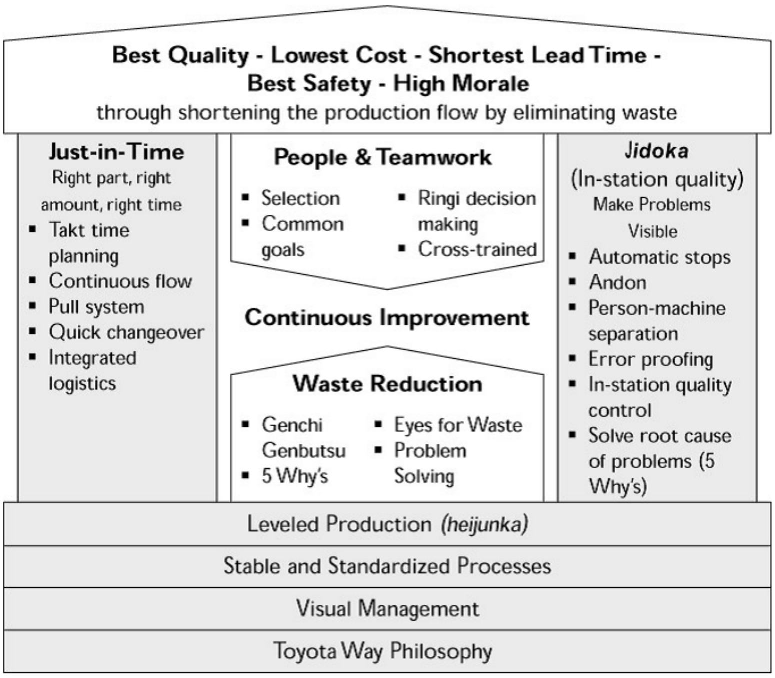
In their paper, Mrugalska and Wyrwicka associated, for each of the five *principles* previously presented, a step in the implementation of Lean (Mrugalska et al., 2017). After an initial phase in which a vision has to be established and a team built, the following steps are identifying products (value) and processes (value stream mapping), then reviewing the factory layout (continuous flow) and selecting an appropriate strategy (pull production), concluding with a never-ending process of continuous improvement (strive for perfection).

Lean paradigm is not limited to the definition of these five *actions*, but it has been explained in several different ways. One of the most common representation relies on a house as a figure to depict Lean paradigm.
For the first time, in 2004 Liker illustrated the most common lean tools in that shape (cf. *Figure 2.1*). There are two main pillars that support the roof of the house: Just-in-Time and Jidoka. People are at the centre of the house, since they see wastes and are able to solve problems, pursuing the paramount attitude of continuous improvement. As foundations, there are 4 main concepts that are Standardized Work, Visual Management and levelled production (Heijunka), together which a strong Lean philosophy, which allows the pillars to stand steadily.

It is worth to underline that the objective of Lean Production is to have *zero* wastes, not only to reduce them. The goal of the Lean production is set in the roof and consists of reaching "the best quality, lowest costs, shortest lead-time, highest safety and high morale" (Begam et al., 2013).

TPS diagram is depicted as a house because it revokes the idea of a structural system, as it is Lean thinking (Liker, 2004). If a weak link is present in the roof, pillars or foundations, it surely weakens the whole system. Moreover, each element is critical by itself as much as it is necessary for the general equilibrium of the system.

Figure 2.1: House of Lean production (Liker, 2004)



2.3.1 Toyota Way Philosophy

In literature, among the authors, dominates a view in which Lean is more than a set of tools (Bicheno, 2004), since it can be considered as a real philosophy (Pettersen, 2009). To be more precise, Toyota Production System (TPS) is only a part of a wider set of principles and behaviours enclosed in the *Toyota Way*: it is designed to provide the tool for people to continually improve their work. This system could be summarized in 14 management principles (Liker, 2004).

TPS supplies the guidelines for driving the change of mentality at the basis of this cultural transformation, which is supported by two mainstays: continuous improvement and respect for people. In fact, Lean is firstly a way of thinking, not a list of things to do (Shingo, 1989). The main difference between Lean and *buffered* systems comes from the philosophy at the basis: mass production aims at *good enough*; on the other hand, Lean Production aims at *perfection*, completely achievable through the attitude of Kaizen.
Furthermore, an important aspect of Lean is the involvement of all the people belonging to an organization (Womack, 2007). Everyone has to contribute to the implementation of the philosophy, as promoted by Juran, Deming and other quality Gurus (Juran, 1991; Deming, 2000) when workforce started to be considered as the greatest asset of the company. Of course, using the power of the workforce within the organization to eliminate problems allows to achieve a continuous improvement towards perfection.

Moreover, Toyota Way shares five paramount values and applies them to all the levels of the organization, to all the employees, in order to always satisfy its customers. These five values are *Challenge*, *Kaizen*, *Genchi Genbutsu*, *Respect for people* and *Teamwork*. (Toyota Motor Corporation, 2003)
Challenge means pursuing a long-term vision, by facing all the dares with necessary bravery and creativity.
Kaizen refers to continuous improvement attitude, a never-ending path towards perfection (Imai, 1986).
Genchi Genbutsu aims at finding the root cause of a problem in order to take corrective action to pursue the objectives.
Respect means to esteem all the stakeholders, by trying continuously to understand them and establishing a trustful partnership with them.
Teamwork means to share growing opportunities and to improve individuals together with team performances.

Finally, it is clear that TPS, interpreted as *Toyota Production System*, is not alone, but it goes with another TPS, namely *Thinking People System* (which is, in other terms, the Toyota Way), to achieve the third, most critical TPS: the ultimate *Toyota Profit System* (Mazzieri, 2015). Of course, each organization has to adapt this business model to the industry and its own company, in order to achieve the standard of cost, quality and safety as the ultimate goal of Japanese philosophy.

2.3.2 Stable and Standardized Processes

Once established a long-term vision, fundamental for the successful implementation of Lean philosophy, it is necessary to realize stable and standardized processes.

In order to foster improvement, firstly it is necessary to be stable in the 4 M's: Manpower, Machinery, Materials and Methods (Ishikawa, 1976). In order to keep stability in a process, without unforeseen variations, a deep knowledge of the situation is mandatory. Stability starts with standard work, a term which is strongly connected with other two important concepts: workplace organization and visual management, another bedrock of Lean House (Liker, 2004).

Standardization is a fundamental concept at the basis of Lean methodology. Standardized Work describes how to execute a typical process, according to the *best practices*, but it refers also to the foundation of an approach that allows the continuous improvement of learning processes (Dolak et al., 2004). It consists in the partition of work in an organized sequence of elements, accomplished repeatedly: in other words, the process is subdivided in packages, in which each phase has to be defined and carried out in the same way. Any form of variation could create an increase in cycle time and could result in quality issues. Instead, standardized work often aims at maintaining productivity, safety and quality every time at high levels (Pascal, 2002).

Three are the necessary components to obtain standardization: takt-time, work sequence and Standard Work in Process (SWIP).

In particular, takt-time is connected to the pace at which the production is performed. The word *takt* refers to beat, timing and regulation of speed. It is the largest time window for the production of a product in order to meet the market demand; the objective is to pursue the production at the same rhythm of the market (Feteke, 2013). The keyword is synchronization: production cycle has to match the external demand, in order to avoid both over- and under-production. Takt-time optimization aims at reducing wastes and inefficiencies, eliminating the risk of delays and excessive production within the whole process. Furthermore, takt-time differs from cycle time, which is the period required to complete a cycle of a certain operation, but also a function, a job, or a task from start to finish. It is the actual time needed to make one unit of production output (Ducharme et al., 2004).

Taking into consideration the concept of synchronization, all jobs within an area or a production line require the same time to be completed. The basic idea is that the lines

have to be balanced (Gurumurthy et al., 2011). Once line balancing is complete, for each operator the work sequence must chase a standard process. This means that each worker has to perform the job in the same manner every time, in order to achieve the best quality results (Pascal, 2002). Moreover, work sequence is connected to ergonomics. In fact, the process must be set up in a way in which the operator does the activities in the most ergonomically manner possible: ergonomics is optimized by workplace organization.
Lastly, SWIP or Standardized Work in Process is defined as the minimum necessary process inventory to maintain one-piece flow, another core practice of Lean.
All together these three elements are useful in order to subdivide the whole process in subgroups, increase the level of standardization and allow a better knowledge and control over the processes. As a matter of fact, "to improve a process, it is necessary to standardize it, once found scientifically one best way to do a task and frozen it" (Imai, 1986).

2.3.3 Visual Management

The concept of Standardization is widely used to make practically effective the concept of Visual Management. Manage the shop floor through naked-eye allows to see the progress state of industrial processes with the usage of simple tools, by increasing the level of visibility for the process actors. The final objective is to gather tangible information about results and progress, in order to highlight criticalities and solve them real-time (Parry et al., 2006).
Methodologies of Visual Management could be used not only during the process execution but also throughout the analysis of the process, allowing the continuous updating by defining improvement activities to be introduced, to reduce wastes. With few intuitive information, it is possible to define the status of a certain element in the process and identify the plan for improvement.
Of course, it occurs to prevent simple signals, appropriately calculated and easily adjustable when the process conditions change. Visual and effective tools, like warning signals, stripes, cards, document holder, coloured borders and the usage of graphic devices, stimulate the operators and immediately communicate important information. Everyone involved must be able to understand each part of the operation and its status at every time (Womack et al., 1996).

The concepts of Visual Management are strictly linked to the management *in view* proposed by 5S methodology for the optimization of workplace, in order to eliminate inefficiencies in the process (Michalska et al., 2007). Five S are the first letter of five Japanese words, which indicates the phases of implementation of that methodology: *Seiri* (Sort out), which means to separate what is useful; *Seiton* (Set in order), which refers to the re-organization of what is useful in order to be used easily by everyone; *Seiso* (Shine), which means to clean and tidy the workplace; *Seiketsu* (Standardize), which regards the standardization of the workplace activities and the communication of the correct operative methods to everybody; *Shitsuke* (Sustain), which means to respect the pre-defined standard for each workplace (Peterson et al., 2001).

5S is a methodology that supports Visual Management techniques and it brings different benefits: to make evident to anyone the behaviours of the system and the people not in line with objectives and pre-defined standards; to get people used to the attitude of cleaning and organizing the workplace, to improve continuously the working conditions; to use optimally the available space; to reduce wasting of time to find materials, tools and documents and the breakdowns of machineries; to make the workplace tidier and safer.

2.3.4 Levelled Production

Another important concept at the basis of the House of Liker is Heijunka, which means “production smoothing or levelling”, that together with takt-time represent the capacity to be flexible respecting the demand, by guaranteeing a fluid, constant and measurable process. Toyota officially defines it as “distributing the production of different body types evenly over the course of a day, a week, and a month” in the assembly process (Coleman et al., 1994).

Heijunka is a further technique to facilitate just-in-time production and, according to the Toyota Production System, is used to ensure that there is an inventory of product proportional to the variability of the demand. In fact, it is no more than the elimination of *Mura* (variability in the workloads) and it allows the right mix flexibility to change faster the production sequence. Heijunka allows also to eliminate *Muri* (over-burden), which could create quality and safety problems. Furthermore, the disruption of production flow is minimised by making sure that components will be available in the right sequence and quantity at the right time, by pursuing just-in-time logic.

The final objective of heijunka is to avoid valleys and peaks in the production schedule, in order to better organize the workforce and manage a steady process over the time (Huttmeir et al., 2009).

2.3.5 Just in Time

In his book, Taichii Ohno describes the two pillars of Toyota's production approach, which became the two pillars of the house proposed by Liker: Just in Time (JIT) and Jidoka (Ohno, 1988).

Starting from the concept of Just in Time, it means producing "the right item at the right time in the right quantity, following the takt-time" (Monden, 1993). It is connected to the elimination of the inventory: zero inventory is defined as a system in which a company keeps no (or very little) inventory in storage, simply producing what it needs to sell, according to a pull production system.
A production process which is flowing, constant and optimized, which have a working cycle accurately planned and measured, in which pieces move only when it is required, reduces the costs incurred by wasting in time, materials and capacity. Team members can focus their effort on their tasks without interrupting themselves, realizing a better quality, on-time deliveries and ensuring customer satisfaction.
The idea of Just in Time was stolen by Toyota Motor Corporation from a technique used by Ford which was defined "dock to factory floor", in which necessary components were put near the production line on the floor of the plant, without passing from the warehouse.
The masterpiece of Just in Time is the Kanban. Kanban is a plastic card which contains all the information required for the current production, for its stage and the next steps for the process completion (Kumar et al., 2007). In this system, the information about units needed, such as quantity and type, are written on a tag, a card which is sent from the operator of a process to workers of previous processes. In this way, many processes are connected to each other in the plant, in order to foster a better control of quantities needed for different production units.

JIT manufacturing systems set the first goal in the continuous reduction and elimination of all the wastes (Brown et al., 1991). Just in Time logic emphasizes the concept of Zero (*Zero Objective*), namely the achievement of zero defects, queues, inventories, breakdowns and inefficiencies. It is the paramount pillar at the basis of pull production, which consists in a sequence of workstations involving value addition in each of them (Spearman et al., 1992). Based on this pillar, companies aim at operating with a very low level of inventory and a very high level of quality and productivity (Sugimori et al., 1977).

2.3.6 Jidoka

The notion of reducing cost by eliminating waste was developed by Ohno out of his experience with an automatic loom which stopped every time the thread broke, in order not to waste materials or machine time. Ohno stated that the loom was "a text book in front of my eyes" (Cusumano, 1985), and this concept became an integral part of the TPS. It went under the name of Jidoka, the second pillars of the House of Lean (Liker, 2004). In fact, Jidoka supports JIT techniques because it never allows defective parts from previous processes to flow into and disrupt a following step (Monden, 1983).

Jidoka aims at providing machines and operators the ability to detect abnormalities and then immediately stop the work. It is also known as "automation with a human touch" (Liker, 2004): the equipment has the ability to distinguish good parts from bad ones autonomously, without being supervised by an operator. The quality is monitored in each phase: each team member is responsible for the quality checks before delivering the product to the following phase. Once detected a defect, the problem is immediately faced, by stopping the production flow, if needed. Indeed, Jidoka is also defined as "the decision to stop and fix problems as they occur rather than pushing them down the line to be resolved later" (Liker et al., 2006).

Jidoka includes also Andon and Poka-Yoke. Andon is a simple board, well-visible within the plant, which indicates the status of production line. It notices immediately if and which operator has detected a breakdown; as a matter of fact, the operators are responsible of quality in production and have the authority to stop production if necessary in order to solve the occurred problem (Parry et al., 2006). Additionally, Poka-Yoke is the Japanese method to eliminate the possibilities of producing defective products (Dudek-Burlikowska et al., 2009). It is an easy but reliable way to reduce the errors and keep a high level of quality. There are two different types of Poke-Yoke systems: warning systems, which send a signal when there is a deviation from the standard, and control systems, when a machine automatically stops whenever there is a deviation from the

standard condition (Shingo, 1989). Typically, there are devices which avoid (almost) completely the operators to commit traditional mistakes in their workplaces.
Again, Jidoka is another paramount concept in Lean, because it is important to preserve a high level of quality along the whole production process. Even if each member has the responsibility to stop the flow, this does not have an impact on the delivery to the customer; in fact, the productivity increases, the idle time decreases and the return of investments grows. The final aim of Jidoka is making the problem visible, and then providing an *in-station* quality. Once a problem is detected, the line is stopped until a solution is found. A possible tool in the identification of the causes to foster an effective solution is the Five Whys analysis (Ishikawa, 1976).

Moreover, connected to the concept of Jidoka and, to a larger extent, the prevention of errors, it is possible to talk about Total Productive Maintenance (TPM), which aims at eliminating the breakdowns (Willmott, 1994). TPM is composed of three words: *Maintenance* refers to that activity aimed at the conservation over the time of the efficiency of plants; *Productive* means that it seeks at improving the productivity of the plants; *Total* refers to the complete and active engagement of the workforce. TPM aims at lowering delivery time in order to provide products with high quality and low costs (Wireman, 2004). It is structured in pillars, each one focused on the elimination of a group of losses in line with the organizational objectives (Venkatesh, 2007). The pillars are introduced involving all the company functions, from operators to plant manager.
TPM works through small groups of work in order to obtain the maximum level of efficiency, focusing on the reliability of the processes and the elimination of their breakdowns. OEE (Overall Equipment Effectiveness) is the main Key Performance Indicator to monitor the results achieved. It is the ratio between value-adding operative time (time in which the machines are actually used) and total available time (Ahuja et al., 2008).

2.3.7 Waste Reduction: Problem Solving Approach

In order to achieve Lean final goal, illustrated in the roof of the house (Liker, 2004), the two above-mentioned pillars must be supported by the attitude of continuous improvement, already explained in the previous section of this dissertation (cf *Section 2.2.5*). Additionally, not only Kaizen needs people committed to it but also a hidden and strong inclination for waste reduction. In fact, Liker states that Lean Manufacturing is a philosophy which, once implemented, decreases the time from customer order to delivery, through the elimination of sources of waste in the production flow (Liker, 1996). This behaviour of reducing wastes in the process until their elimination is another important reference point for the successful implementation of Lean, which is strongly connected to the approach of problem solving. As a matter of fact, TPS is not only a set of tools, but it devises a philosophy to refer in problem solving, which aims at searching and analysing the situation from different perspectives. Indeed, each member of the organization has to be aligned with the business objectives and foster continuous improvement, by leveraging on teamwork (Bhuiyan et al., 2005). In other words, each member of the organization is essential in the decision making process and can bring his contribution for Kaizen (Imai, 1986).

At the basis of Lean Problem Solving there is the basic idea of a continuous enhancement through an iterative approach designed by William Edwards Deming (Moen et al., 2006). The so called Deming Cycle (PDCA) is composed of four repetitive phases, namely Plan, Do, Check (of results) and Act. After an initial phase of planning (Plan), where activities are studied in order to define the final objective, the execution phase (Do) is when are performed. The monitoring phase (Check) is the core one: it coincides with the moment in which feedbacks are gathered and analysed, in order to identify variances and problems and subsequently organize possible corrective actions for improvement. These planned activities are put in action in the last phase (Act), that could be followed by a re-planning and so a re-start of PDCA cycle.
Taking the cue from Deming studies, Toyota developed a structured approach for problem solving, named A3 Process (Sobek et al., 2011). The aim was finding a simple procedure with immediate effect: in doing so, all the information should be written in a A3-size sheet. This allows to focus on necessary information to solve the problem, without getting lost in useless details. Another advantage is related to the engagement of people, by fostering communication and participation: each actor is allowed to write on the A3 sheet each time new information or problems emerge. The A3 model is composed of seven areas, following the PDCA cycle: Background, Current Situation, Goal and Root Cause Analysis (Plan), Countermeasures (Do), Confirmation of the results (Check) and Follow-up plan (Act). Moreover, this structured and precise approach is supported by

other problem solving techniques like Value Stream Mapping, Fishbone Diagram and Five Whys.

To be more precise, Value Stream Mapping (VSM) is used to map the current situation, in order to identify where the value for the customer is created and later focus on areas to be improved, by the elimination of non-value adding activities (Rother et al., 2003).

The Fishbone Diagram (or Ishikawa Diagram) is one of the most interesting tool used in problem solving, because it affords the identification of all the trigger factors until the root cause of the problem. In order to go deeper into the analysis of the justifications for each factor, the Five-Whys technique is used to find the issues and continue proposing solutions. As a matter of fact, Kaizen requires that, before the implementation of a certain improvement plan, the rationale and the benefits of all the measures are evaluated with close attention. This is why Five-Whys technique is so important: each planned improvement has to be criticized and questioned before its implementation, moving towards five level of *whys* in order to be sure of the final result (Ishikawa, 1976).

The logic behind these techniques founds its rationale on the concept of Genchi Genbutsu, which literally means “going to the source”; it is necessary to evaluate all the causes in order to analyse the root of the problem, by understanding it in a complete and accurate manner, instead of relying on information provided by third parties (Haghirian, 2010).

2.3.8 People and Teamwork

In mass production, process was designed in a repetitive way, in order to allow also unskilled workers to easily complete their tasks. On the contrary, in Lean enterprise, workers have higher number of tasks and responsibilities: they are able to trace each problem quickly and find the ultimate cause (Poppendieck, 2002). The focus moves to people who add value. Organization becomes team-oriented, centred on value stream and no more on functional expertise (Womack et al., 1990). The attitude of continuous improvement must be shared by the whole organization, through the support of top management and also the necessary engagement of people. For them, companies must set common goals, which are specific and measurable.

As also other works in literature underlined, respect for people is one of the main principles of Lean, together with the slogan *Elimination of Waste* (Taleghani, 2010). *Respect for people* is presented as a new idea for management teams (Cardon et al., 2015). Of course, it is necessary to change the approach towards decision making process. In

fact, the traditional autocratic decision making practice was overcome in order to pave the way to the new *Ringi* decision making process. It is based on a bottom-up approach, in which more members of the organization are invited to endorse on a decision, in order to foster collaboration in finding the optimal solution for a problem (Sagi, 2015).
People must be involved every time to implement Lean paradigm successfully. It is mandatory, before the implementation, to establish the correct mind-set in the whole organization (Bicheno et al., 2016). The internal resistance in Lean implementation is strong and it is necessary to change the culture of the company towards Lean approach. Of course, change management must be strongly customer-driven, in order to foster the value creation for the customer at all levels of the organization. Furthermore, in order to support the continuous improvement process, people must be engaged and continually trained on each job, following a cross-trained approach *company-wide*, by fostering a better team effectiveness (Marks et al., 2002).

2.4 Application Fields

The implementation of a pull production system requires the intervention on different operational areas, by using a series of tools and techniques that together constitutes the core of Lean production. Lean methodology is applied in practice specifically in different areas, with different objectives through diverse techniques: product design, process design, production management, workforce management and suppliers' management.
According to product design, the objective is to simplify as much as possible the product, and to re-think the engineering phase in terms of global costs. This is achievable through modularization and standardization of components and processes.
According to process design, it is necessary to guarantee the process flow, the temporal uniformity of the mix and the operative regularity. The flow of process is obtainable through Group Technology, new layouts, split of production capacity and the implementation of dedicated or mixed-model lines. The temporal uniformity is achievable by reducing set-up time, while the operation regularity is obtained by process quality and the availability of means.
Production management needs a perfect synchronization between production and market demand, together with a simplified management system in order to fasten the production flow. Respectively, these objectives are achieved through a levelled and synchronized production planning (Heijunka) and through an operative production plannig, with a flat

bill of materials, a pull control of the flow, an overlapping of activities and Visual Management techniques.
Regarding the area of workforce management, it is possible to intervene in order to achieve a high level of professional flexibility and decisional authority (though job enlargement and enrichment) and adapt the workforce to market requests.
Regarding the last area of intervention, the suppliers' management, it is necessary to assure reliability and synchronisation in deliveries. It is possible to reduce the number of suppliers and their distances, to certify their quality, to establish long-term partnerships with them and to evaluate them according to cost-driver and their improvement trend. In order to foster just-in-time replenishments, it is necessary to be pulled by the market and it requests small lots, with high variety and high frequency.

Moreover, practically speaking, pull production systems like TPS with above-mentioned just in time techniques perceives the *Zero* objective (Kumar et al., 2007). For instance, Kanban aims at reducing the level of inventory; TQC (Total Quality Control) is focused on the elimination of defects; TPM supports the elimination of breakdowns; finally, Sekkei Kanri allows to reduce the time to market (Koudate, 2003). Of course, the *Zero* approach has to be implemented and achieved every day with the attitude of Kaizen.

The following section introduces the other topic of the dissertation, Industry 4.0 (cf. *Section 3*). After a brief presentation, an accurate review of literature is presented, in order to show the researches previously made about the comparison between the two industrial *languages* (cf. *Section 4*). Finally, the missing part is the core of the dissertation, namely the explanation of the model (cf. *Section 5*).

3. INDUSTRY 4.0

3.1 Current Situation

As already presented before, Industry 4.0 conveys a view of the future in which manufacturing companies will increase their competitiveness and efficiency, through the higher interconnection and cooperation of their resources (namely machineries, people and information), both internal (to the Factory) or external (spread along the value chain). This radical improvement will be enabled by modern industrial technologies, from software to automation, that still today allow the increase of human productivity and the change of traditional and rigid models inherited from Taylorism to flexible archetypes more customer-driven. As a matter of fact, the Fourth Industrial Revolution, sometimes also called Smart Manufacturing, is connected to the concepts of servitization, mass-customization of products and remote control of processes. In other words, Industry 4.0 will afford the integration of all these industrial technologies, emerged during the Third Industrial Revolution, in a complex mechanism in which companies will be able to reduce inefficiencies, by adding value to the knowledge and improving the ability of planning and anticipating the market.

Many experts and authorized personnel think that the Fourth Industrial Revolution begun years ago. Industry 4.0 refers to a series of changes in the way in which products are produced and services delivered: by producing thanks to the systematic application of IoT (Internet of Things) and by delivering processes in a large scale through the usage of different technologies. The concept may be enlarged, as a possible scenario, also in the change of production relationships between employer and employee, fostering a wider corporate re-organization.

Industry 4.0 makes possible to collect and analyse information across machines, enable faster and more flexible response, but also more efficient processes in order to produce high quality products at a lower cost. All these components will lead consequently to an increase in manufacturing productivity and industrial growth, and then the modification of the profile of the workforce.

The fascination for *Industrie 4.0* is twofold. On the one hand, for the first time an industrial revolution has been predicted *ex-ante*, not observed *ex-post* (Drath et al., 2014).

Obviously, this allowed companies to find and exploit various opportunities and researchers to shape the future (Hermann et al., 2016). On the other hand, this revolution was supposed to be huge, bringing with it promises such as an increasing operational effectiveness and the creation of completely new business models, entrepreneurial modes, services and products (Kagermann et al., 2013). Just to give a rough economic benefit, a recent study estimated that Industry 4.0 will contribute for 78 billion euros to the German GDP by the year 2025 (Bauer et al., 2014).

Nevertheless, not everyone has a clear definition of what Industry 4.0 exactly is.

3.1.1 Industrie 4.0: the Birth of Fourth Industrial Revolution

The term *Industrie 4.0* is a concept that takes its origin in Germany in 2010 and which was for the first time introduced to the public by the GEF (German Engineering Federation) at 2011 Hannover Messe, the world's biggest industrial fair. It was initially defined as the digitization and automation of supply chains, comprehending a transition to greater levels of interconnectivity, smarter manufacturing and communication between people, machines and equipment.

It symbolized the advent of the Fourth Industrial Revolution, in which the use of three main technological innovations (automation, IoT and artificial intelligence) would have helped to create ground-breaking industrial and economic models.

While during the Third Industrial Revolution mass production in factories, automation and delocalization had main effects in optimizing cost (prices), through raising volumes to a level at which investment was justified, the Fourth Industrial Revolution changed the scenario. The factors that create value are no more volumes, the scale effect or the labour cost, but the product and service customization and the reduction of capital employed in economic terms.

Therefore, industrial players started investing significant resources in Industry 4.0 due to the fact that traditional productivity levels had been widely exhausted. In 1970s and 1980s, Lean adoption was the enabler, especially with the implementation of Toyota principles in Western regions. In 1990s, outsourcing and off-shoring allowed greater profitability by moving low-skills manufacturing to LCC (Low Cost Countries). In 2000s, the advantage of offshoring started to shrink whereas LCC wages raised up and freight cost increased.

Nowadays, the key factors of competitiveness are time to market and customer responsiveness, so companies are investing in robots, technologies and automation, redesigning their entire manufacturing networks and moving closer to their customers. Moreover, the disruptive technologies at the centre of Industry 4.0 will help Smart Factories to be highly efficiency and enable data integration, which is the core driver in this new paradigm.

3.2 Traditional Solutions

At the centre of this changing paradigm are the digital technologies. These are the means, not the goal of the Fourth Industrial Revolution. These technologies are called commonly *Smart Manufacturing Technologies* and are the starting point of a digitization process of the operations that finds its roots in the past, in what are called *Traditional Solutions*. The Traditional Solutions represent the kick-off of an innovation process and they can be found in the field of production and logistics, but also in the engineering and product development process.

3.2.1 Solutions in Logistics and Production

In the area of logistics and production, different Traditional Solutions can be found.
For instance, SCADA (Supervisory Control and Data Acquisition) and PLC (Programmable Logic Controller) are responsible for fundamental operations like data acquisition, supervision and control (SCADA), but also implementation of control logic based on a specific program (PLC). They are at the basis of industrial automation (Boyer, 2009).
MES (Manufacturing Execution System) is an operations management system aiming at the optimization of manufacturing operations and at the integration with the whole enterprise (ERP) (Saenz de Ugarte et al., 2009).
Moreover, scheduler is a flexible and Smart tool able to formulate an operative short-term program of production.
APS (Advanced Planning System) is a system designated to monitor the effective production progress and the level of resource consumption.
In addition, WMS (Warehouse Management System) refers to a system able to control and manage all the warehouse logistic processes (Novàk et al., 2011).

CMMS (Computerized Maintenance Management System) is a system responsible for managing information to control and oversee maintenance processes (Garg et al., 2006). Finally, SM (Safety Management) is a system designated to monitor the safety conditions of the process.

3.2.2 Solutions in Product Development and Engineering

In the area of product development and engineering, many others had been developed.
CAD 2D/3D allows to design technical document in a PC in two dimensions, following the technical design standard, or three dimensions, and providing a more realistic view of the product.
FEM (Finite Element Method) and CFD (Computational Fluid Dynamics) are systems designated to the analysis and the simulation in order to evaluate the structural behaviour and fluid dynamics of components and systems, aiming at reducing development process.
PLM (Product Lifecycle Management) concerns a set of tools able to coordinate and support development and engineering processes (Stark, 2015).
PDM (Product Development Management) is responsible for the management and the storage of technical data of a product (Loch et al., 2008).
Lastly, Configuration Lifecycle Management (CLM) supports the management of different configuration of bill of materials especially for complex and dynamic products.

3.3 Smart Manufacturing Technologies

These traditional solutions are the pillars of the *Smart Manufacturing Technologies* of Industry 4.0. As a reference point, it was decided to take into consideration the subdivision of Industry 4.0 Observatory of Politecnico di Milano. For the Observatory, Industry 4.0 is defined as "a vision of the future of Industry and Manufactuirng in which Information Technologies are going to boost competitiveness and efficiency by interconnecting every resource (data, people and machinery) in the Value Chain" (Politecnico di Milano, 2017). According to Politecnico di Milano's point of view, Smart Manufacturing Technologies can be divided in two main groups of technologies, presented in detail below: they are Information Technologies (IT) and Operational Technologies (OT).

3.3.1 Information Technologies

The first one is a more cohesive group, which includes Industrial Internet of Things (IIoT), Industrial Analytics and Cloud Manufacturing.
Industrial Internet of Things represents a path in which every physical object acquires its digital alter-ego (Jeschke et al., 2017). These products are Smart Objects, which are able to identify and localize themselves, make diagnosis about their conditions, acquire and elaborate data, take decisions and communicate to centralized controllers, in order to enable real-time responses. The application in the industrial sector of Smart Objects and Smart networks (open, standard and multi-functional ones) is gathered under the paradigm of CPS (Cyber-Physical Systems), which will be discussed later on in *Section 3.3.4* (Baheti et al., 2011).
Industrial Analytics are tools and methodologies that allow the elaboration of a huge amount of data, the so called *Big Data*, coming from IoT systems connected with the manufacturing layer or also from the data exchange between IT systems that support planning and flow integration process. This collection and comprehensive evaluation of data from many diverse sources, from production equipment and IT systems to enterprise and customer management systems, allows to support real-time decision making.
Finally, Cloud Manufacturing guarantees an open, shared and programmable access to resources, though internet, in order to support production process and manage efficiently the whole supply chain (Armbrust et al., 2010). A greater data sharing across sites and company boundaries is necessary to achieve reaction times of just several milliseconds. Cloud enables more data-driven services for production systems, also the control process is cloud-based. The accessible resources can be at infrastructural level (IaaS: Infrastructure as a Service), at platform level (PaaS: Platform as a Service) and at manufacturing level, by the virtualization of manufacturing resources (MaaS: Manufacturing as a Service) (Buyya et al., 2009; Xu, 2012).

3.3.2 Operational Technologies

The second group is more heterogeneous and enables a great interconnection between resources used in the operational processes. It includes Advanced Automation, Advanced Human-Machine Interface (HMI) and Additive Manufacturing.

Advanced Automation refers to the recent evolution of the automated production system. The more evident case is the one of Co-bots (Collaborative Robots), designed to work side-by-side with individuals in safety conditions. These robots are becoming more autonomous, flexible and cooperative, and they can learn from humans (Colgate et al., 1996).

Advanced Human-Machine Interface (HMI) makes reference to wearable devices and to interfaces able to acquire data or manage information in vocal, visual or tactile format. Two examples can be seen in touch displays and in 3D scanner, suitable for acquiring gestural movement (Downs, 2005). Also Augmented Reality is a case of HMI: it supports a variety of services, such as the picking of parts in a warehouse and the dispatch of repair instructions over mobile devices. Augmented Reality aims at improving work procedures and conditions and enables faster decision making (Nee et al., 2012). Another application of Augmented Reality can be virtual training for workers.

Additive manufacturing is also known as 3D printing, which produces objects through a layer-by-layer printing (Yoo et al. 2016). It is widely used to produce small batches of products which are customized and can offer construction advantages, like complex and lightweight design in aircrafts. Additive manufacturing can be applied in four different contexts: Rapid Prototyping, Rapid Manufacturing, Rapid Maintenance and Repair, Rapid Tooling (Wong et al., 2012).

3.3.3 Smart Lifecycle, Smart Supply Chain and Smart Factory

In this innovative scenario, these Smart Manufacturing Technologies can be integrated in order to connect resources, innovate processes and bring intelligence and Smart Solutions. They are applied in three main fields: Smart Lifecycle, Smart Supply Chain and Smart Factory.

Smart Lifecycle refers to the whole product development process, including the management of its lifecycle and the suppliers involved in these phases. In this field, the Cloud Manufacturing is widely common to boost collaboration with suppliers, for a better product development process.

Smart Supply Chain includes the planning of physical and financial flows in the whole supply chain. It has not a lot of applications, the main ones are concentrated in the usage of Industrial Analytics for optimizing planning processes.

Smart Factory, which is the most developed field of application, involves core manufacturing processes, like production, logistics (both internal and external), maintenance, quality and safety compliance.

3.3.4 Cyber-Physical Systems (CPS)

Probably, the most fascinating application of Industry 4.0 are Cloud Manufacturing (cf. *Section 5.3.2*) and Cyber Physical Systems (CPS). The latter is probably the most sophisticated composition of different Smart Technologies, and so also the most critical to understand.

A CPS is defined as a system in which physical object can be integrated with elements that enable calculation, memorization and communication. The term *physical* is easy to understand, while the term *cyber* is trickier. It refers to a virtual alter-ego (also called *Digital Twin*) which reflects the world in which the physical object belongs. This digital image has a life in ICT (Information and Communication Technology) environment. Taking the perspective of a manufacturing environment, CPS comprehends Smart Machines, storage systems and production equipment able to autonomously exchange information, generate actions and control each other independently (Lee et al., 2015).

There are several benefits promoted by a CPS. Firstly, they foster new data-driven services and new business models, that allow companies to be closer to the clients' needs and to add value for them. Moreover, they allow data-based improvements for products, in order to obtain real-time feedbacks from clients and boost visibility for creating more customized services and products. They can have a strong impact on different actors of the value network, from suppliers to clients. Again, they enhance the creation of a *cyberized* plant, in which system flexibility is the main advantage, in order to obtain an easy set-up of the production system and to facilitate the optimization of the operations management. Also the assets management is increased, providing a next step production efficiency. Finally, also the workers may have benefits, due to a digital ergonomics of the work conditions: this means faster flow of knowledge in the factory, quicker improvement in work experience and lower complexity of operative tasks.

The fast spread of this new phenomenon was mainly due to the recommendation for implementation suggested by German Government, which coined this term, strongly focused on the importance of CPS. As it was reported in the final Report of Industrie 4.0 German Working Group called "Recommendations for implementing the strategic

initiative Industrie 4.0", it is reasonable to assume that in the future "businesses will establish global networks that incorporate their machinery, warehousing systems and production facilities in the shape of Cyber-Physical Systems (CPS)" (Kagermann et al., 2013).
This huge topic will be addressed in a more specific manner in *Section 5.3.7*.

3.4 General Opinions towards Industry 4.0

As reported by McKinsey, Industry 4.0 is more than just a flashy catchphrase; it does not simply mean introducing isolated new technologies but rather thinking about the factory as a whole as a fully integrated ecosystem (Baur et al., 2015). Smart Production, Smart Logistics, Smart Grids and Smart Products together with Industrial Internet of Things and Services in manufacturing are going to transform value chains and lead to the necessity of new business and entrepreneurial models. Industry 4.0 offers the possibility of getting new opportunities and creating a different way of thinking about the factory at all.
The sectors in which the paradigm of Industry 4.0 is more widespread are machinery, automotive, aeronautics and defence industries.

3.4.1 Potential Benefits

In general terms, the benefits obtained are related to a better and more flexible planning and control process, to a higher customer satisfaction and an improvement in company image, but also to a reduction in costs and a consequently increase in companies' revenues.

Smart Technologies will definitely transform the production from optimized and isolated cells to fully integrated data and product flows across borders, which lead to a greater efficiency. They will change the traditional relationships between suppliers, producers and customers, but also between human and machines. Specifically, along the value chain the production processes will take advantages through integrated IT systems.
The manufacturing processes will raise the flexibility and pave the way for the production of small lot sizes. In fact, this flexibility will be provided by Smart Machines and Products that will be able to communicate between each other (cf. *Section 3.3.4*).

The usage of autonomous vehicles and robots will adjust automatically the production needs and enhance faster response to unforeseen events.
Products, production processes and production automation will be designed virtually in a single integrated process, also thanks to the collaboration of suppliers and producers.

In the end, Industry 4.0 will bring benefits to productivity, revenue growth, investment and employment. It enables a dematerialized control, which will be faster, more efficient and *in remote*, which means anytime anywhere (Boschi et al., 2017).

3.4.2 Barriers for Implementation

In “Industry 4.0 after the initial hype”, McKinsey Digital reported that 90% of companies saw the application of Industry 4.0 as an opportunity rather than a threat, especially in Germany, and that they expected an increase in their competitiveness in the next few years (McKinsey Global Institute, 2016).
Even so, these companies mentioned different barriers related to the implementation of Industry 4.0. Firstly, it emerges the difficulty in coordinating actions across diverse organizational units. The walls between different functions make the coordination of digital strategy and projects really hard across the entire organization.
Another barrier mentioned is the lack of courage to achieve a radical change, both technical and organizational. This is related to the topic of change management, strongly present also in Lean.
Companies faced also a problem connected with the lack of necessary talents. As a matter of fact, Industry 4.0 will need people with the necessary skills and expertise to manage the new paradigm and make it works. Since the Fourth Industrial Revolution will require new skills, there will be many job losses in some work categories, like manufacturing and maintenance, whereas also some gains in others, such as IT. The most desirable skills in Industry 4.0 are data management, software development, programming, data security, data science and analytics.
Another concern is about cybersecurity, especially when companies work with third-party providers. Many companies are hesitant to share their information and data to other partners. It is a matter of trust: secure and reliable communications, but also sophisticated identity and access management of users and machines are essential to cope with this issue.

Moreover, one of the most important barrier is related to the lack of clear business cases that justify such investments. The money required for new technologies are significant, and so accurate and clear plans for their Industry 4.0 expenditures are needed, especially for those companies with concerns about their ability to cover the necessary investment. However, this investment is necessary for maintaining competitiveness in the industry and in this changing environment.
Additional barriers, especially for those organizations that have already started the digitization process, are presented, like some worries about the ownership of data, for instance when a company works with external partners. This issue is deeply connected with the above-mentioned cybersecurity question, by adding the issue of losing ownership over their data.
There are also uncertainties about which technologies source internally and which acquire or learn from third-party providers.
Lastly, companies face the challenge of integrating data from disparate sources. In fact, Industry 4.0 works by pulling data together, which is really critical because this integration could be a difficult task to implement.

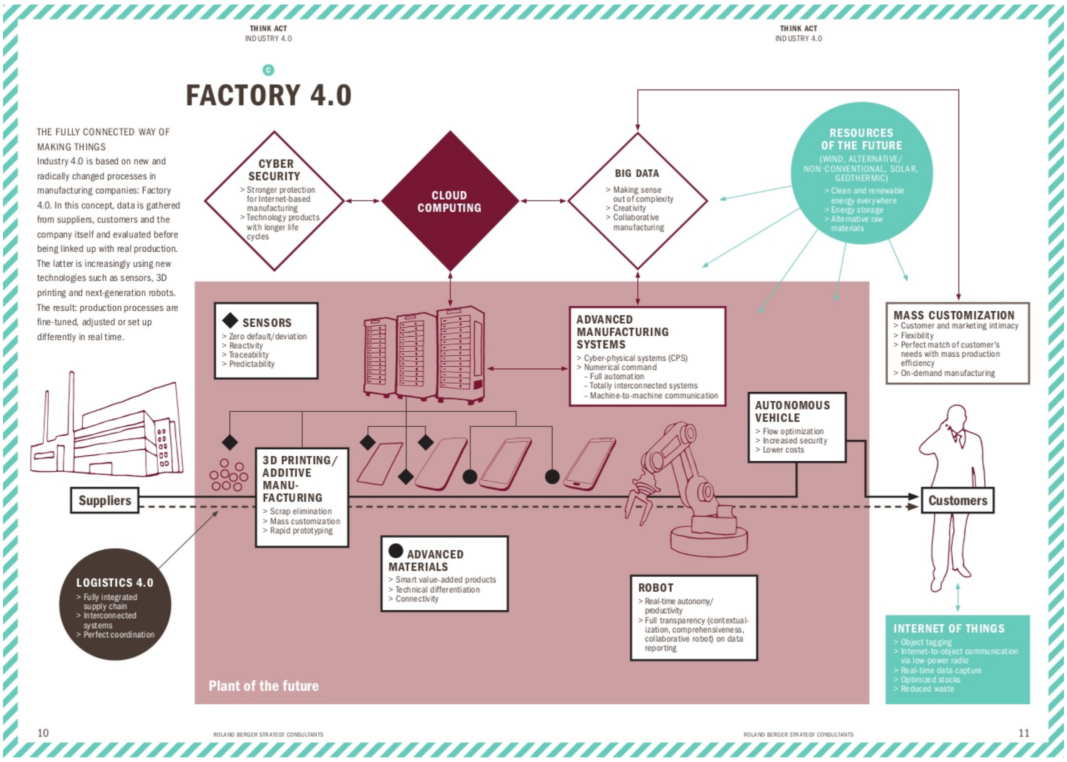
Moreover, in *Section 3.3* it was written that the presence of Traditional Solutions paves the way to the implementation of Industry 4.0. On the contrary, the restricted diffusion of these technologies represents a limit in digital maturity and readiness of processes. As a matter of fact, the lack of appropriate Traditional Solutions in a company coincides with difficulties in the application of new and more advanced technologies, enabling Industry 4.0.
The main point here is that the Fourth Industrial Revolution has its foundations in the Third one. In order to invest in new Smart Manufacturing Technologies, a deep knowledge of the corporate status quo is mandatory: the level of *digital readiness* to change is the starting point to plan decisions and add a significant value to the company processes and the whole value chain.

3.5 Example of Smart Factory Provided by Roland Berger

Before presenting the literature review regarding all the papers written recently about the comparison of Lean and Industry 4.0, it was decided to show briefly an example of how should be organised and should work the *Factory of the Future*.

The reference point was identified in Roland Berger's publication of 2014, "Industry 4.0: the new industrial revolution – How Europe will succeed". The opinion of the German consultancy company is clear: "The fourth industrial revolution is already on its way; revolutions are fast, disruptive and destructive, and there is no going back; Industry 4.0 will be an answer to the challenges lying ahead" (Roland Berger Strategy Consultants, 2014). The firm proposed a *disruptive* overview of what they called *Factory 4.0*. It is seen as "an interconnected global system on a microeconomic level". In *Figure 3.1*, the model though by Roland Berger is depicted. The graph shows the key factors, like supplier network, resources of the future, new customer demands and the means to meet them, if it is considered the part outside the factory. Instead, inside the factory, Roland Berger imagined new production technologies, new materials and ways of collecting, processing and sharing data.

Figure 3.1: Factory 4.0 (Roland Berger Strategy Consultants, 2014)



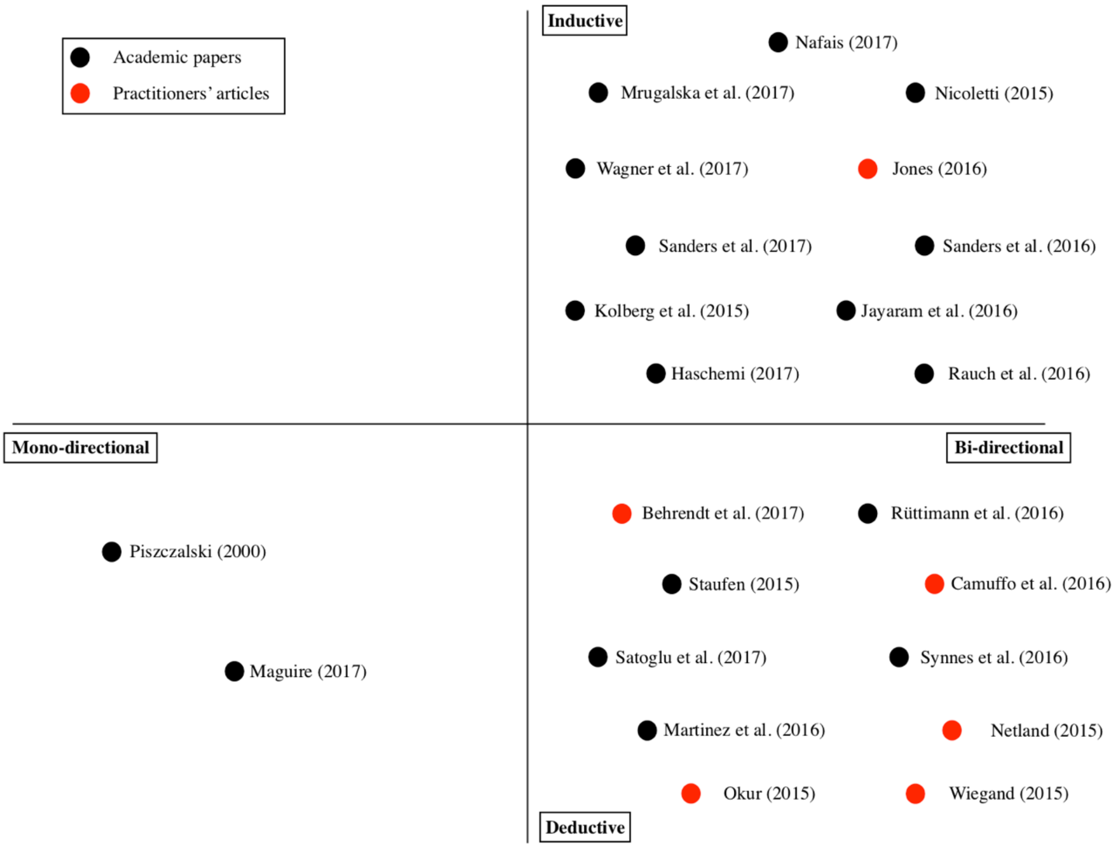
4. LITERATURE REVIEW

This systematic literature review has the aim of clarifying what has been already studied and reported by academics and practitioners about the relationship between Lean Manufacturing and Industry 4.0. It was decided to select scientific researches and academic conferences from Scopus, Research Gate, Google Scholar and ScienceDirect. Regarding articles written by practitioners, they were found on Websites or magazines and accurately selected in terms of reliability (e.g. articles where a professor was interviewed or consultancy projects). All the papers and articles were searched starting from some keywords such as *Industry 4.0*, *Lean*, *Lean 4.0*, *Smart Manufacturing*, *Smart Lean Factory/Production*. More than thousands papers were found considering just Lean Manufacturing and Industry 4.0. They were mainly used for a deep understanding of the two theories.
Considering the other keywords previously mentioned, around 350 papers were found. However, only 17 academic papers and 6 practitioners' articles were completely relevant: they truly investigate the relationship between the two, according to different perspectives. It is worth to underline the novelty embedded in this topic, considering that the majority of the articles completely read were written in the last three years.

It was decided to classify the specific readings investigating Lean-Industry 4.0 relationship according to two dimensions.
The first one refers to the method adopted by the author(s) to approach the topic and express his(their) opinion, which could be *deductive* or *inductive*. Basically, a deductive method is based on hypothesis and premises and, finally, an inference. On the contrary, inductive reasoning makes broad generalizations from specific cases observed.
The second dimension is strictly related to the relationship between Lean Manufacturing and Industry 4.0: *mono-directional* or *bi-directional*. In order to clarify this last subdivision, it is worth to underline that Lean Manufacturing is considered the existing business philosophy on which Industry 4.0 takes shape. On the one hand, a relationship is mono-directional if Lean is a pre-requisite in order to avoid the digitization of inefficiencies, but the two paradigms are completely different; in this case, Industry 4.0 is a pure *revolution*, which generates disruptive innovations, radically changing business and entrepreneurial models. On the other hand, a bi-directional relationship considers

rather Industry 4.0 as an *evolution*, in which the two paradigms are complementary and they support each other, adopting Smart Technologies to improve what already exists. Papers and Articles classification is graphically shown through four quadrants in *Figure 4.1*

Figure 4.1: Academic Papers and Practitioners' Articles of Literature Review



4.1 Lean and Industry 4.0 at a Glance

"We have seen what happens when 3 billion people get connected, next we are going to see what happens when 20 billion machines are connected" (Comstock, 2016). These words, belonging to GE's Vice Chair, clearly highlight the great potential triggered by the Fourth Industrial Revolution. Currently, sensors have been improved, clouds platforms are able to send, receive and quickly manage huge amount of data and software are smart enough to draw meaningful conclusions from data in real-time. Basically, these digital innovations constitute the foundation of Industry 4.0 (Batalha et al., 2017).

Evidently, to exploit the opportunities enabled by Industry 4.0, companies must understand the real potential of new technologies. According to Manyika et al. (2015), it is vital that different systems are fully integrated into each other to unlock the concrete value provided by Industry 4.0. Moreover, data analysis is a critical issue since the vast majority of collected data is nowadays not fully taken into account in decision-making processes. In this sense, cloud-based software platforms could be a solution to this problem. Furthermore, they can contribute to streamline the process, predict future demand, reduce machine downtime, improve maintenance programmes and increase efficiency of input, at the same time maximising output (General Electrics, 2016). Coherently, the result will be more efficient and effective operations: costs will be reduced and, simultaneously, revenues increased.

Despite of the great interest in the concept of Industry 4.0 worldwide, there is no formally a respected definition for it. A common understanding of the term Industry 4.0 is not established at this time (Wagner et al., 2017). Anyway, a good definition according to the Industry 4.0 Observatory of Politecnico di Milano could be "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, machinery) in the Value Chain". The phenomenon is based on the belief that through innovative technologies like machine to machine communication, sensor technology and analytics, a new Smart end-to-end Production would be enabled (Magruk, 2016; Sanders et al., 2016).

The vision of Industry 4.0 could be summarized in the connection of the environment with a *Digital Twin*, collecting and interpreting data to better predict results and support the decision making process (Sanders et al., 2016; Magruk, 2016). The Internet of Things and a Service-oriented Architecture (SoA) allows to network the entire factory to form a Smart environment (Sanders et al., 2016).

Nowadays, Lean Manufacturing is still representing the best established driver for a company to reach a high-level efficiency. Lean philosophy is based on the reduction of waste in production processes, simultaneously increasing productivity and reducing production costs (Womack et al., 1990).

Efficiency has always been a major concern for manufacturing companies (Batalha et al., 2017). There are some different manufacturing philosophies focused on boost efficiency; yet, Lean concept is the most rigorous in this direction.

Briefly summarizing what already reported in *Section 2.1*, after the WWII and the huge devastation of the Japanese manufacturing in combination with a scarce availability of money to invest, Japanese manufacturing companies had to adopt an innovative solution to cope with that challenging environment. In particular, Taiichi Ohno and Shigeo Shingo created a different and revolutionary way of manufacturing goods, called Toyota Production System (TPS) (Sugimori et al, 1977). TPS started to be considered superior to traditional models (e.g. Fordism) since it provided to Toyota a method to produce cars with lower inventory levels, lower human effort, lower investments and lower defects while simultaneously offering a greater product variety (Womack et al., 1996). Lean Manufacturing aims at reducing waste, limiting the production to only value adding activities: therefore, costs are reduced by improving productivity, quality and lead times while minimising inventory level and maximising capacity (Womack et al., 1990). In other words, the central idea of Lean manufacturing is to create a streamlined flow of processes to satisfy the pace requested by the customer, with little or no waste (Shah et al., 2007).

For many years, companies have tried to pursue and apply Lean manufacturing principles, especially to increase their productivity. Nowadays, Lean principles can be considered understood and grasped in the DNA of many businesses. However, classical Lean tools are losing some of their edge (Behrendt et al., 2017). In other words, the great success of these approaches leads to marginal further improvements, even difficult to achieve. In the meanwhile, being profitable and competitive in today's global business environment requires an even higher productivity, quality, flexibility and service levels. Following this pattern, companies are more and more interested in Industry 4.0 and its impact in today businesses. Obviously, Industry 4.0 is more than just a flashy catchphrase (Baur et al., 2015): it represents a powerful emerging phenomenon with strong potential to change the way factories work. Digital integration characterizes the new era of industrial production. Therefore, developed countries are approaching this new phenomenon and the interest in it is still growing.

4.2 Investigating the Relationship between Lean and Industry 4.0

Probably, at this point, an obvious question comes to mind: *What could be the role of the established Lean philosophy in this new Digital Era?* And then, *Would the computerization of manufacturing make the established Lean principles unnecessary or Industry 4.0 could be an enabler of the real Lean philosophy?*
Recently some researches, both academic and not academic, have been investigated this potential connection, resulting in some interesting outcomes related to how these two approaches can coexist or not or support each other as well.
However, because of the newness of Industry 4.0 topic, the link between the two concepts is still being investigated (i.e. how Lean manufacturing can be influenced by Industry 4.0 or the place Industry 4.0 might take within Lean).
Integrating both the spheres of Lean and Industry 4.0 is considered an important research field to be extensively explored (Sanders et al., 2016). Basically, the concept of Industry 4.0 can be perceived as a necessary strategy for being competitive in the future (Mrugalska et al., 2016). Anyway, the recent decades of Western industrial manufacturing were characterized by the wave of Lean Production and Lean Management (Wagner et al., 2017; Soder, 2014).
Therefore, an implementation of Industry 4.0 often means an integration of new technologies into already existing Lean production systems and, consequently, an adjustment of business processes. Strong links between what is now happening in Industry 4.0 and Lean development could be found (Jones, 2016).
While Toyota Production System has been accepted to be the most performant manufacturing system, Industry 4.0 initiative is still in its initial phase, with the challenging goal to become a highly integrated cyber production system (Rüttimann et al., 2016). The huge change triggered by Industry 4.0 goes hand in hand with other renewals (e.g. of product, service, business and entrepreneurial model) currently underway. As a consequence, the relationship between this new paradigm and Lean production should be strongly examined.

Manufacturing techniques have evolved during the past years from artisanal production to mass production and to the current tendency of mass customisation. Simultaneously, the way of producing itself has transformed from *batch & queue* to *single piece* transfer-line manufacturing, to full automated manufacturing cells, following the TPS approach (Rüttimann et al., 2016). On the one hand, Lean concept has been extended also to the outbound logistics, through the supply chain integration. On the other hand, Industry 4.0 adds the Internet of Things (IoT) and all the other Smart Technologies to an existing production system to create an interconnected cyber-physical dimension. Nowadays, the main challenge is to understand what will be the manufacturing system which may ideally satisfy all customers' needs (Wagner et al., 2017).

4.3 Industry 4.0: "Lean's Next Level"

An interesting starting point could be the research made by Martinez et al. (2016). It was aimed at investigating the current involvement of Lean management in the Fourth Industrial Revolution. They started from reviewing the abstracts of publications on Industry 4.0 and they measured the level of relationship of Lean on them. The main interesting aspect is that, apparently, the two paradigms seem to have a low correlation coefficient between the different keywords. However, words such as *Value*, *Waste* and *Continuous Improvement* have 26% of total occurrence among the abstracts. This is considered, at first sight, as a sort of sign of Lean inclusion into Industry 4.0 initiative (Martinez et al., 2016).

However, some authors investigated on the uneasy relationship between Lean and IT (Maguire, 2017). For instance, Piszczalski (2000) defined them as "two opposing camps", referring to Lean as "almost anti information systems in its stance". Other issues are connected to the number of risks that new technologies can introduce to a traditional Lean approach. Lean is associated to an idea of simplicity, while IT solutions provide opportunities to introduce complexity (Bell, 2006; Jones, 2012). Moreover, sometimes automation generates lower flexibility: some processes, once automated, become much more difficult to change and hence improve (Bell, 2011). According to this issue, another perceived risk is the interruption of *learning by doing*, thereby obstructing operators from effectively understanding how the factory works (Crabtree et al., 2006).
Moreover, it is a widespread idea that TPS puts crucial importance to reduce IT dependence (e.g. manually managed Kanban cards). Industry 4.0 tries to integrate every available information via IT already with the incoming orders in the Supply Chain

Management (SCM) (Piszczalski, 2000). Implementing automation causes some issues to the manufactures company like complexity, huge investments and challenges in the production area (Nafais, 2017). Moreover, implementing the wrong technology could cause disastrous results. Traditionally, Lean and IT have been in conflict (Maguire, 2017). Therefore, the strong IT-focus may be one of the reasons leading to the believed *inferiority* of Lean compared to Industry 4.0 initiative.

According to Rüttimann et al. (2016), the partial and often limited knowledge about Lean production represents the reason why distorted ideas become popular; for instance, the fact that the two approaches are incompatible. Probably, this is due to the fact that in Western world, Lean is purely and often reduced to the concept of *Kaizen* (i.e. continuous improvement) and the elimination of *Muda* (i.e. wastes), which is by far too simplistic (Rüttimann et al., 2016). This could be considered one of the reasons why Lean usually does not cope with the highly automated Industry 4.0 initiative.

As a matter of fact, Industry 4.0 will not make Lean obsolete, but the two manufacturing systems will generate a mutual dependency and they have their particular domain of application and combination in product variability and production volume (Sanders et al., 2017). Actually, Lean is much more than waste elimination and a simple toolbox from which to choose the appropriate *tools* needed; at the basis of Lean stands a comprehensive manufacturing theory (Rüttimann et al., 2016).

Nowadays, the combination (i.e. *Lean 4.0*) is essential to boost productivity. Anyway, in literature, the shared idea is looking at Lean as a prerequisite since it is always important to consider and use Lean practices, before automating a process to avoid costs and wastes, achieving a better quality (Nafais, 2017); otherwise, companies would digitize inefficiencies. According to this viewpoint, the idea that Industry 4.0 will not materialize as a real revolution, but in different parts that have to be integrated into a Lean framework, is widespread in literature (Ruttimann et al., 2016; Kolberg et al., 2015; Synnes et al., 2016). Sensors, virtual and augmented reality, artificial intelligent algorithms are powerful tools, that need the correct context and domain of application in order to be exploited effectively. "Industry 4.0 is the topping on that cake": in this way, Rüttimann et al. (2016) defined the relationship between Industry 4.0 and Lean manufacturing. In other words, integrating the CPPS in Lean factory is a key challenge: it improves Lean production, making it more flexible but Lean still remains a prerequisite. Therefore, it is possible to assume that there is a mutual dependency relationship.

One of the main purpose of Industry 4.0 is to generate a Cyber Physical Production System (CPPS) aimed at making the scheduling interacting with the IoT to generate a smooth and internet-based production plan, allowing the maximum flexibility in managing the incoming material and arriving orders (Kolberg et al., 2015). Lean, by definition, successfully challenged the mass production practices, providing a greater flexibility of production systems and processes resulting in more complex products and supply chains. In order to further achieve it, it is advisable to familiarize with IT integration between the production level and the planning level, customers and suppliers exploiting the CPPS. Therefore, according to Mrugalska et al. (2017), the two approaches should be linked. On the one hand, Lean concepts and Lean thinking can be completely embraced into the business model to generate towards Industry 4.0 (Staufen, 2015). On the other hand, research activities in Industry 4.0 even allow to improve the Lean manufacturing philosophy (Sanders et al., 2016). Thus, the two paradigms support each other.

"Industry 4.0 technologies may be exactly what we need in order to create Lean supply chains and networks"

(Netland, 2015)

In concrete, "Lean will not fade with Industry 4.0": this is Dr. Torbjorn Netland's perspective, from the Norwegian University of Science and Technology. In particular, digital revolution can incorporate Lean and, at the same time, Lean principles could even become more important. As a matter of fact, the Fourth Industrial Revolution may permit to generate the true Lean Enterprise. Industry 4.0 allows a much richer understanding of the customer demand and, at the same time, the immediate sharing of the demand data throughout complex supply chains and networks. Moreover, Smart Factories should be able to produce faster with less waste, enabling a quicker one-piece flow of customised products. Inventories throughout the supply chain should be reduced.

According to this perspective, these radical changes in the environment will lead to changes in Lean as a practice. For example, there will be less physical Kanban cards, whiteboards and traditional technical Lean solutions in future factories. Anyway, it is worth to remember that Toyota has never looked at these tools and practices as objectives in their shelves; they are proper technical solutions to reduce as much as possible wasteful processes (Womack et al., 1990). Professor Netland is resolutely convinced that Industry

4.0 technologies may be useful to create Lean supply chains and networks. For instance, Lean should exploit the possibility to share real-time information in a coordinated end-to-end supply chain. As a consequence, this enables a radically improved form of just-in-time pull production.

Another shared point is that Digital production and Lean thinking are completely compatible (Okur, 2015; Wiegand, 2016; Sanders et al., 2016; Wagner et al., 2017). Radical changes in production would transform the way in which Lean thinking has been implemented. Anyway, there is no reason why outdated tools shouldn't be given up if new, better ones are introduced by digitalization.

The current literature seems to believe that Lean management could be the most suitable strategy for a digital transformation.

Nowadays, innovations offer a wonderful opportunity to build on a company's Lean efforts by enabling huge cost savings and eliminating work and processes that do not add value. For instance, Internet of Things allows to gather enormous quantities of data through RFID devices or sensors (Mrugalska et al, 2016); the sharing of these data among machines and their fundamental analysis available in Cloud lead to machines operating in full synchronization, often without the necessity for any human intervention. According to Okur (2015), chief researcher at the Lean Institute Turkey, this could be thought as an evolution of Lean practices, considering a possible renewal in the Value Stream Mapping that may become automatic through the usage of IoT.

The same idea has been expressed by Behrendt et al. (2017). As a matter of fact, he strongly believes that "Industry 4.0 will be less a revolution than a valuable and welcome evolution". Hence, innovative technologies can be a way to increase productivity, reaching important developments in the manufacturing environment.

Improvements in data collection, sensors, 3-D printing, robotics will enable advanced analytics, providing a new era for established and proven methods as Lean Manufacturing. In addition, organizations will use these reinforced Lean practices to introduce a new way of working for three strategic dimensions: technical systems (i.e. processes and tools), management systems and people in terms of capabilities, skills and behaviour. In this unavoidable evolution, a core role will be assumed by data, IT and connectivity, that will become new value drivers.

Possible impacts of Industry 4.0 on Lean Management practices are not trivial and they started to be deeply investigated in the recent years. It has been demonstrated that the interaction between the two paradigms reveal many opportunities for achieving synergies, leading to a prosperous implementation of future interconnected Smart Factories (Sanders et al., 2017). Although as a first step, a natural scepticism prevailed over the compatibility of Industry 4.0 and Lean philosophy, supporting aspects are even more. The idea supported also by these authors is that Industry 4.0 can be considered as a natural evolution of Lean principles, useful to make Lean reaching its full potential.

Industry 4.0 can be thought as digitally enabled Lean (Behrendt et al., 2017). In fact, sensors, more data and advanced analytics will boost the capability to solve problems and define some specific improvement measures, obtaining a higher productivity supported by smarter solutions. The breakthrough provided by new digital technologies reflects also in transparency regarding performance. As a matter of fact, today, performance management happens more or less after the fact, at the end of the shift. In a digitalized world, deviations and variability from the expected result can be monitored in real time and faced immediately, overcoming some Lean barriers.

It is difficult to find companies that are so Lean that they are completely free from wastes considering the major processes and all the minor sub-processes. Industry 4.0 can be able to optimize the value-adding areas in order to reduce wastes in the system. It would be possible just if all the products and processes are coordinated and aligned. Hence, Lean and Industry 4.0 are not alternatives but rather they complement each other (Wiegand, 2016). First of all, processes must be stabilized and they have to become reliable. Moreover, another aspect not to underestimate is the product. Indeed, adopting new technologies, complexity and variability do not become easier to be managed and controlled. Therefore, it is important that products have already standard interfaces and modular structures. Using digital innovations to automate obsolete approaches do not lead to the expected benefits. These technologies are considered as enablers useful to support improvements in operations, in a well-organized Lean environment: this condition is necessary to assure and sustain the success and sustainability of disruptive technologies (Camuffo et al., 2016).

Referring to product development, it has to come closer to the development of Industry 4.0 (Rauch et al., 2016); also in this case, Lean should be considered at the basis for a further step forward. In particular, current challenges are related to the reduction of long correction loops and improvements made before the product development end. In this direction, Industry 4.0 may support these efforts through modern and advanced technologies. Differently by Lean Product development, at the basis of Industry 4.0 there is the concept of *autonomous self-organization*, so a switch of the work away from people. However, Industry 4.0 in terms of product development means integration and interconnection of people and information at different levels and in diverse manners (Gassner, 2016). Moreover, new technologies pave the way to the customization of the product life cycle from scratch (Ebert, 2015). Thus, it is reasonable to assume that Industry 4.0 is not replacing Lean; indeed, it introduces modern technological tools, through which the Lean principles can be developed properly (Rauch et al., 2016). Lean product development and a 4.0-oriented Smart Product Development go hand in hand: the usage of innovative and advanced solutions allows to better pursue Lean principles, creating a true Lean Enterprise (Behrendt et al., 2017).

To conclude, Industry 4.0 may be considered as “Lean’s next level” (Behrendt et al., 2017; Jones, 2016). It meets Lean in the provision and management of information: for instance, technologies like RF tags can be used to assign material to the right workstations and manage flow through the factory in real time. To provide another example, it is possible to notice the implications of Industry 4.0 for the management of Lean Equipment through TPM, often used in a Lean environment. The goal of TPM has always been to reach a situation of condition based maintenance. The main barriers have been the cost of the technology and the expertise required. Industry 4.0 allows the exploitation of real time data via web-based applications, coming from machine monitoring systems in order to provide continuous feedback. In this way, the TPM goal of *Zero Breakdowns* would be facilitated and effectively achievable in reality (Jones, 2016).

4.4 Practical Applications: Some Examples of Interaction

Integration of ICT into production could complement the established Lean Production to challenging future requirements. Lean philosophy can be matched with Industry 4.0

solutions and there are some examples that prove this feasibility, reported in literature by Kolberg et al. (2015). Basically, they are referred to Smart Operator, Smart Product, Smart Machine and Smart Planner. The same aspects were highlighted also by Mrugalska et al. (2017). For instance, taking into consideration Smart/Augmented Operator, time from failure occurrence until failure notification could be reduced using Smart Watches and failures are also recognized automatically by sensors. Moreover, augmented reality may assist employees to assure a continuous flow of pieces. In this perspective, Lean can be supported through the usage of new technological tools. Passing to Smart Product, as it was reported before, through the easier collection of many data, the value stream mapping results to be more precise and faster. The most interesting aspect about that is the possibility of creation of a Current State Map, showing wastes in specific processes and assigning future strategic planning activities. Smart Machines can contribute to that as well.
In terms of Smart Machine, in fact, data collected from them could give better operational intelligence, especially to avoid mistakes that is the first idea of Poka-Yoke (Ohno, 1988). Finally, Smart Planner means that fixed amount of Kanban, fixed cycle times and fixed round trips for transporting goods switch into dynamical productions, exploiting CPS (Cyber Physical System) to find the exact optimum capacity utilization per working station and granting a continuous flow of goods. In short, Industry 4.0 and Lean Production do not eliminate each other but together they can absolutely add value to users (Kolberg et al., 2015). All these examples are made to reiterate the fact that these two approaches can sustain each other: so, starting from specific observations, it is possible to make a broader generalization.

Sanders et al. (2016) demonstrated the presence of a positive correlation between Lean Manufacturing and Industry 4.0. Similarly to Kolberg's research, a summary of ten dimensions of Lean Manufacturing were approached in order to demonstrate their improvement through Industry 4.0 technologies. They used a more inductive approach; in particular, they demonstrated that every problem for Lean manufacturing implementation has a proper solution in the innovative technologies related to Industry 4.0. Moreover, they addressed problems in terms of integration. The research has the important merit of clearly confirming that by embracing Industry 4.0, companies are capable of becoming leaner, without too much effort in maintaining a conscious and persistent *striving-for-Lean* mind-set. Particularly, it has been demonstrated that

technologies are fundamental in improving conception, operation and maintenance of a manufacturing industry. It is important to underline that through integrated information and communication systems, the limits of conventional practices can be overcome (Sanders et al., 2016). The result allows industries to achieve the combined benefits of real-time integration and minimal waste generation. This research has not been purely theory-oriented, but it gives some advices for future implementations.
A similar research was carried on by Satoglu et al. (2017) who took into consideration the typical seven Lean wastes and he matched them with advanced Industry 4.0 technologies. He demonstrated that Lean manufacturing and Industry 4.0 are not mutually exclusive; rather, "they can be seamlessly integrated with each other for successful production management" (Satoglu et al., 2017).

Table 4.1: Comparisons of Seven Lean Wastes and Industry 4.0 Technologies (Satoglu et al., 2017)

	Additive Manufacturing (3-D Printing)	Augmented Reality	Simulation & Virtualization	Adaptive Robotics	IoT	Data Analytics	Cloud Computing
Transportation		√	√	√		√	
Motion		√		√			√
Waiting	√		√	√	√	√	√
Inventory	√				√	√	
Unnecessary Processing	√		√	√			√
Overproduction	√				√	√	
Defectives	√	√	√	√	√	√	

For instance, firstly the layout of a manufacturing system should be converted into a Cellular manufacturing system according to a Lean perspective; besides, Industry 4.0 can further reduce wastes by employing Adaptive Robotics for an enhanced parts loading-unloading and material handling. Satoglu et al. (2017) confirms the idea that Industry 4.0 Smart Technologies should be applied to "Lean activities [..] performed successfully before automatization", reiterating the concept that Industry 4.0 and Lean Manufacturing mutually dependent.

Going more practically and making some examples, it is well-known that Value Stream Mapping is a widely used and proven methodology to map and analyse process chains according to Lean Manufacturing; VSM (Value Stream Mapping) has been established as one of the preferred ways to implement the principles of Lean Manufacturing (Grewal, 2008). This method should be improved according to digitalization and there are several opportunities for upgrade existing operations, deriving measures for improvement (Meudt et al., 2017). Haschemi et al. (2017) considered as key features of a Digital Manufacturing implementation the end-to-end digitization of manufacturing-related information flows, the horizontal integration through connected IT systems, processes and information flows along the whole value stream (also across companies) and the automation of information and material flows. In particular, these are the elements that contribute decisively to improve the proven methods and principles of Lean Manufacturing. They proposed a *Smart Value Stream Mapping* to integrate Lean principles and Digital Manufacturing, generating optimum fact-based decisions and exploiting the huge quantity of valuable information gathered. Also in this case, a specific case is taken into account by the authors, subsequently generalizing the idea of a bi-directional support. Another similar example is provided by Jayaram (2016) and it is related to a *Global Supply Chain*. The main takeaway is that Lean Manufacturing and Industry 4.0 can support each other and, in particular, the latter should help to improve the efficiency of production and supply by exploiting real-time data. In this perspective, Digitization integrated in a Lean Supply Chain could be a source of competitive advantage, allowing a faster, efficient and systematic management of it. Therefore, taking into consideration the supply chain as a whole, an enterprise would become more autonomous because of the combination above mentioned.

Another interesting aspect not yet mentioned in this analysis is related to the great innovation wave triggered by the combination of the two paradigms. Nowadays, organizations need to be agile and smart to deal with the challenges of the changing global economy (Wilson et al., 2011). Nicoletti (2015) in his article "Optimizing Innovation with the Lean and Digitize Innovation Process" explains how to combine Lean and Digitization to achieve a higher innovation rate, stressing the idea that this integration would lead to a greater processes improvement. As a matter of fact, the new method called *7 Ds* (i.e. Define, Discover, Design, Develop, Digitize, Deploy and Diffusion) aims at adding value to customers, improving effectiveness and eliminating waste. In particular, Nicoletti tested his practical approach in several successful business cases demonstrated that Lean principles can be optimized by the use of ICT systems to transform novelty and complexities in innovation processes.

It is clear that the assumption behind is that digital technologies support Lean Manufacturing as well, making the organizations faster and more efficient than competitors. In this way, companies have the opportunities to create the basis for competitiveness and future success. Anyway, these two approaches should be linked in the appropriate way, following precise steps in order not to digitize inefficiencies and introduce useless technologies.

4.5 Conclusion

Sanders et al. (2017) elaborated a two-way interaction matrix to formally demonstrate the evolution from Lean Manufacturing to Industry 4.0.

Figure 4.2: Two-way Interaction Matrix (Sanders et al., 2017)

			Industry 4.0 Design Principles					
		Beneficiary Coefficient	Real-Time Capability	Decentralization	Modularity	Interoperability	Service Orientation (SoA and IoS)	Virtualization
	Supporting Coefficient		6.6	6.1	3.1	6.2	4.7	6.1
Lean Management Tools	Kaizen (PDCA)	5.3	10	5	0	10	0	7
	TPM	9.5	10	10	7	10	10	10
	Standardization	2.8	5	0	0	7	0	5
	Forms of wastes	7.3	10	10	7	5	5	7
	5S	2.5	5	7	0	3	0	0
	TQM	4.7	7	7	0	7	0	7
	Kanban (JIT/Pull)	7.0	10	10	5	10	0	7
	Takt Time	-8.0	-7	-10	-10	-7	-7	-7
	Value Stream Mapping	4.7	10	5	0	3	0	10
	Heijunka (Smoothing)	7.7	10	7	5	7	10	7
	Autonomation	7.0	5	10	3	10	7	7
	Andon	4.0	5	7	0	5	0	7
	Poka Yoke	4.7	3	8	3	7	0	7
	SMED	6.0	10	3	5	10	3	5

Legend		Basic Lean Tools for Industry 4.0

Value	10	7	5	3	0	-3	-6	-7	-10
Degree of Influence	Full support	High support	Moderate support	Limited support	No impact/neutral	Limited hindrance	Moderate hindrance	High hindrance	Full hindrance
Range	9.1 to 10.0	8.1 to 9.0	3.1 to 8.0	0.1 to 3.0	0	-0.1 to -3.0	-3.1 to -8.0	-8.1 to -9.0	-9.1 to -10.0

Looking at the matrix, the basic Lean and Industry 4.0 elements have been defined. In particular, design principles adopted for Industry 4.0 come from Hermann et al. (2015). They started from creating a common understanding of the term to derive six basic design principles. The main interesting point could be the view of which 4.0 Design Principles support Lean Management tools, according to the authors. Moreover, it is possible to catch also what are the Lean Management tools which assist Industry 4.0 implementation (blue coloured). This matrix can be considered as a useful framework to better understand the relationship between the two. The concept of Lean Management will not fade away by Industry 4.0 but, as it is possible to notice, it is likely to become more essential for a successful implementation of Industry 4.0. However, the interactions are still not clear and globally accepted and there is no yet a Lean IT (i.e. *Lean 4.0*) body of knowledge (Maguire, 2017).

In literature, there is no a comprehensive framework which explains how Lean principles and pillars will be modified in the viewpoint of Industry 4.0. Moreover, it has not been already provided a strong comparison between the real essence of the two paradigms from a philosophical perspective (for instance looking at their ultimate aspiration). Rather, many researches provides a set of advanced 4.0 technologies to be applied to overcome Lean barriers and limitations (Sanders et al, 2016; Satoglu et al., 2017), forgetting the real meaning of Industry 4.0. The great majority of authors mentioned above consider a bi-directional relationship between Lean Manufacturing and Industry 4.0, intending the latter as an evolution which complements and improves the former, being in turn a pre-requisite. However, the Fourth Industrial Revolution has in its pure essence a seed of radicalism. Deeply analysing Industry 4.0 in all its shades, it is true that there some elements of continuity with Lean that generate a considerable duality. At the same time, it is also true that some Industry 4.0 aspects are completely different from Lean basic assumptions.

Basically, the huge element of originality provided by this dissertation is connected to the definition of a balance between *sustaining* and *disruptive* elements generated by the introduction of Industry 4.0 paradigm in a Lean ecosystem. In other words, the attention is focused on how Industry 4.0 principles and Smart Technologies can support Lean Manufacturing or completely produce a breakthrough from the past, triggering disruptive innovations and radical changes. Taking Lean as starting point, on the one hand, Industry 4.0 could be seen as a *sustaining* evolution; in fact, it might complement Lean practices, creating the *true* Lean Smart Enterprise. On the other hand, Industry 4.0 is also called *revolution*, so it can produce radical changes, by providing new business and entrepreneurial models, distancing from the traditional Lean paradigm.
To conclude, the thesis of this work could be summarized through the following sentence: "Lean in the viewpoint of Industry 4.0 is composed by some principles and pillars that will be modified according to a sustaining perspective whereas others to a disruptive one".

5. LEAN AND INDUSTRY 4.0: MODEL THINKING

5.1 Between Sustaining and Disruptive

It has already been written that, nowadays, companies are trying to link Industry 4.0 with pre-existent business philosophies. For instance, more and more firms are looking at a potential connection with a deeply-rooted industrial paradigm such as Lean Manufacturing. This dissertation aims at finding and showing these interactions.

In the light of the literature review, there is no a comprehensive framework which explains how Lean principles and pillars will be modified in the viewpoint of Industry 4.0, according to a sustaining or a disruptive perspective, considering the genuine essence inherent the two paradigms.

This research was structured according to a pure comparison between principles and pillars of the two paradigms, by adopting the path of *normative* model. For the sake of clarity, a normative model is a model in which the rationale behind cannot be called into question: it is based on the strong hypothesis that it is built upon an absolute logic. In fact, taking Lean principles and pillars (retrieved by Liker's House of Lean) as starting point, the model was devised assuming that also the *digital* part (the one connected to Industry 4.0) has the same scheme, type and numbers of elements of the reference paradigm (the Lean one). In other words, the model was designed by applying the same scheme at the basis of Lean philosophy: five principles, the so called *actions* from Womack and Jones (Womack et al., 1996) and a series of pillars, taking as a reference point the house of Liker (Liker, 2004).

Even though this normative model does not reflect the only way to represent the comparison, it was selected for this dissertation because it is schematic and easy to understand. Sure enough, in the absence of a robust framework for Industry 4.0, it was necessary to find a solid conceptual structure for its design. The idea behind this dissertation is that Industry 4.0 catches the scheme for its foundations in the deeply-rooted Lean paradigm. It is important to underline this hypothesis, because in this way the model could be thought without any obstacles, only with a simple comparison between *old* principles (of Lean) and *new* principles (of Lean towards a digital viewpoint), and subsequently between *old* pillars and *new* ones.

Going deeply into the analysis, it came to light that the two paradigm are not always closed. In fact, even if most of the time it seems that they support each other in this change, paving the way for a beneficial evolution of the *old* paradigm of Lean, some other times the situation changes drastically; a *disruptive* view accompanies with Industry 4.0, laying the foundations for the creation of *new* entrepreneurial models and the implementation of *disruptive* manner in running the business.
As explained previously in *Section 1.2*, the continuous transition between *sustaining* and *disruptive* is the key part of the model: although the two paradigms have common points, sometimes they *speak* different *languages*. The whole model was designed in this way: starting from Lean principles, it was tried to understand how they could be redefined assuming a digital viewpoint; then, regarding Lean pillars and foundations of the House (Liker, 2004), it was attempted to explain how they could be improved or radically changed through the implementation of Industry 4.0 Smart Technologies.

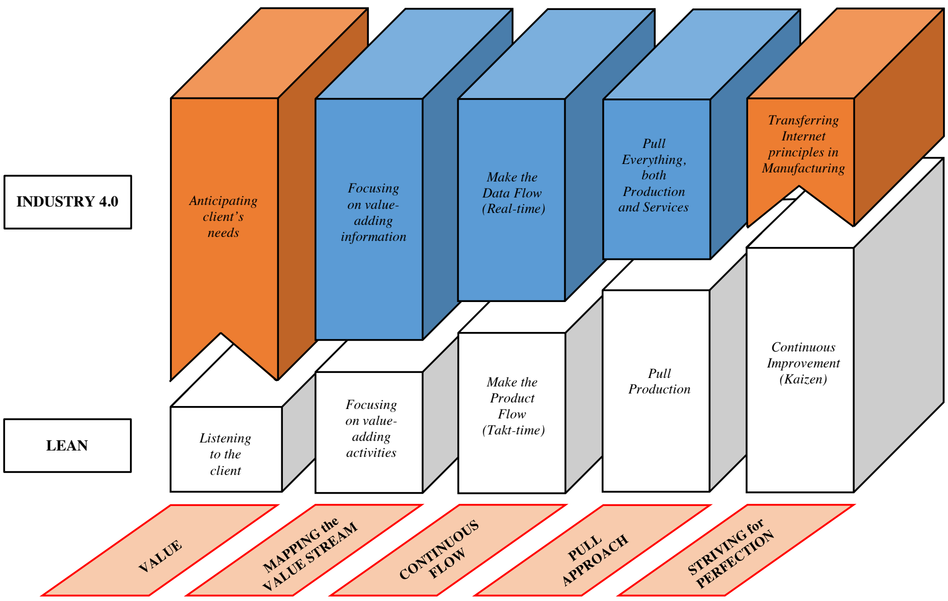
It could be reasonable even referring to the concept of *autopoiesis* in order to describe the linkages between the two paradigms. The term was coined by Chilean biologist Humberto Maturana in 1980 starting from the merging of two Greek words, *auto* which means *self* and *poiesis* which means *creation*. It refers to a system which is dynamic, which develops continuously and it is sustained by itself, from the interior. An autopoietic system could be represented as a series of processes of creation and transformation of components that, by interacting each other, sustain and regenerate continuously the system in itself. It is focused on the functional relationships between the components of the system, which are not static as the mechanism of a clock, but dynamic, permanently and actively in interaction.
Of course, this concept could be adjusted for Lean paradigm, which is dynamic and interrelated, characterized by the attitude of continuous improvement and the collaborative approach in the supply chain between parties and departments. Moreover, these features are nearby also to the digital environment, which is characterized by a strong interconnection between elements of the factory and not only (cf. cloud dimension), which evolve dynamically and real-time. To conclude, it could be worthy to think that also the *ecosystem* created by the intertwining of Lean and Industry 4.0 will have the same characteristics.

5.2 Model Principles

The normative model developed in this dissertation started with the five *principles* at the basis of the Lean paradigm. The question behind the model is *whether* and *how* Industry 4.0 could interact with the paramount recognized cornerstones of Lean Production, namely the five *actions* presented by Womack and Jones (Womack et al., 1996).
Before presenting the model, a step-back is required in order to outline how the relationship between the two philosophies was developed. As starting point, for each Lean principle it was decided to clearly define the meaning behind it. Keeping in mind each Lean principle, and how Lean practically satisfies it, the focus was shifted towards Industry 4.0. Hence, it was tried to establish a comparison, based on how Industry 4.0 would have dealt with each of the five principles, either in a sustaining or a disruptive perspective. This comparison was supported by a deep literature analysis and insights from practical cases with experts.

At the end, the resulting model seems to be double-edged (cf. *Figure 5.1*). As a matter of fact, there is a strong central part in which Lean and Industry 4.0 *speak the same language*; Industry 4.0 help Lean in answering to the same needs, providing a sort of *evolutionary* perspective (*sustaining*). Nevertheless, there are some points that are seen completely in a different, more *disruptive* way, compared to the traditional Lean paradigm.

Figure 5.1: Lean 4.0 – Model Principles



5.2.1 Value

The main objective of Lean could be presented by the slogan "*Customer first*" (Walker, 1990). In fact, the concept of *value for the customer* is the starting point for succeeding in Lean implementation; Lean philosophy strongly believes that customer has to be put at the centre. In order to be successful in the market, it is necessary to carry on actions and develop solutions customer is willing to pay for.

In a Lean perspective, each company has to re-think on how to create value for the customer, by offering process for value creation faster than competitors. Putting the customer first, for Lean, is not only a mission, rather an inner behaviour to adopt.

According to Lean paradigm, the objective could be achieved listening to the customer, establishing robust relationships that enhance a strong form of collaboration between the parties. From the engineering phase, Lean aims at understanding what is valuable for the customer talking with him, by leveraging on trustful partnerships in order to work together towards the final objective. Of course, the client creates needs and validates the solutions proposed, pulling the demand of a particular outcome requested. The Voice of the Customer was the main driven for the definition of the Value Stream (Found et al., 2012).

However, even if the slogan "*Customer first*" remains bright nowadays, the way in which Industry 4.0 carries out this purpose could be seen in a more *disruptive* way than merely listening to the customers' requests. In other words, the value for the final customer endures as the starting point also in Digital Enterprises, even if the process of value creation is performed trying to anticipate what the customer wants.

According to Industry 4.0, the keyword related to the first principle could be *proactivity*. In organizational behaviour, a proactive approach refers to an anticipatory and self-initiated conduct, oriented to the action in advance of a future situation, rather than just to a reaction. Yet, that does not mean returning to a *monolithic* complete planning in advance, rather understanding in advance the future desires of the customers, in order to offer proactively valuable solutions to them.

And if this did not seem possible in 1980s, nowadays Big Data, Cloud and Internet of Things can really give the chance to know better the clients, not only listening to them more precisely, but also catching the market trends and bringing forward valuable solutions. Without forgetting that it is necessary to read and interpret properly the information contained on Data.

During last years, it has emerged a new methodology for American digital start-ups, called *lean start-up*, which is closed to the concept of proactivity. This approach uses customers' feedback to support intuitions by product or service creators, Smart Prototyping instead of advance planning and flexible testing rather than a rigid scheduling of processes and activities. Through Big Data and real-time information, which are shared by customers with different sources (such as IT systems and Smart interconnected Products) the company will be able to pre-empt their future request, disclosing new trends (i.e. latent needs) and arriving faster to the market, instead of just reacting.
Obviously, a first gap between Lean and 4.0 emerges: instead of listening and participating with the final customer in the value creation process, the company will be able to know earlier what the customer will expect from the market or what he actually needs. This approach will open the doors for a *new* scenario, introducing a *new disruptive* way of creating value for the customers.

5.2.2 Mapping the Value Stream

Going ahead with the others principles, it seems that Industry 4.0 is quite in line with Lean *operative* requirements of Value Stream Mapping, Continuous Flow and Pull production. As it is presented below, the linkages between these three *actions* and how Industry 4.0 put into practice these principles are examined under an *evolutionary* and *sustaining* perspective. There are no reasons to think that, in this part of the model, Digitization will create new business and entrepreneurial models; rather, Industry 4.0 supports Lean in accomplishing these *actions*, improving the situation through an evolution of concepts behind the *old* Japanese paradigm. In other words, these three *operative* principles will be just redefined under a digital viewpoint.

The second Lean principle refers to the importance of understanding and mapping the Value Stream. Indeed, once defined what is indisputably valuable for the customers, it is necessary to map the situation internally, within the organization, in order to make the value-adding activities emerging, whereas the wastes have to be eliminated. *Muda*, *Mura* and *Muri* are the paramount enemies for the company. It is necessary to focus only on those activities customer is willing to pay for; otherwise, there is an extra-cost for the company, which cannot be requested to customers, because they do not want to pay for inefficiencies of the system.

However, in a digital world based on IoT, Big Data and Analytics, the focus will move from physical elements to data and information. Data become the core of the Digitization, and so Lean principle of value-adding activities has to be converted in *value-adding information*.

It is no more necessary poring on the physical identification of non-value adding activities; yet, the process is transposed to the digital world. Physical elements of the factory generate information which are spread around the digital environment. Obviously, information needs to be filtered, in order to understand which could be used to create value for the customers and which could be neglected. In this sense, the value creation is provided by those data that, once analysed properly, could provide beneficial solutions for customers, without incurring in unnecessary wastes.

Industry 4.0 needs competences in identifying, managing and analysing data to create value for business processes. In fact, Data is collected everywhere, but it has to be filtered in order to have the correct information to support the right decision, even if it will be more critical to interpret a higher quantity of information than in the past.

Having value-adding information is essential to control and further improve the process. Of course, if Data are gathered and filtered properly, the decision-making process will be fastened.

Therefore, it is possible to assume that Industry 4.0, through Smart Technologies, is an *enabler* of Lean since it allows not only to identify value-adding activities, but also value-adding information, that are an invaluable treasure for companies in the decision-making process. Industry 4.0 supports value stream mapping, widening to Data, which is the core of Digitization: the concept will remain the same, there will be only a transposition from physical to digital environment, based on Data.

5.2.3 Continuous Flow

Furthermore, in Lean, once eliminated all those activities that to do not create value, the remaining ones must be arranged in a flow. Behind the term *flow* lays the idea of a process which has to be carried out without obstacles. In fact, barriers during the process means wastes, the paramount enemies of Lean. One-piece flow is the ideal arrangement of a Lean process; the idea of a continuous flow is key in Lean philosophy, according to which the production process must follow takt-time, which is the defined production rhythm in order to satisfy the customer demand.

According to this third principle, *pieces* should move continuously, without interruptions. Retrieving the reflections previously done in *Section 5.2*.2, Industry 4.0 does not talk about physical entities; in turn, the focus will be on data: those value-adding information, filtered in the second *action*, must be arranged as a *continuous flow*.
Make the Data Stream flow is the *new*, *sustaining* way to support Lean; at the same time, the concept of takt-time will evolve into real-time. Data and information will flow around digital factory exactly at the same instant in which they are generated. With the increasing importance given to the information and data flow, Digitization will allow the complete traceability of the production: every time and everywhere it will be possible to control and monitor the state of each component along the whole supply chain, *sustaining* in any case the basic concept of flow. In other words, it is necessary not only to make the product but also the Data stream flow: beside a physical flow managed by takt-time logic, there will be a flow of data, derived by IT and factory systems, which will become valuable when managed in a continuous flux and possible to analyse in real-time.

5.2.4 Pull Approach

The fourth principle is connected to the approach towards production. In fact, once the activities are arranged in a flow, it is necessary to produce without forgetting the first key principle: the value for the customers. In doing so, the production has to be pulled exactly by the customers' demand. In other words, once all the wastes and the interruptions are eliminated and the process is carried out as a continuous flow, the final objective is producing only what the customer wants, at the time he wants. Therefore, production is pulled by the customer.

Although it is still true that the customer decides when and what to produce, another step forward must be added with Industry 4.0. Indeed, the concept of *pull production* will evolve in the verbal expression of *pull everything*, where *everything* means exactly more than a simple physical product.
What Industry 4.0 is trying to sell is more than a manufactured element. Nowadays market trends are much closer to mass customization and service-orientation: it is important to offer, together with the product, all the *services* related to it, in order to increase the service level and customer satisfaction. Literally, *pulling everything* could be translated in pulling both production and services related.

Following this logical path, the fourth principle could be seen as a necessary evolution of an *old* concept, production-based, to an enlarged service-oriented one, triggered by Industry 4.0. In this sense, Smart Technologies could support the evolution behind: pull approach will be still at the basis of the fourth principle, but new *services* will be added together with traditional products.
In other words, according to Industry 4.0, products are always associated to their related services and sold as if they were a *unique entity*. Industry 4.0 can enable the design and engineering of services based on data analysed and knowledge, generated through data analysis, can be used to create services that add value for the customer. Therefore, companies develop products with value-adding services, providing their customers with services that are needed. In this new business environment, "the market goal of manufacturers is not one-time product selling, but continuous profit from customers by total service solution, which can satisfy unmet customers' needs" (Lee et al., 2014). For instance, the diffusion of Industry 4.0 in manufacturing allows setting up a secure remote access to distributed assets, improving the maintenance support and creating new services associated to a product. Every time and everywhere, data coming from customers' products can be analysed, providing them with promptly value-adding information. One great example is predictive maintenance: through a secure connection, data are collected from machines, analysed and used to detect errors and possible failures at an early stage. Problems can be remotely identified, communicated to customers and correct, decreasing drastically the reaction time.

In this new ecosystem, customers will tend to give value more to all the services associated to a product than to product itself, *pulling everything*. Obviously, this actually can be considered a *sustaining* evolution.

5.2.5 Striving for Perfection

Considering the fifth principle, it refers to the way in which the paradigm is applied daily and put into practice. In fact, Lean strives every day for perfection, getting heated by continuous improvement attitude, which goes under the name of *Kaizen*. Through daily Kaizen projects, the performance of the processes is continuously improved and further wastes eliminated.

As already explained, Kaizen is more an attitude than only an implementation of tools (cf. *Section 2.2.5*); indeed, continuous improvement means facing and solving problems every day, in a never-ending process of value creation. Everything is done in order to eliminate inefficiencies and interruptions in the process, generating a continuous flow pulled by the customer. Each member of the organization, from top managers to the *last* worker, needs a change of mind-set, according to which this attitude for continuously trying to strive for perfection, step-by-step, is instilled and put into practice every day, in each performed activity.
On the contrary, with Industry 4.0, there is no more a focus on daily incremental improvements, whereas on a *disruptive* intent of proposing *radical changes*.
At the basis of this fifth principle there is what could be assumed to be the paramount aspiration of Digitization: Fourth Industrial Revolution will aim at transferring those internet principles, already consolidated and perfectly functioning, in an industrial and manufacturing ecosystem. Digital factory will be built upon the bedrock of CPS, providing *disruptive* innovations in Smart Factories of the future. Therefore, the aspiration inherent the two paradigms is definitively different and the concept of incremental and continuous improvement, owned by Kaizen, will be radically overtaken.
It was taken as a reference point the study of Hermann regarding the design principles of Industry 4.0 (Hermann et al., 2015) to define what could be those Internet principles to be transferred into manufacturing industry. They are identified as interoperability, virtualization, decentralization, real-time capability, service orientation and modularity.
To be more precise, interoperability refers to an ecosystem in which all the elements within the plant (workpiece carriers, products and assembly stations, namely the Cyber Physical Systems) are able to communicate through open nets and semantic descriptions.
Virtualization means that these elements described above in brackets are able to monitor physical processes remotely, creating a virtual copy (cf. digital twin) of the physical world.
Decentralization, in the context of Smart Factory, means that central planning and controlling is no longer needed (Schlick et al., 2014), because embedded computers enable these CPS to take decisions on their own.
Real-time capability refers to data collection and analysis process already explained, which is performed in real-time.

Service-orientation means that all the factory is based on a Service-oriented Architecture (SoA), according to which the services of companies, CPS and humans can be accessible and be used by other parties.

As previously mentioned for the first *principle*, also for this aspect an element of *disruption* emerges. In fact, the traditional Lean aspiration (i.e. striving for perfection) is based on Kaizen, which fosters obsessively incremental improvements every day. Therefore, Lean paradigm can be considered as totally unable to trigger radical innovations, since it is based on the idea of pursuing continuous improvements through a persistent, cyclical and committed effort. Conversely, Industry 4.0 has in its DNA a seed of radicalism; it embraces lateral and abstract thought in order to apply Smart Technologies and Solutions already successful in the Internet world (e.g. the above-mentioned principles) into manufacturing one, leading to disruptive innovations. With Industry 4.0, new business and entrepreneurial models are created, together with new products and services. To conclude, Industry 4.0 will modify radically the *high-level* principles (the first and the fifth) towards a digital perspective.

To conclude, Herman tried to define Industry 4.0 principles without considering a possible link with Lean Manufacturing. The analysis in this dissertation has gone deeper, keeping in mind these principles already defined, but trying to relate them to the *old* paradigm of Lean.

5.3 Model Foundations and Pillars: 4.0 Applications in Lean Practices

The model thinking phase continues by analysing the foundations and pillars of Lean paradigm, towards a digital viewpoint. As starting point, it was decided to consider the House of Lean proposed by Liker (Liker, 2004; cf. *Figure 2.1*), composed by foundations, pillars and a roof. The purpose was to find Industry 4.0 aspects related to Lean pillars and foundation, either in a *sustaining* or in a *disruptive* way. Not all the concepts present in Liker's House were singularly addressed: this is the case of People & Teamwork, Levelled Production and Toyota Way Philosophy. Regarding the latter aspect, the main reason lies in the fact that it essentially represents the philosophy at the basis of the Lean paradigm, so the globally recognized Lean Thinking in its *pure cultural* aspect. Instead, it was decided to mainly consider *operative* aspects and how the *new* Industry 4.0

ecosystem could interact with an already established Lean one. In fact, Industry 4.0 paradigm has not been already univocally theorized, so the comparison from a pure cultural point of view was too strained. Regarding People & Teamwork, also in this case the Lean concept comprehends mostly *high level* aspects such as Lean culture about people or the right mind-set to be spread across the organization. Finally, Levelled Production (Heijunka) was not considered as a foundation but as a useful practice strongly related to Just in Time, so it was talked about it in *Section 5.3.3*.

As highlighted above, the two paradigms have some points that could be considered an *evolution* and others more related to something *disruptive*, more connected to the concept of *revolution*. In order to carry out the analysis for the normative model and as much exhaustive as possible, for each element of the House it was tried to find those concepts and techniques owned by Industry 4.0 and link them, where it was possible, following a *sustaining* or *disruptive* viewpoint. On the one hand, *sustaining* means that a particular tool or technique of Industry 4.0 is in line with a certain Lean pillar or foundation element, and it simply reinforces it leveraging on current technologies; on the other hand, *disruptive* perspective is considered if it generates new business and entrepreneurial models, opening new scenarios.

Nevertheless, the analysis in this dissertation has been deeper with respect to the previous works, bearing in mind principles already defined by Hermann et al. (2015), and trying to relate them (and new ones as well) to the *old* paradigm of Lean. For each pillar or foundation, a *sustaining* element for Industry 4.0 was found, whereas not for all of them a *disruptive* one was pointed out (cf. *Table 5.1*)

Table 5.1: Lean and Industry 4.0 in a *Sustaining* and *Disruptive* perspective

Lean Pillar/Foundation	**Sustaining I4.0**	**Disruptive I4.0**
Stable and Standardized Processes	Interoperability	MaaS
Visual Management	HMI	
Just in Time	Cloud Computing	Additive Manufacturing
Jidoka	Advanced Automation	Autonomous Automation (CPS)
Waste Reduction	IoT and Data Analytics	

5.3.1 Stable and Standardized Processes – Sustaining Viewpoint

Starting from the concept of Stability, nothing new and innovative needs to be added: a stable process is necessary in order to foster digitization. Without a deep knowledge of processes and the complete elimination of wastes, the possible risk is to incur in the *digitization of inefficiencies*.

Standardization is the other Lean bedrock and it plays a crucial role also in 4.0. According to the Principle 6 reported in the book "Toyota Way" (Liker, 2004), Standardization is the foundation for continuous flow and pull production. It has been identified the concept of *interoperability* as the *sustaining* element between the two paradigm. Indeed, the topic of standardization will evolve in the concept of interoperability of machines (hardware) and information systems (software).

There were many attempts to define the concept of interoperability:

"Interoperability is the ability of multiple systems with different hardware and software platforms, data structures, and interfaces to exchange data with minimal loss of content and functionality"

(NISO, 2004)

"The compatibility of two or more systems such that they can exchange information and data and can use the exchanged information and data without any special manipulation"

(Taylor, 2004)

Therefore, Interoperability could be defined as the capability of an IT system or product to cooperate and exchange information or service with other systems, products or machines in an accurate manner, pledging reliability and optimization of resources. These systems can exchange information and mutually use the information that has been exchanged.

Probably, the main interesting aspect is that interoperability implies from the beginning the development of Open Standards to overcome the concept of *compatibility*. Nowadays, customer requirements are based on a high product variability and shortened time to market, meaning that the production structure must be agile and flexible. Therefore, modular factory structures made of Smart Devices are necessary to overcome a rigid

production process (Broy et al, 2010). The only way to guarantee the success of highly modular factory structures is the creation of coordinated and standardized actions between the main technology providers, integrators and end-users, by allowing the interoperability of automation technology (Weyer et al., 2015). Interoperability is for sure one of the most important aspect of Industry 4.0; as a matter of fact, it allows to overcome some traditional limitations like local-only-accessible dashboards or constraints related to scalability. Indeed, interoperability in necessary to create a Smart Factory in which on-demand resources will be always accessible in Cloud.
In order to highlight the importance of Interoperability, in 2015 McKinsey concluded that "The ability of IoT devices and systems to work together is critical for realising the full value of IoT applications; without interoperability at least 40% of potential benefits cannot be realised. Adopting open standards is one way to accomplish interoperability" (McKinsey Global Institute, 2015).

Taking into consideration the concept of standardization in a Lean perspective, there will be an *evolution* through the concept of interoperability. As a matter of fact, the idea beyond a Smart Factory relies on the creation of solid and standardized solutions: interface requirements, mechanical, electrical as well as communication standards. In a few words, through Industry 4.0 it is possible to assume that standardization encompasses a broader set of activities.
Another concept, strongly in line with Lean thinking, is *modularity*: as Lean wants to subdivide the process in subgroups of activities easily manageable, Internet environment is built up on web modules strongly related and interconnected within each other.

Basically, the Lean philosophy attributes to standardization the merit of ensuring improvements. Standardized work consists of takt-time, the precise work sequence in which tasks have to be performed within the takt-time and the standard inventory needed to keep the process operating smoothly (SWIP). "Standardized work is far easier, cheaper, and faster to manage. It becomes increasingly easy to see the wastes of missing parts or defects" (Liker, 2004). Many documents exist to guide companies in defining and standardizing processes. In particular, two common documents easy to be found in production area are the Standardized Work Chart, to combine all the job elements into an effective work sequence, and Quality Check Sheets, to define the quality actions that must be performed by team members.

Interoperability, looking at Industry 4.0 perspective, brings with it *new* standards. It is considered vital across many companies since it enables businesses to catch benefits of a new technology without leaving existing IT investments. A real example could be *Anypoint Platform* by Mulesoft, that empowers companies to create integration and interconnection across different environments. Through a robust set of solutions, this powerful platform helps businesses creating interoperability between systems, software and applications. Moreover, instant API connectivity is created through others platforms (e.g. *Mule ESB*): this can be associated to hundreds of the most popular systems and applications. The concept of standardization evolves into the creation of Open Standards that enable different software applications to work together, allowing companies to use apps from different vendors as if they were from a single one. In other words, business processes can flow from one application to another; one system can work with another to share critical business information in real-time. One of the most famous example in this direction is Oracle's *JD Edwards EnterpriseOne*, which allows flexibility, investment preservation and manageability (Oracle Help Center, 2017).

5.3.2 Stable and Standardized Processes – Disruptive Viewpoint

Considering Lean purpose of achieving stable and standardized processes, interoperability will support processes standardization; however, this is not the only aspect to consider in terms of standardization. As a matter of fact, Industry 4.0 will lead to a new standard business model, denominated "Manufacturing as a Service" (MaaS). In this perspective, companies are no more focused on production-oriented processes but on service-oriented ones, in which manufacturing will be completely virtualized like IT services. Obviously, this is a very *disruptive* initiative, still in progress today.

In order to define what actually MaaS is, it is worth to underline that it is a particular meaning of Cloud Manufacturing, which, in turn, comes from the concept of Cloud Computing. Basically, Cloud Computing refers to a set of ICT services accessible on-demand and self-service, through Internet technologies, based on shared resources and characterized by the scalability of them and the real-time assessment of companies' performance level, in order to be used in a pay-per-use way (Politecnico di Milano, 2011). One of the most important enabling aspects at the basis of Cloud Computing is a Service Oriented Architecture (SoA); basically, SoA represents the set of design principles of an

IT system software architecture in which the easy integration of decoupled Web services that can be reutilized for creating other application components is boosted. In a SoA, it is easy to modify the interaction between the different services and add new ones to be aligned with specific business requirements.

Referring to services provided by Cloud Computing, they are classified in *service models* according to their positioning in the architectural layers of a company IT system and they are: Infrastructure as a Service, Platform as a Service, Software as a Service. There are two main interpretations of Cloud Manufacturing. The most established one refers to the application of Cloud Computing for manufacturing processes, supporting them; Cloud Manufacturing applications belonging to IaaS (Infrastructure as a Service), PaaS (Platform as a Service) and SaaS (Software as a Service) are part of this first area. The second one, which is still in an *experimental* phase, concerns the possibility of having a widespread and on-demand access (through the network) to a virtualized, shared and configurable set of productive resources (Politecnico di Milano, 2015).
MaaS is connected to this second definition and it can be considered the fourth *service model*, enabled by standard process interfaces, interoperability, virtualization and SoA. Therefore, advancements in Cloud Manufacturing are creating a new way of driving business, where companies can *rent* production capacity and capability when needed. The disruption relies on the fact that Industry 4.0 implies the development of a new business standard architecture, based on the idea of re-imaging manufacturing process in a manufacturing service. Following this new pattern, Cloud platforms acquire a fundamental importance: if a company or a private would realize a product, it can access to productive resources offered by a cloud platform and buy what they need (e.g. customized parts), as today happens for the purchase of mailing services.
Nowadays, 3D printing seems to be the most mature technology to support MaaS, as it is happening in famous platforms such as *MakerCloud* or *Sculpteo*: customized prototypes and end-use parts designs are uploaded in a cloud platform; then, they are instantly manufactured through 3D printers. Finally, it is worth to underline that MaaS is not merely linked to the idea of making a product in outsourcing; rather, it is connected to product servitization since Cloud platforms allow a lot of services such as having on-demand access to the resource, tracking and tracing it.

To sum up, Manufacturing has long given priority to engineering and efficiency, both at the product and at the factory level. Nowadays, Manufacturing as a service (MaaS) can be considered as a true *game changer*: although advanced economies have become recently more focused on services, instead of products, the huge innovative wave brings with it the *anything-as-a-service* trend which has truly transformed the factory floor (Moreau, 2016).

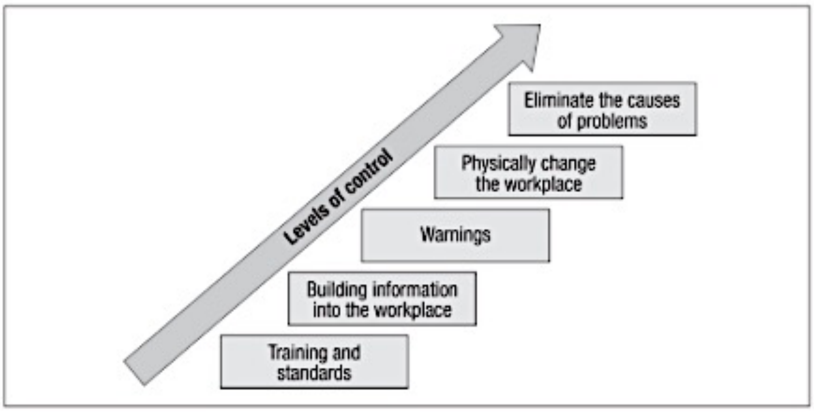
5.3.3 Visual Management – Sustaining Viewpoint

Moving forward, according to a Lean perspective, everything into the factory must be easy to see and visualize, in order to eliminate wastes and defects; it should happen both while moving around the plant and also during production or assembly process. In this case, it is reasonable to assume that Human Machine Interface will represent a *sustaining* aspect for Industry 4.0, by digitizing traditional *Visual management* signals within the factory.

A visual factory is based on a single premise: "One picture is worth a thousand words" (Tapping et al., 2002). For this reason, the core of the visual factory is *just-in-time information*.
Visual management is a key concept referring to Lean production, at the basis of the Lean House. The workplace has to be organized and signalized in a correct manner to make evident each waste or defect. Moreover, it has to be standardized, without possible subjective interpretations. Workers, through visual management, should have immediately information they need. Human Machine Interface could be considered as *enabler* to improve Visual management practices, thereby to support them.
Human-Machine Interface (HMI) is one of the technology pillar of Industry 4.0, usually consisting in "a software application that provides information to operators and/or end-users about the status of a process, and receives back and implements the operators' control instructions" (Politecnico di Milano, 2017).

On the shop floor, the main purpose of visual management (in Japanese *Mieruka*) should be "to give people control over the work-place" (Tapping et al., 2002; Liker, 2004). There are different levels of control that apply, as the *Figure 5.2* shows:

Figure 5.2: Levels of Control (Tapping et al., 2002)



According to this, HMI will improve Visual management techniques since everything into the factory will become more visible; hence, the Lean concept of *Visual Factory*, as an essential part of everything you are doing in a certain moment, will be reinforced. Starting from training process, HMI comprehends the concepts of Augmented Reality (AR) and Virtual Reality (VR). To clarify, AR "is an emerging technology whereby information from the real world is integrated in real-time with digital content processed by a computer" (Politecnico di Milano, 2017). Basically, Augmented Reality allows to create an interactive combination between the real word and a computer generated world, into one seamless environment. On the other hand, VR could be defined as "a way for humans to visualise, manipulate and interact with computers and extremely complex data" (Isdale, 1998). Exploiting these technologies, an operator will be able to make training sessions, for instance having in front of him a virtual machine, simply wearing a pair of Smart Glasses.

Furthermore, through the usage of Smart Devices (such as tablets), an operator would see the entire manufacturing process, in a screen in front of him. "HMI, in its simplest terms, includes any device or software that allows you to interact with a machine" (Beilke, 2015). So, these new technologies can improve the traditional Visual Management by translating the traditional techniques in a digital way. In other words, Industry 4.0 in its HMI allows to foster this Lean foundation, enlarging and getting better what can be *viewed*. The domain of HMI is related to display near real-time operational information. The evolution consists in the fact that HMI will give operational insight into the process, enabling control and optimization. Moreover, an important aspect to highlight is that modern HMI must be aimed at more than a simple process visualization. In fact, they should connect people, applications and machines to reach a greater collaboration and, therefore, efficiency and productivity. All the information has to be visible, to the right people at the right time: in this way, better decisions should be taken (Schneider Electric, 2016).

According to Lean thinking, one of the most important aspect related to Visual management is the 5s program (*Seiri*, *Seiton*, *Seiso*, *Seiketsu* and *Shitsuke*), namely the series of activities for eliminating wastes, organizing and standardizing the workplace (Liker, 2004).

Furthermore, Lean fosters the implementation of *Visual Management Boards* (Williamson G., 2012). There are several types of VMB; for instance, the one proposed by the Kangan Institute has 4 key modules: Key measures, Operational Work, Team Information, Problems and Resolutions. They are considered useful to build trust and positively influence the behaviour of all the workers, pushing the problems-sharing across departments. The possibility to quickly see what is happening through visual tools avoids time wasted to work an issue out.

Another common example is the *Andon*, which allows to see the production rate, the quality defects and the status of the machines. Often, data are printed or handwritten and visible in graphs, tables, diagrams. Sometimes, they are shown using a display.

Visual Management could be pursued also by using *Markings*: it consists on marking and labelling locations on the shop floor using different colours. In this way, it is possible to sign what goes where and label the places in order to position the items in the correct places. Basically, the best type of visual management relies on a direct view of the information in the system. In other words, tool drawers where each tool has its location allow to immediately see which tool goes where and which tool is missing as well.

Augmented and Virtual Reality, Smart Watch and others Smart Devices are surely in line with these Lean concepts and tools: for instance, an operator could be more and more helped by his Smart Glasses, which shows him what to do during the process, or where to pick up the piece he needs. Moreover, Augmented reality could help companies in designing a new product. Designers can connect digital practices to physical products, getting visual feedbacks to aid improvements, as it was a virtual PDCA. Furthermore, Augmented Reality allows a simplified model-based definition. There are many different technologies that simplify product design like eyeglasses or the head-up display, through which a display presents data without requiring users to change their viewpoint. Other

technologies such as the *EyeTap* or the *Virtual Retina* display, are all based on the projection of an image to favour the creation of a new product.
The aspect connected to the Virtual reality can be considered *evolutionary* as well, since a new product can be built using displays creating the manufacturing lines in the virtual world. Moreover, by re-creating the product, potential problems can arise even before a product is built at all. This technology is adopted by Manufacturing equipment developer Gabler: designers at this company can explore and interact with a piece of equipment together in Virtual Reality. Gabler's business processes has been very lucrative, resulting in 15% of development time reduction. Moreover, a virtual walkthrough of a facility might be easily and often performed, making safety inspections and routine maintenance less expensive and easier.
A properly designed HMI solution will not just enhance productivity for the operator but it will usefully provide line of sight into the system to control or maintain the machine. For instance, alarming is a HMI function that allows to see visual indicators of a machine's issue and its degree of severity. *Rockwell FactoryTalk View SE* is a practical example: it provides display screens that help the operator to easily analyse the current operation and interact with each current task or alarm condition.

Virtual and Augmented Reality play a key role for what concerns operators training as well, enlarging into a factory the perspective about what can be really visible.
According to Fitts, who developed one of the most important theories of skill acquisition, there are three stages for development process: cognitive, associative and, at the end, the sequences of actions are combined into activities (Fitts, 1954). Each stage is made of a decreasing level of *overt conscious control*, until the final stage representing skilled activity. It has been proven that using VR to carry on manufacturing tasks assures superior and fast learning sequences, compared to 2D drawing conditions (Boud et al.,1997). A practical example could be the one of *Epson partner ScopeAR*, which modified the *Epson Moverio BT-100* in order to be used for self-guided training: in this way, by adding a camera to the Moverio platform, trainees are allowed hands-free opportunities to learn. Moreover, another important application is *Siemens COMOS Walkinside*, which enables the usage of 3D engineering data, starting from the basic and detailed engineering phases and going throughout the entire asset lifecycle. The most important evolutionary aspect relies on the possibility of representing highly complex process plant models realistically in three dimensions; therefore, COMOS acts as a global data centre.

In the industrial manufacturing sector, companies are using Augmented Reality and Virtual Reality in broad ranging set of applications. Another interesting cluster that exploits AR potential is logistics. Weerts Supply Chain (WSC) uses 15 pairs of Google Glasses to pick and store products. The information is sent to the glasses' lens and the operator goes to the right location where the item is stored, once he read the information. After picking the right item, the next one is displayed until the order is completed. After that, the operator can start with the following order. Smart Glasses are also used for assembling and production; companies can increase work efficiency and accuracy, saving time and costs: this reinforces the idea that HMI supports Lean Manufacturing. In Florida, General Electric Renewable Energy allows operators to use Smart Glasses to access training videos or even contact experts through voice commands, solving problems in real-time and being sure of installing parts correctly. Nowadays, *Google Glasses* are more and more used to display information to operators in real-time, by giving instructions, tutorial videos and data to help them during their work.

Kanban, which literally means *signboard*, is an integral part of Visual management. In an Industry 4.0 ecosystem, the traditional Kanban system becomes an *Electronic Kanban* system, in which all cards are electronic. In a manual Kanban system, if the card gets lost or duplicated, an issue will arise. Moreover, the signal does not get triggered until the physical card reaches the next point. Companies are increasingly adopting *e-Kanban* systems, in which an Electronic Kanban software can be installed on every digital device, fostering a more intuitively and paperless way of working.
For instance, Productoo electronic Kanban software can run on tablets or touchscreen kiosks. Delays and deviations from scheduled plans can be checked anytime and an instant overview of the current production is provided instantly. E-Kanban can be considered as an evolution of Lean Kanban cards. Conventionally, each card issued visually communicates important information and details about the order; an e-Kanban allows managers to keep track of production from any location where computer access is available, extending the set of data and details visually and instantly provided.

To conclude, it is possible to assume that Advanced Human Machine Interface represents a *sustaining* aspect compared to Lean Manufacturing, since it will help in the process of making "the whole factory more visible"; Industry 4.0 allows to use more sophisticated tools, cheaper and faster compared to past years. Instructions, advices and procedures can be viewed at all times, hands-free and voice controlled, also increasing the level of complexity (e.g. in assembly processes) in the operator's tasks.

5.3.4 Just in Time – Sustaining Perspective

Just in time (JIT) is the second Lean pillar; JIT philosophy advocates: "producing and/or delivering only the necessary parts, within the necessary time in the necessary quantity using the minimum necessary resources" (Liker, 2004). In this way, productivity is improved by eliminating wastes, inconsistencies and unreasonable requirements. Through Industry 4.0 advent, this manufacturing approach could be supported by Cloud Computing, stretching out JIT also to the availability of the needed information, in the right amount and time. It will support a step-forward from JIT production to JIT information.

With the fast development of Internet, processing and storage technologies computing resources have become more available, powerful and cheaper than ever before. This new technological trend has allowed the realization of cloud computing, in which resources "are provided as general utilities that can be leased and released by users through the Internet in an on-demand fashion" (Zhang et al., 2010). A proper definition of cloud computing could be the one coined by The National Institute of Standards Technology.

"Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction".

(NIST, 2010)

Cloud Computing is characterized by several features, different from traditional service computing. First of all, services owned by multiple providers are located together in a single data centre and the infrastructure provider makes available a pool of computing resources that can be easily assigned to different resource consumers. Moreover, any device with Internet connectivity is able to access cloud services. Furthermore, one of the key characteristics of cloud computing is that "computing resources can be obtained and released on the fly" (Zhang et al., 2010). This is the main reason why it is possible to consider Cloud Computing as a Lean *supporting* aspect. As a matter of fact, this dynamic resource provisioning will allow service providers to get resources according to the current demand, by lowering the operating cost. Since Cloud Computing allows on-demand resources allocation, service providers can manage their resource consumption according to their own needs. Obviously, service providers are enabled to respond quickly to rapid changes in service demand.

Companies are more and more embracing Cloud Computing as the software and services available are improving in both reliability and sophistication. It leads to great business advantages, such as the instant access to information via mobile phone or tablet; it also gives real-time alerts in order to facilitate the decision making process based on reliable and updated data. Indeed, data can be explored on a near-real-time basis, at scale, allowing to identify pattern and relationships, “flatten out the time to insight” (Ezell et al., 2017).

Cloud makes available the right information when it is needed (also in real time), thereby waiting times are more and more reduced. Hence, workers on the shop floor can view orders as they are placed, having also a clear documentation of where materials are positioned. This great possibility of having an up-to-date perspective of work to be done and suppliers in stock gives workers both tools and information they need in order to work faster. Cloud Computing allows to eliminate time consuming manual data entry, creating an immediate relationship with customers about order delivery times, managing better client expectations.

In other words, the *evolutionary* aspect relies on the fact that Cloud Computing will foster the availability of just in time information, with all the above-mentioned benefits related.

It is important to remember that Toyota Production System is able to promptly satisfy customer requirements since all the manufacturing activities are managed based on market requests. Heijunka, which means *levelled production*, is the fundamental prerequisite in order to create just in time processes. In practical terms, required components reach the workstation only when they are necessary.

Moreover, Lean suggests to eliminate *Mura* (i.e. irregular workload) to generate a fluid production flow, following a pull approach. Heijunka eliminates also *Muri* (i.e. excessive workload and effort) that could cause safety and quality problems.

Furthermore, another important concept is the takt-time (also related to Standardization), namely the correct work cycle in order to satisfy customer demand, avoiding over- and under-production. Takt-time and Heijunka represent the ability to be flexible according to the market requests, reaching a perfect synchronization and granting a continuous flow. Lastly, also the Visual management practice of Kanban is a traditional Lean tool which fosters Just in Time logic. The Kanban system has also been called the *Supermarket method* since Taiichi Ohno took the concepts of supermarket and customers and he equated them with the preceding and the next process in manufacturing (Ohno, 1973). Basically, Kanban could be considered as a system to signal a need for action. This can be done by cards on a board or by other devices used as markers as well.

As already illustrated, Cloud Computing put into practice just in time logic towards a digital viewpoint. In fact, Data will be collected within the factory through tracking devices, by fostering their synchronization and real-time sharing in the supply chain through cloud platforms, in order to provide the right information, at the right place and at the right time. There are more and more companies that are adopting this technology and a lot of cloud service providers are rising. One of the most famous Cloud Computing platform is *Microsoft Azure*; "it is a comprehensive set of cloud services that developers and IT professionals use to build, deploy and manage applications through our global network of datacenters" (azure.microsoft.com). *Azure* allows to use tools and open source technologies already known by manufacturers and it supports a range of operating systems, programming languages, framework, devices and databases. Users can pick and choose from all these services to scale and develop new applications or run existing applications, in the public cloud. Several companies adopted *Microsoft Azure* like ABB, Schneider Electric or BMW. Other companies such as Google, IBM and Amazon are developing their proper cloud computing solutions. For example, *Sanmina* is a leading electronics manufacturing services provider that opted for Google; in turn, Bosch is collaborating with IBM in order to make its *Suite* of IoT services available on IBM's *Bluemix*. Anyway, according to a research on Forbes (April 2017) made by Columbus, "Gartner predicts the worldwide public cloud services market will grow 18%" by the end of 2017 and Cloud Computing will increase with a compound annual growth rate of 19% (Columbus, 2017).

5.3.5 Just in Time – Disruptive Perspective

Regarding Just in Time, Cloud Computing can be considered as a *sustaining* aspect; however, Industry 4.0 can also be *disruptive* considering another Smart Manufacturing technology, which is Additive Manufacturing. In particular, the disruption is triggered by 3D Printing that represents a new dimension for manufacturing. As a matter of fact, the great and innovative wave associated to 3D printing relies on the possibility to decrease inventories at maximum, simply manufacturing on demand. Moreover, this would include manufacturing one-of-a-kind products as well, achieving an even higher level of customization (Di Stefano, 2012). With 3D printing, the cost of manufacturing a unique product would be reduced.
Of course, this huge disruption, as it is true for all the radical changes, needs time to establish and become the new accepted *production standard*. Probably, it is not so far the day in which the customer could simply send the CAD specifics to a manufacturer who has to merely download them to a sophisticated 3D printer. This big revolution offers the freedom for a manufacturer to test out more ideas, to produce exactly what is needed, whenever it is needed and ultimately to customize tools and parts for unique applications. Therefore, this would be really different from the large scale manufacturing done today.
For instance, Hans-Georg Kaltenbrunner, VP Manufacturing Strategy Emea of JDA, strongly believes in this radical change in manufacturing, sustaining that it would be possible to better satisfy the necessity of spare parts to produce customized products; therefore, companies will focus the attention on creating more complex products, with a high technical level. Moreover, it will be necessary to rethink the supply chain processes to make them more agile and able to sustain a real JIT production.

Compared to an evolutionary innovation, typical of traditional manufacturing, which will lead to stagnation, 3D printing can be considered as a revolutionary innovation, leading to growth and competitive advantage. In fact, this revolution consists in the rise of a new and unexpected product within the market. According to Deloitte, 3D printing is forecasted to grow by 300% from 2012 to 2020. In fact, as stated by the website on 3D Printing, "the 3D printing industry is expected to change nearly every industry it touches, completely disrupting the traditional manufacturing process. As a result, the projected value of the industry is expected to explode in the near future" (Deloitte.com). 3D Printing removes constraints found with traditional manufacturing, reducing cycle time and, at the same time, production costs.

3D Printing is changing the way of driving the business; anyway, it is a *work in progress*. Market is continuously growing and also 3D manufacturers are improving the offer, passing from the focus on prototyping to a direct digital production, in an interconnected ecosystem. Nowadays, Siemens and Stratasys are investing a lot and creating partnerships to concur for the creation of a real Smart Factory.

There are plenty of companies that are interested in utilizing 3D printing to create new product, improving business processes. The perception is that this technology is supposed to become very soon more mainstream.

For example, General Electric adopted 3D printing to "produce more than 85,000 fuel nozzles for the new Leap jet engines" (Gilpin, 2014). In this way, nozzles can be made in one metal piece "and the finished product is stronger and lighter than the ones made in the traditional assembly line". Boeing, in turn, was one of the early adopters of 3D printing technology and it has already made thousands of 3D printed parts for 10 different commercial and military planes. This company, using Stratasys 3D printers, also printed an entire cabin. The Aerospace industry is designing a lot of small to large 3D printed parts saving time, material and costs. Moreover, 3D printing accelerates the supply chain by manufacturing non-critical parts on demand, maintaining JIT inventory.

The French multi-national corporation Schneider Electric is another interesting example. Its value proposition is based on efficiency enhancement; it decided to incorporate Stratasys 3D printing technology across its manufacturing operations in France to streamline the processes, in order to be more efficient in both short and long term. SE is now able to produce new manufacturing tool prototypes in just one week, when they are needed, with a massive time-saving of around 70%.

These are only few examples of big companies that are still investing in 3D printing; it is considered as a fundamental advanced technology to adopt in order to achieve a fully integrated Smart Factory. In the next future, more and more companies will benefit from 3D printing disruption, especially for what concern flexibility into the supply network; in fact, they will almost be wholly demand-driven, having the ability to synchronize multiple factors, processes and real-time production data. In doing so, the JIT philosophy will be completely revolutionized, reaching unparalleled levels of responsiveness, decreasing costs to produce and serve. As a matter of fact, Additive Manufacturing, designed for small product lots with a high level of customization and complexity in order to reduce product lead time, will allow to fasten the prototyping, the production and the maintenance, by fostering innovative logic of just in time and one-piece-flow.

5.3.6 Jidoka – Sustaining Perspective

Jidoka essentially means "automation with a human touch" (Liker, 2004). Basically, it refers to make the workers free from machines and to perform value-added work. Following the Jidoka pillar, in-station quality made by workers is much more effective and less expensive than facing the quality issues after the fact. Advanced Automation is the feature of Industry 4.0 particularly related to this Lean aspect and it could represent an *evolution* of the Jidoka concept, since Co-bots and humans work together in a balanced interaction. This new collaboration will definitely improve the work conditions, the productivity, the quality of production and the safety.

Advanced Automation refers to solutions characterized by high cognitive skills, configurability, self-learning and a great ability to adapt to the context (Politecnico di Milano, 2017). Basically, the supporting aspect triggered by Industry 4.0 is connected to the idea of Co-bots (i.e. collaborative robots) that "enable an entirely new form of teamwork" (hannovermesse.de).

The main idea is that, instead of replacing human workers, machines are to become their colleagues, establishing a collaborative relationship. In this work, collaboration is defined as "working jointly with others or together especially in an intellectual endeavour" (Nass et al., 1994). As a matter of fact, co-bots come into direct contact with the workers; through sensor technology, they observe how people perform their tasks and they directly assist them with their work, without exposing humans to the risk of injury (Veloso et al., 2013). Furthermore, by observing individuals they learn from them how to cope with different issues. Co-bots are really flexible and easy to manage: the collaborative lightweight robots can be moved by a single person and easily put into action when needed.

Co-bots might be a *supporting* aspect connected to Jidoka since they represent an advanced automation but, at the same time, they collaborate with humans, being a help for them. Therefore, it is possible to assume an *evolution* of Jidoka concept. As a matter of fact, "a co-bot provides assistance to the human operator by setting up virtual surfaces which can be used to constrain and guide motion" (Colgate et al., 1996). In the new Industry 4.0 ecosystem, human and machine work hand in hand. The most interesting aspect is that robots perform the physically boring and strenuous work, helping the human operator in controlling and monitoring production. The innovation relies in this new balanced interaction, rather than a traditional rigid division between humans and robots. Therefore, the production results to be more automated but, at the same time, there is no separation between automated and manual workstations.

Faults or failures of products and machines during production lead to dangerous effects on production scheduling as well as morale of the employees (Sanders et al., 2016). Quality is a key concept in a lean perspective and Jidoka forces several quality checks in order to immediately face and solve an anomaly, bearing in mind the fact that all processes should be perfectly visible. However, failures of machines are not always under control and considerable time is spent in order to identify the root cause and solve issues. In a Smart Factory, machines are all interconnected with information and communications systems and human-machine relationship can be improved and simplified. As a matter of fact, Co-bots will be able to send direct alerts and information to trained technicians, overcoming Lean practices. Therefore, "the purpose of these machines is not to eliminate jobs, but to make them easier" (Robo Global, 2015).

Lean practices about Jidoka are well established and clear. First of all, improvements are always the final result of issued noticed and solved. For this reason, Lean suggests to truly understand problems through the Genchi Genbutsu approach and then evaluate the problem where it happened, rather than base the considerations on third party information (Liker, 2004). Moreover, other Lean practices mentioned before are the Andon panel and the standardization of tasks, which allow to have a clear benchmark. Finally, another important practice related to Jidoka is *Poka-Yoke* or *Mistake proofing*. In fact, Shingo defined quality control as a three level hierarchy of effectiveness: Judgement Inspection, Informative Inspection and Before the fact. The latter refers to Poka Yoke, which is based on the purpose of overcoming the inefficiencies of inspection. There are several examples of Poka Yoke: Contact Poka Yoke devices have specific physical shapes to prevent the use of incorrect components; instead, Fixed Value Poka Yoka is a method based on physical and visual methods to highlight that components are ready to be used or they are available in the right quantity.

Referring to Industry 4.0, companies are moving towards the creation of smarter and smarter Co-bots, due to their high impact on the business. For example, one of the most famous collaborative robot is the ABB *YuMi*, which is a solution that allows humans and robot to cooperate creating endless possibilities. It is an innovative human-friendly dual arm robot that is able to unlock several additional automation potentials in industry. Another example is the *KUKA LBR iiwa*, which "uses intelligent control technology, high-performance sensors and state-of-the-art software technologies" (kuka.com), enabling new collaborative solutions in production technology. This aspect represents an important evolution since even the most difficult tasks that have previously been performed manually can be automated in a more efficient way compared to the past. Furthermore, KUKA offers maximum flexibility since it optimally supports the operator as an assistant in case of workload peaks and resource bottleneck, suggesting alternatives. Finally, a real case appreciated by companies is *Sawyer* by Rethink Robotics which allows to automate and execute complex tasks, impossible to do previously with traditional industrial robots. It is clear that collaborative robots have to join Internet of Things since they have to communicate problems helping workers. For example, Microsoft presented a software demo in collaboration with KUKA that is able to stream movement data straight to the Azure cloud; this innovative robotics cloud platform will make automation easier than ever. This is a new trend in manufacturing, on which many companies are focusing on.

For example, *Baxter* by Rethink Robotics is a Co-bot able to collect data through sensors and react to problems immediately as humans do: "if workers are testing red parts and blue parts and the red tester breaks, the human worker can see this immediately and instruct a co-worker to send him just blue parts" (Lawton, 2016). *Baxter* will be able to do and suggest the same, being a real colleague of a human worker. Moreover, this adaptive robot is able to collect information about the performance and provide interesting data analysis.

The combination of Lean Production and automation technology can be beneficial, as it has been highlighted so far. In fact, Ono claimed that "process should be automatized and supervised by employees". (Ohno, 1988). In the last 20 years, many companies decided to implement Lean Manufacturing and automatize some processes, investing also in industrial robots. Therefore, it is worth to highlight that Industry 4.0 does not mean merely including a robot to perform repetitive actions, with humans as supervisors. The main difference between factories of the past (considering even the automated ones) and the Smart Digital Factory of today is the concept of *connectivity*. In a Data-Driven Manufacturing environment, a collaborative robot is a node of the network; through the analysis of Data produced by it, it is possible a real-time machine-level monitoring, giving manufacturers the possibility to become more proactive. The emergence of the Internet of Things allows the availability of streaming data from co-bots' sensors; hence, they are able to learn autonomously and also share the information they have learned.

The same reasoning could apply for AGV (Automated Guided Vehicle) and LGV (Laser Guided Vehicle) as well. These driverless vehicles have been used in manufacturing for the past six decades to increase efficiency in plants and warehouses. Again, in a Smart Factory they keyword is interconnectivity; so, AGVs become part of the network and not isolated automated systems. One of the best examples comes from Indeva, which has been able to generate an interconnection between AGV and KUKA robots. An AGV and a robot are able to communicate through companies Wi-Fi connection; the robot decides which function the AGV has to perform.

5.3.7 Jidoka – Disruptive Perspective

Moreover, it is also possible to assume a *disruptive* aspect associated to Jidoka, considering Cyber Physical Systems (CPS), that represent a complete revolution from what companies have in place nowadays. They are defined as "engineered systems that are built from and depend upon the synergy of cyber and physical components" (Zhang et al., 2013). In other words, CPS are enabling technologies that allow to bring the virtual and physical worlds together, creating a networked factory in which Smart objects communicate and interact with each other. Obviously, they represent the next step from existing embedded systems.
Recent developments have made sensors, data acquisition systems and computer networks more available and affordable; the competitive nature of today's business forces companies to move toward the implementation of high-tech methodologies. CPS can be developed to manage Big Data collected and leverage the interconnectivity of machines to make them smarter and self-adaptable.

CPS are considered the key enabling technologies of Industry 4.0; they require the presence of interconnected objects that, through sensors, are able to generate data, decreasing distances and information asymmetries. All workers would be able to easily communicate in each moment and in each condition, providing value-added activities. In a few words, CPS includes the concept of *Digital Twin*, placing side by side the physical aspect and the virtual one. Therefore, CPS is an integrated system that requires that each physical object has its representation in a digital way. The most revolutionary aspect relies on the fact that the single physical factory component has a lot of information in its virtual sphere. Although it could be decentralized, it would be able to support decisions in an autonomous way and communicate them directly to the others physical components. Therefore, CPS will have a double perspective: it will be able to autonomously evaluate operative situations, supporting the decision making process, and it will also be sure that the other CPSs will do their tasks correctly, being able to self-adapting (Boschi et al., 2017). An important aspect to underline is that machines do not merely decide by themselves; there are thousands of algorithms designed by plenty of engineers behind CPS. Individuals still decide, although it is not that worker next to the machine. Hence, workers do not become less important, rather than less present on the factory floor, leaving *autonomy* to the machines in the decision-making process, exploiting intelligent algorithms designed by human brain.

CPS allows physical and virtual world to become closer and closer; through the Fourth Industrial Revolution, the focus has shifted towards virtualization and virtual world since it is a fundamental requirement to guarantee the right interventions to what can be identified by physical sensors and analytics. The virtual layer is the mean through which information are shared and, as a consequence, actions can be taken by physical systems. Basically, a CPS is equipped with sensing systems through which it is able to autonomously identify its actual operative condition in the ecosystem, virtually providing information. Data-driven corrective actions are defined passing through a decentralized intelligence that takes into account also information coming from other CPS. It is worth to underline that cyber level is realized through Smart Technologies that provide centralized hub of information (e.g. cloud). In this way, information run determining a further possibility of connection between physical objects and their virtual image. Some authors describe this radical change as it was a *social network*, in which the virtual image (i.e. *digital twin*) of an object is in the cyber level but it needs a strong connection with the real one. The huge disruption lies on the rise of this virtual world alongside the traditional physical one that will positively impact on products, supply chain, people and the factory as a whole. Remembering that Smart Factory will be built upon the bedrocks of CPS (cf. *Section 5.2.5*), it is worthy to think that CPS will allow individuals to play the role of supervisor in decision-making process, without the necessity of being necessarily physically present on Gemba for solving operative problems: though powerful and robust algorithms, designed by, a lot of process engineers and data scientists, CPS will become operationally autonomous in the Smart Factory of the future.

5.3.8 Waste Reduction – Sustaining Perspective

The goal of Lean manufacturing is to decrease the waste in "human effort, inventory, time to market and manufacturing space to become highly responsive to customer demand while producing world-class quality products in the most efficient and economical manner" (Todd, 2000). It is well-recognized that the basis of Lean manufacturing is the elimination of waste. A waste could be defined as "anything other than the minimum amount of equipment, materials, parts, space and time that are essential to add value to the product" (Russell et al., 1999).
According to Shigeo Shingo, "the most dangerous kind of waste is the waste we do not recognize" (Shingo, 1989). Anyway, through Internet of Things, Big Data collection and Analytics, wastes and broken processes will be more promptly identified and, once fixed, enhanced. This is the reason why these Smart Manufacturing Technologies can be considered as *supporting* aspects for the approach of problem solving in waste reduction.

Generally speaking, Internet of Things (IoT) "refers to the networked interconnection of objects, which are often equipped with ubiquitous intelligence" (Xia et al., 2012). IoT allows to increase the ubiquity of the Internet "by integrating every object for interaction via embedded systems, which leads to a highly distributed network of devices communicating with human beings as well as other devices" (Xia et al., 2012).
The connection between physical things and Internet creates the opportunity to access remote sensor data to control the physical world also from a distance. "The mash-up of captured data with data retrieved from other sources (e.g. data contained in the Web) gives rise to new synergistic services that go beyond the services that can be provided by an isolated embedded system" (Kopetz, 2011). New sensors, mobile and wireless technologies are at the base of IoT evolution; however, the true business value of the IoT

lies in *analytics*. As a matter of fact, a device can easily transmit information from a device but analytics have to be rich enough to extract meaningful insights. Sensors are able to gather data about the physical environment that have to be analysed or combined with other data in order to find patterns.
Big Data and Analytics have created one of the most profound trend in business intelligence (BI). Some people define analytics with the term *exploratory analytics*, to better explain this concept. As a matter of fact, through the analysis of a huge quantity of data, it is possible to discover new business facts that no one in the enterprise was able to know before. Talking about Big Data, size matters but there are two other important features: data variety and data velocity. Nowadays, Big Data and Analytics are often considered together, since analytics platforms tend to be optimized by using large data sets and they are able to manage them better than ever (Russom, 2011).
"In manufacturing, operations managers can use advanced analytics to take a deep dive into historical process data, identify patterns and relationships among discrete process steps and inputs, and then optimize the factors that prove to have the greatest effect on yield" (Auschitzky at al., 2014). Companies, in the past 20 years, have tried to reduce waste and variability by implementing different programs such as Lean and Six Sigma. However, manufacturers need a more granular approach to diagnose and correct process flaws. Big Data collection and Advanced Analytics provides a powerful approach in this direction, improving the already existing practices in waste management.

A traditional Lean practice related to waste management is *Genchi Genbutsu*, which means the Toyota practice of understanding a condition by confirming something with personal observation at the source of the condition. Lean suggests to go to the shop floor to observe the process and interact with workers to confirm data and understand the situation. Another practice strongly recommended by TPS is *Five Whys*, a useful approach aimed at truly investigating and solving the problem, by identifying the root cause. In Lean manufacturing, waste reduction is also pursued by eliminating inventory not required to fulfil specific customer orders and by adjusting production processes based on customer demand. In turns, reducing overproduction can help to reduce labour costs by eliminating unnecessary transfer of goods. Moreover, in order to reduce wastes, Lean suggests to go to *Gemba* to see how processes are performed, in order to eliminate unnecessary extra work (Womack et al., 2003).

Industry 4.0, through IoT, Big Data and Analytics helps in supporting factory improvements in order to reduce wastes. In particular, predictive analytics are really useful when assumptions need to be made. Moyne et al. (2017) made a research on semiconductor manufacturing, which is characterized by a high level production challenges to remain profitable in a global scale. So, "waste reduction must be addressed in terms of product scrap, lost production due to high cycle and non-production times, environmental waste and general capital waste due to factors such as poor use of consumables and poor planning". To address these challenges, specific analytics called *Advanced Process Control* (APC) are currently used. Of course, this example could be extended to other industries.

Basically, Analytics platforms provides useful data out of all the stored information, gathered through Smart sensors. These data are mostly utilized to improve processes performance, trying to increase the productivity level. Another practical example refers to Petroleos Mexicanos (Pemex) which began outfitting its refineries with IoT devices to measure sound vibrations. When engineers view abnormal measurements, they can go right to a piece of equipment and they are able to replace it with a low downtime.

Bosch defines production data as the most important raw material in Industry 4.0 and Analytics helps to use these data to add value. As a matter of fact, through their data analytics initiative in waste management, scrap costs were reduced by 65% in pump module production leading to a monthly saving of EUR 200,000. In particular, Bosch created Manufacturing Analytics services based on the *Cross-Industry Standard Process for Data Mining* (*CRISP-DM*).

Finally, IBM developed a lot of sophisticated analytics platforms commonly used. In particular, *IBM SPSS Modeler* aims at "structure what is unstructured" being a graphical data science and predictive analytics platforms useful to reduce wastes and improve the company business.

6. METHODOLOGY

6.1 Research Design

Table 6.1: Methodology – Phases of Research (Whittemore et al., 2010)

Phase of Research	Techniques and Tools	Objective
Conceptual	Literature review Critical thought Discussion with professors	Understanding the scope and the significance of the problem Understating the current situation Understanding eventual gaps in literature
Design and Planning	Non-experimental Research – Qualitative Analysis	Selecting the overall plan for conducting a study
	Sampling Plan composed of 50 experts (9 of them for case studies)	Selection of the sample for the analysis, once defined three requirements: Manufacturing industry, Lean experts, Industry 4.0 knowledge (with eventually project started)
	Interviews and Delphi Method (model thinking) and brief Survey (validation)	Defining the methods to collect data and finally validate the research
Empirical and Analytic	Interviews Delphi Method	Understanding external point of views Receiving hints for drafting the model
	Personal research	Understanding different realities in order to apply practical examples to the dissertation and complete the normative model
Validation	Construct and Statement for Beta and Alpha test	Beta test: perfection of the statements Alpha test: collecting data from a sample of experts in order to understand the average opinions related to the model Analysing results in order to understand if valid (confidential interval) and useful for the research
Dissemination	Dissertation Writing	Writing the report, with introduction, model, comparisons, data analysis and conclusions Drafting opened points for discussion: Follow-up

The work behind this dissertation was carried out through different phases. The research started, as always, with a conceptual phase, in which a deep mandatory literature analysis was performed, together with a curious and critical thought, fed by continuous discussion about research ideas with professors. The objective of the first phase was understanding the avant-garde about this huge topic and, eventually, the gaps in literature. As the *Section 4* shows, these above-mentioned gaps arose after the review and became the starting point for the dissertation.

Nevertheless, as already presented in same section, carrying out the literature analysis was truly complicated because there were a few previous researches that compared Lean Manufacturing and Industry 4.0, in particular really recent and anecdotal. The first idea was separating literature review between academic articles and opinions of practitioners, namely experts in the field who gave their point of view about this topic in magazines or websites. It was decided to select scientific researches and academic conferences from Scopus, Research Gate, Google Scholar, Science Direct and Websites. Regarding articles written by practitioners, they were found on Websites or magazines and accurately selected in terms of reliability (e.g. articles where a professor was interviewed or consultancy projects). Nevertheless, the review was finally performed together, finding in the end 23 between papers and practitioners' articles (even reliable) that truly investigate the relationship between the two, according to different perspectives. For the sake of clarity, the gap was identified in the absence of a complete structured model which would have linked (or isolated) the two topics of Lean and Industry 4.0.

The conceptual phase ended by defining the research purpose: understanding if it is true that Digitization has connections with Lean paradigm both according to a *sustaining* perspective and respecting a *disruptive* point of view (cf. Christensen, 2013).

It was important, at the end of this first phase, to have articulated a complete research purpose which could be developed into feasible, important and valid study design (Hulley et al., 2006).

First of all, in order to build the model behind the two paradigms, it was necessary a design and planning phase of the whole study. Many methodological decisions needed to be chosen, such as validity, type of research design, the sampling plan and the methods for collecting and then validating data.

In qualitative research like this dissertation, which aims at investigating the ecosystem of Lean and Digital, there are different quality criteria that seek to understand a phenomenon; the most frequent cited include credibility, dependability, confirmability and transferability (Whittemore et al., 2010).

It was decided to proceed with a non-experimental shape, in particular by designing a normative model. As a matter of fact, it was assumed that the logic behind the model was absolute, and so its structure became undisputable, by fostering also the validity of data previously mentioned. By following this research design decision, a rigorous comparison between the principles and pillars of Lean and Industry 4.0 was initially devised. In other words, it was assumed Lean principles and pillars as starting points for depicting a *Lean digital* model with the same scheme and structure. In fact, even if Lean is a complete and well-known paradigm, for its part Industry 4.0 has no strong theoretical basis behind. As a consequence, a mono-directional approach was designed: for any Lean principle and pillar it was identified the way in which Industry 4.0 could support (or disrupt) it. Regarding the two core words behind the work, *sustaining* and *disruptive*, it was decided to refer to Christensen's studies, as already explained in *Section 1.2* (Christensen, 1997; Christensen, 2013).

Generally, qualitative designs are flexible, and typically include small sample in order to collect data for better understanding the framework (Creswell, 2009). In fact, an initial group of 9 experts was selected to perform formal interviews by using a structured questionnaire with opened questions, which cover all the part of a model roughly drafted in advance (cf. *Attachment 9*.1). It is important to underline that the questionnaire was used as a guideline and not all the questions were asked to all the interviewees. It would have been talked about Lean implementation, benefits and barriers, Industry 4.0 portfolio of projects and mostly about their opinions regarding the comparison between the two topics. The interviews were helpful in order to understand the external point of view and gathering *free* data, without forcing the spokesmen with static survey for collecting information. These 9 experts were selected on the basis of three criteria: they should be a manager of a company in the manufacturing industry, or at least have participated in projects for manufacturing companies; these companies must have implemented successfully Lean, and must have at least started to plan Industry 4.0 projects. Whereas 8 of them were coherent with the requirements, one (i.e. Battezzati) was selected even if it is not part of a manufacturing company, especially because of his deep knowledge and academic expertise on this field, maturated also in Lean and digital projects within manufacturing industry. The objective of this planned phase was gathering data to better complete the draft of the model. In fact, each interview was analysed in term of recurring *keywords* enunciated during the speech. Each keyword is associated to a part of the model initially thought. According to the level of agreement towards this part of the discussion, final results were organized in order to arrive at a definitive version of the model (cf. *Section 6.3*).

Once *internally* settled, the missing step was its *widespread* and external validation, in order to refine it again with more accuracy. By this point, other players were selected, from a group of companies partners of Industry 4.0 Observatory of Politecnico di Milano, the sponsor of this dissertation. Another questionnaire was prepared, more structured but shorter. Starting from the 9 experts already selected for the previous phase, a brief survey was sent to a significant sample of 50 companies. Once reached an initial target of 30 answers, it was calculated the level of reliability of the research by using the alpha coefficient of Cronbach (Cronbach, 1951).

Once all the steps to follow from the beginning to the validation were defined, the practical model-thinking phase started. In the empirical phase, case studies with 9 experts were performed. In fact, face-to-face interviews were preferred, in order to leave interviewees to express their ideas without barriers, to outline their points of view which finally resulted in the model of the dissertation, once all their opinions were refined.
This approach was arranged as a sort of Delphi Method, in particular a Mini-Delphi Method, called also ETE (Estimate-Talk-Estimate), which is, in a few words, a face-to-face technique which follows the same rules of Delphi Method (Linstone et al., 1975). In reality, the approach used for this model-thinking phase grouped together some elements of the traditional method and others of the ETE, in order to solve some limits of these two approaches. After having drafted a first idea of the model after the conceptual phase, those partners selected were provided a questionnaire before the face-to-face interview. The questionnaire was composed of three main parts: a first section in which they were asked to talk about Lean, its implementation, its benefits and barriers; a second part in which they gave impressions about Industry 4.0; a final section in which some hints and foods for thought about the model of *Lean 4.0* were inserted. Each interview was carried out alone and it gave tips for the complete writing of the model, in both its *sustaining* and *disruptive* parts. The main difference between the traditional approach lied in the fact that the interviewees did not exchange opinions, that there was only one round, and lastly the final results was obtained without the intervention of experts again, but only by putting together common points about their opinions. The final outcome was the perfection of the model: according to the data collected, brief case studies were written, in order to summarize the critical element of the discussion and point out the common ones. The analysis was carried out organising the similar points in recurring keywords.
Once the model had been drafted, and the keywords translated in a complete scheme, in the way in which it is previously explained (cf. *Section 5*), a further personal research helped in adding other practical elements to the non-experimental research, in order to complete the work with current applications to describe widely the phenomenon, as the *Section 5.2* shows.

Arrived at this point, the validation phase was missing. It was necessary to test the model, in order to confirm it and understand at which point this dissertation could be useful for the academic research and, on the contrary, at which point it could have been revised by future works, starting from its criticalities. Before the testing phase, a conceptual map was sketched in order to understand how many statements were necessary to validate the model. A four-level map of reasoning was depicted, in order to subdivide the thinking process in sub-passages which were unique and valid stand-alone. Finally, the composition of each passage for each part of the final level of the map would have generated a single and comprehensive statement to be evaluated. The reasoning behind the conceptual map will be explained later on (cf. *Section 6.2*).

In the end, 13 statements were devised, one for each part of the model, no matter if principle of pillar, sustaining or disruptive. The way in which they were designed is better explained in *Section 6*.3: briefly, for each of them, a short presentation is made (namely the *construct*, the third level of the conceptual map) and then each statement is translated concretely in a complete sentence through the *statement* to be validated. It is important to underline that it was chosen to put in a random sequence the *sustaining* and *disruptive* statements, following the way in which they are illustrated in this dissertation. Moreover, there were no hints in the statements regarding this division: in this sense, it was allowed to avoid auto-correlation in answers, and it fostered the reasoning of each member of the sample.

For the analysis, a wider sample was considered, starting from the 9 partners already used in the model-thinking phase, with the help of another 50 suitable subjects selected from the bucket of companies involved in consultancy projects with Politecnico di Milano. From these 59 potential subjects, five of them were taken for *Beta* test. As a matter of fact, these phase helped to perfect the first version of the statements before sending them to the final sample. They should have given feedbacks and comment in order to perfect the statements before the *Alpha* test.

Table 6.2: Level of Agreement/Disagreement – Options for Alpha Test

Number of Options	**Description**
Option 1	Totally disagree
Option 2	Partially disagree
Option 3	Partially agree
Option 4	Totally agree
Option 5	I don't know

Moreover, it was asked to each addressee to express his level of agreement according to different statements in a scale from 1 to 4, following the scale illustrated in *Table 6.2* above.

For the sake of clarity, in order to cope with the possibility of having neutral answers, this choice was substituted with the possibility to select the answer *I don't know*. With this answer, interviewees would have been left the possibility to send a comment regarding the statement, in order to solve for future researches some criticalities around them.

Since modifications of statements in *Beta* test referred only to the form and not to their content, these 5 answers were considered valid also for the *Alpha* test. In the *Alpha* test, a less restrictive sample was selected: the only driver considered was an intense knowledge of the theme, among different subjects of different sectors.

Once 38 answers were registered, a final analysis was performed in order to understand, first of all, if the answers for each construct could be considered valid. However, since all the statements were presented in positive terms, it was reasonable to assume that the presence of agreement answers would have been higher than the disagreement ones. In order to cope with this issue, it was thought to assign a scale of scores to each answer, giving more weight to negative answers (i.e. *disagree*) than to those positive (i.e. *agree*). For each statement, a numerical index of agreement was set, by summing up the numerical score (presented in *Table 6.3*) obtained from each answer.

Table 6.3: Scores for Index of Agreement

Types of Options	**Score**
1 – Totally disagree	-4
2 – Partially disagree	-2
3 – Partially agree	+1
4 – Totally agree	+2
I don't know	0

The analysis was performed separately for *sustaining* and *disruptive* statements, in order to understand which were the opinions for the two different parts. Furthermore, once having understood the trend separately, an *Average Sustaining Index* and an *Average Disruptive Index* were computed. This allowed to compare the average level of agreement for the two parts. Final results will be shown in *Section 7.1*.

Of course, after the validation phase, a dissemination phase was necessary, in order to write clearly the model, draft the conclusions and define the open points of discussion for further researches.

6.2 Interviews for Empirical Phase

In this section, the 9 interviews done with the experts selected for the first part of the model-thinking are summarized. For each of them, a brief introduction of the company and the spokesman is presented (in a box), before disclosing the main points of discussion of the interview. Finally, the conclusion after the round of interviews is exhibited (cf. *Section 6.2.10*).

6.2.1 SEW Eurodrive Italia

Location: Solaro (MI, Italy)
Industry: Industrial Automation
At a glance: EUR 2.5 billion turnover; +15,000 employees; worldwide presence in 190 countries
Reference: Francesco Di Pasquale (Operations Manager)

SEW Eurodrive played an important role in the model thinking phase because the company based in Solaro (Milan, Italy) was the first interviewed and the one which more accurately defined the boundaries of the dissertation. Firstly, in SEW it was clear that lean is a philosophy, a way of thinking, according to which the client must be put at the first place. The focus is always on what the clients ask and need, also trying to anticipate their request with a deep analysis of trends and data. For SEW Lean is a matter of adaptation: each company has to model the paradigm according to its need, in order to improve the productivity and the level of performance. A continuous improvement process is needed in order to tackle the visible wastes and all the non-visible ones, which could be seen as intangible and for which technologies could help for detection.
Industry 4.0 in SEW goes under the name of Intralogistics, with four main aims: flexibility, both in term of product and volume mix; productivity, in term of uptime, efficiency and quality; energy saving; operational efficiency, regarding Total Cost of

Ownership, engineering and maintenance. In order to embrace correctly this new revolution and put it in practice, a company needs adequate competences in automation, together with appropriate software as a support, in order to simulate before all the possible scenarios. SEW strongly believes in the implementation of CPS, which fosters the integration between elements before diverse in the factory and increase a lot the level of flexibility in the plant. The ERP is intertwined directly with these CPS, providing real-time information for the prompt management of problems. Towards this radical change, SEW has recently decided to change completely the layout in the factory, in order to create a real Smart Lean Factory. The results achievable are important: the output of the plant will increase of 70%, the mix will be doubled, the lead time will be shortened and the productivity will increase by 25%. Moreover, there will be the complete automatization of non-value adding activities, through the intervention of 45 AGV, internally produced and interconnected, which will become also a tailored workbench for each operator in different phases of the process. It will provide a huge amount of data available and manageable real-time in order to trace better the situation and be faster in reaction. In fact, SEW is trying to provide the complete package, a solution in which the factory is completely integrated and has a remote control and visibility to support decision making process. This concept is translated also into their products, which become Smart and service-oriented: the client will be able to have information real-time about the actual status of the product, with system of diagnostic, and the potential status, in order to prevent some future risks, in line with the predictive maintenance concept.

6.2.2 Galdi S.r.l.

Location: Paese (TV, Italy)

Industry: Food & Beverages Packaging

At a glance: EUR 25 million turnover; +100 employees; 4 commercial International sites (Russia, Morocco, China, U.S.A.)

Reference: Federico Bardini (Engineering Department Manager)

The family company headquartered in Paese (Treviso, Italy) was the second interviewed. It is a manufacturer of machineries for food packaging, producer of filling machines for gable-top containers. Its competitive advantage is based on a high level of flexibility and productivity, which has been increased through the implementation of lean production, and its business is characterized by a robust service-orientation, in line with the trend of mass customization. Furthermore, it emerges that the idea behind Lean 4.0 is perfectly consistent with this trend. The company aims every day at innovation: the market requests new products and Galdi cannot produce with a mass production system, but always provides new models on the market, in connection with the emerging needs of the customers. However, the innovation is continuous and incremental, not disruptive: thanks to the modularity and the high configurability of its machines, Galdi is able to offer a wide range of customization for its customers. In general, Galdi deems that it is necessary a balanced mix between incremental and disruptive innovation: moreover, Lean paradigm does not coincide perfectly with the concept of disruption, and this is why Industry 4.0 moves towards a different direction.

The implementation of Lean started in 2010, and over the years it has been extended to the whole organization, even if without tangible results in the beginning, due to the difficulties faced in shifting the mind-set of employees. The hardest barrier was making people aware that it is possible to change and that this change must start from the bottom: especially for Lean Office, the mental scheme in each person had to be switched. This led to a re-organization in the company structure, strongly driven by an intense top commitment. The first target achieved was the reduction of the delivery time to the client. Another limit connected to the Japanese paradigm lies in the application of Lean principles without being adapted correctly to the sector in which it is implemented.

According to Industry 4.0, Galdi confirms that it is not only a group of separate technologies: in fact, some companies, especially in the automotive industry, have already implemented them since the third industrial revolution; however, the fourth industrial revolution gives a package of integrated solutions that can be used in an innovative way. Nevertheless, Galdi is convinced that the benefits of Industry 4.0 will be showed in the next future: at the moment, it is an announced revolution.

From its part, Galdi owns innovative machineries, connected to the concept of servitization: having a Service-oriented Architecture since years paves the way for the creation of new business models fostering a higher competitiveness. A Hoshin Kanri project called “Being close to the client, without being there physically” is perfectly in line with a 4.0 concept of interconnection between different machines, which increases the visibility along the supply chain. A plan for the future is related to the implementation of predictive diagnostic for a better maintenance process. The attention for employees is

high, and this led to the idea of introducing collaborative robots in the production line, in order to achieve benefits in terms of ergonomic condition and avoid critical activities for workers.
Different barriers have emerged in the implementation of enabling technologies: it is not a cultural mind-set, but the problem stands in finding the right resources, which practically means looking for new professional figures accustomed to a digital world. Moreover, it is strongly present the problem of cybersecurity of data. Industry 4.0 could also evolve the concept of Visual management, moving from paper-based to digital information.
Galdi strongly believes that the two paradigms can have their own lives: on the one side, Lean could live without the implementation of technologies, whereas on the other side, technologies could be implemented within a non-Lean organization. However, it is shared that Industry 4.0 could sustain and improve Lean performance. It is also true that a deep knowledge of the process is mandatory: even if in a non-lean organization, digitization of a non-efficient process creates more inefficiencies. Indeed, there are synergies between the two: it is necessary a strong knowledge of process, and Lean fosters this situation but it is not the only way to achieve it. According to the topic of Big Data, Galdi disclosed a clear point of view: they are fundamental in the decision-making process, because a top management which is able to use them will be in a stronger position than before. Modularization is at the basis of Galdi's machineries and it allows to simplify the complexity: although, it has to evolve with Industry 4.0 and Galdi introduced the concept of interoperability between machines. Finally, Galdi agreed according to the idea of proactivity: in the Smart Factories of the future, the anticipation of the clients' needs will be possible, thanks also to the correct management of Data.

6.2.3 Toyota Material Handling Systems

TOYOTA
MATERIAL HANDLING

Location: Casalecchio di Reno (BO, Italy)

Industry: Automotive & Material Handling

At a glance: EUR 640 million of turnover; +7,500 employees; 3 production plants (Italy, France, Sweden)

Reference: Maurizio Mazzieri (Senior Advisor); Stefano Cortiglioni (Business

The first hint that emerged from the interview with Maurizio Mazzieri of Toyota Material Handling Systems is that while the third industrial revolution took the risk of computerize the errors, Industry 4.0 will take the risk to digitize the process inefficiencies: the first paradigm lies in the sentence “It cannot exist Smart Factory without Lean Factory”. It is also true that the implementation of lean depends on the context, and it is no more only a Japanese-issue: an American research made in 2007 (Anand, Ward, Tatikonda and Schilling) shows that within the 70% of the US companies that have tried to implement TPS, 74% of them had no results, and that only 20% of Japanese companies apply Lean correctly. It is a matter of adaptation to the context: some companies need lean paradigm to face the high level of customization present in the markets, in which it is no more needed mass production. And if it is enlarged to Industry 4.0, also Smart ERP has to be adapted for a specific company: technologies could foster and facilitate the improvement of performance, without losing the importance that the process has.

Digitization is putting in crisis the concept of forecasting: the customer is no more only the user of a product, but also its inspiring. Marketing has to be proactive: autonomation (Jidoka) in production phases is needed together with proactivity towards the market. Forecasting is a science, but the decisions should be based not only on numbers but also on market requests, listening to the client and trying to anticipate their needs. The client is difficult to satisfy, and Lean provides the fair level of flexibility in order to get closer to the customers’ requests, especially through the analysis of Big Data, which provides information about macro-signals and trends.

For Toyota Kaizen has to be an attitude, that every day has to be performed, like a never-ending story. In doing so, people maintain their core roles: even if with the arrival of co-bots and artificial intelligence, humans maintain their core roles. Mazzieri declared the following postulate: beforehand individuals transferred the intelligence to machines, whereas in Industry 4.0 machines will transfer intelligence to individuals, generating an interconnected cognitive system. Robots could automatize the knowledge of humans, which has to be the bedrock for generating the process at the beginning: technologies and new digital tools are introduced in order to better understand the new ecosystem of “Lean 4.0”. Of course, digitization will help in evolving the process, but the concepts behind the process has not to be lost: this preserves the ability to manage data with high sensibility, which is only possible with direct experience and going to Gemba also with Smart Machines that are able to decide alone. It is important to underline that technologies are used only in the part of the process in which they are really needed, and always in an

essential way: it is possible to support humans in their working, but their presence remains fundamental.
A possible definition of *Lean 4.0* emerged from the interview, which is connected to the fact that it could be seen as an autopoietic ecosystem: this term, stolen from psychology, refers to a situation in which a perfect machine like a clock, whose interdependence between gears is static, does not exist but it is more a dynamic mechanism, which is able to adapt itself continuously and it is in incessant evolution through to the different interrelations between the components of the organization.
Moreover, the topic of standardization could be translated into the concept of servitization: new digital systems highlight those elements which could have a potential orientation in the service creation for the clients, through technologies, continuously offering valuable solutions and enlarging the final offer for the customers.
For Toyota, Lean has no intrinsic limits, but problems in implementation, especially regarding the strong commitment and determination of management at least in the beginning: it is a matter of trust and collaboration, which has to be extended to the whole supply chain.
A process which is unstable and not lean leads to a digitization of the inefficiencies. Digitization have intrinsic inefficiencies, even if they are less evident and not physical, and so difficult to detect. Moreover, Industry 4.0 could be interpreted as a model which could solve all the problems only digitizing all the elements in a factory: this is not the easiest path, because sometimes physical elements could be more traceable and have more visibility. Of course, with Industry 4.0 the level of remote visibility increases, influencing the concept of traditional Visual Management of Lean.
Toyota thinks that Industry 4.0 is the natural evolution of a process already optimized and for which a further optimization is the digitization. The main problem related to "Lean 4.0" is the flexibility. Companies will have to be closer to the customers, and in this direction real-time traceability of each element, visibility along all the process and predictive maintenance will become important in the continuous creation of value for the clients.

6.2.4 Agrati Group Fastening Systems

Location: Veduggio con Colzano (MB, Italy)

Industry: Fasteners

At a glance: EUR 650 million of turnover; +2,500 employees; 12 production plants

Reference: Emanuele Mistò (Plant Manager), Gaia Ripamonti (Lean Manufacturing Engineer)

Agrati produces only special screws, perfectly in line with the trend of mass customization. Even if the product is simple, for Agrati both product and process innovation are important for maintaining a competitive advantage in the industry: in particular, co-engineering is used to design and deliver complex screws according to customers' requests.

Agrati strongly believes that Lean is only a way to implement a methodology, that aims at improving performance, while lean tools are those techniques that are able to achieve that objective. For its plant manager, lean implementation is a never-ending story, focused on continuous improvement every day. Of course, people are in the centre of the organization: they are the only ones able to look for new opportunities and to implement valuable solutions for value creation.

At first glance, Lean and Industry 4.0 are not closed. The main objective of Lean lies on finding wastes in production and eliminating them: 4.0 technologies could help the organization in those processes where humans are not a value-adding for the situation. The company believes that humans are the most flexible and adaptable tools for a company: although, if for example movement throughout the factory is considered a waste for Lean, it is reasonable to implement a technology instead of human in this part of the process. Industry 4.0 and all the technologies related could be applied only when the 80% of the results has been obtained by the implementation of Lean, through humans that work with paper and pen. A problem emerges when the level of motivation of people is not so high: workers needs to fell themselves realized and involved in improving the company, being engaged and with the possibility to propose and implement a possible solution to improve. Nevertheless, Industry 4.0 cannot solve the problem of change management: mind-set shifting is something that must be done before. Through co-engineering Agrati is able to satisfy its customers, but also to anticipate the client: this is achieved thanks to the usage analytics and artificial intelligence which gather and analyse Big Data correctly, even if the client is always in the centre. Lean asks obsessively for improvement, and this is possible again through Big Data and Analytics: however, data has to be secured (cybersecurity) and reliable (with technology I can increase the possibility that the information gathered is more correct). Moreover, being able to work on Data allows real-time, correct and synthetic results, in order to support a faster decision-making process. This is important also because it is connected to a higher level of traceability of production than in Lean.

6.2.5 Poliform S.P.A.

Poliform

Location: Inverigo (CO, Italy)
Industry: Furniture
At a glance: EUR 150 million of turnover, +400 employees, 4 production plants
Reference: Edoardo Anzani (Associate)

Poliform is a family company placed at Inverigo (Como, Italy), leader in the furniture industry: its drivers are automatization and easier processes. With the arrival of new technologies, Poliform was able to move from automation, in which people usually take decisions, to autonomation, in which machineries are able to smartly take decisions. It sees a progressive elimination of paper in the company, which has not a huge financial impact, while it allows to eliminate wasting in the process. Digitization of paper-sheets helps in making the traceability of elements easier within a process, because information are not physical but real-time and it is possible to detect what is needed only with a click. Of course, for Poliform this means also having only the information that is needed, when it is needed. Traceability, which is measured in the return of information, and standardization make easier the management of a complex system like the ones in Poliform, characterized by a great variant of standards and certifications to be respected according to the country of delivery.

Poliform does not perfectly agree with Japan thinking according to which Industry 4.0 will be applied in a factory without people, completely automatic and interconnected, and where quality checks will be made by video-cameras. In fact, especially in the furniture industry, humans are fundamental to ensure a high level of customization, which is deeply connected to the level of product quality. However, new interconnected machineries have changed the production: there are no more production lots, stored in intermediate warehouse, but they allow to produce only what is needed and requested by the customer, customized, reducing the space dedicate to the storage. This leads to a higher flexibility and reactivity, because it is necessary to ensure a certain degree of customization in each product. Nevertheless, Poliform believes that machineries are not sufficient: instead a robust change of mentality in each part of the organization is necessary. Edoardo Anzani supports the transparency and the visibility along the whole supply chain: it is necessary to share the management system thanks also to the Cloud Computing, in order to be aligned with suppliers of the internal process, giving them higher responsibility for motivating them to deliver what is needed according in line with the performance requested. Poliform deems that information has to be filtered, especially in small companies: Big data are important but it is necessary to decide fastly what to see and what could create value after the analysis of a huge amount of information. Poliform thinks that processes are important, but people are in the centre: however, it is important to introduce software in order to help them in solving daily problems, giving them a part of supervisor in daily decision making process.

Regarding the barriers, Anzani focused the attention on two main limits: on the one side, people and their engagement in the innovation process, which has to be connected anyway with a top commitment; on the other side, the resources able to re-think the whole system. It emerges also the possibility to decentralize the decision-making process: this could be done thanks to the arrival on the market of Artificial Intelligence (Watson – IBM), which can increase the level of precision. However, the problem is that many industries are not aware of the presence of technologies, or part of them are only “work-in-progress”, not ready to be used in the market. Finally, the slogan “customer first” is shared also by Anzani: he also believes that is utopic to think about anticipation of customers’ needs.

6.2.6 LIUC – Carlo Cattaneo University

Location: Castellanza (VA, Italy)

Industry: Private Services

At a glance: +2,000 students; Faculties of Economics, Law and Managements

Reference: Luigi Battezzati (Professor of Smart Factory)

This interview was different from the others because it did not look for an opinion of a manager of a Corporate, whereas it was important in giving hints for perfecting the model. Battezzati highlighted that the model for this dissertation is a normative model, which presumes an absolute truth and rationale, where there is a wanted decision of comparing principles with principles, and pillars with pillars of the two paradigm. For his point of view, Industry 4.0 has already some paradigmatic elements. Firstly, the strong cooperation between humans and robots, which is a new concept with respect to the idea of automation of 1980s, in which it was born without humans a priori and neglecting this new idea of interaction. Subsequently, he thinks that before automation it is necessary to follow a lean approach, which simplifies the process, creates value for the factory and the client, and modularizes the process of the product: only once everything useless has been eliminated, it is possible to automatize, performing a useful automation. Finally, the concept of interdisciplinary: automation has to be performed in the factory, but also integrated along the whole supply chain, enhancing the visibility, for instance using a MES in the factory and an ERP synchronized with partners, for example through the usage of Cloud Computing. According to this element, a problem of change management occurs, related with trust between parties, together with the problem of skills needed. To sum up, automation is limited on one side, but on the other side it integrates all the supply chain in an essential manner, used only when it is needed. However, it has to be integrated correctly: ERP is a good model, but it has to be applied well, and only for what is essential, what it is possible to automatize. To conclude with the first part of the interview, Battezzati claims that it is not possible to apply 4.0 without a lean process, both in the factory and in the whole organization.

Furthermore, it emerges that Kaizen is a way of thinking, a behaviour that has to be done every second, an attitude which occurs automatically, without thinking: Battezzati underlined the fact that in Italy companies need the result, but sometimes projects have not tangible results at the beginning, and so it is necessary to maintain this tension every day.

He distinguished also digitization process for B2C and B2B: for the final consumer, digitization has a value if he or she orders a customized product and the IT system is able to inform the client about its state (what is important is the final output); whereas with B2B he connects the concept of traceability and visibility along the process.

For industry 4.0, real-time interconnection is a peculiarity: however, in lean there is an artifice, the takt time, to manage production. Instead, with the fourth industrial revolution, the management will become real-time, with a punctual control over the process: JIT systems are perfectly synchronized, but respecting the ERP systems they do not have the possibility to track each element of the process and increase its visibility. A new concept that emerges is that the Data is atomic, with a degree of detail never seen before: digital factory will not talk about lots of production, but single elements traceable everywhere every. Thanks to Big Data it is possible to understand macro-trends for receiving information on actions to perform to improve the situation: with a huge amount of data it is reasonable to think that also a little variability, which in the long term can influence the final result, could be detected and could provide a huge saving in the future. This concept is connected also to predictive maintenance. Real-time is very useful in order to react faster, while in collecting data is not so essential. A faster reaction is the enabler of shorter lead time in production, which is also possible, in a disruptive way, with the usage of Additive Manufacturing, that allows to manage and produce complex unit of production shortening the lead time. According to the decision-making process, an interesting opinion emerged: in fact, the top management will have probably all the information to take decisions from the centre, as a remote control, without going to Gemba, a concept which is impossible in Lean. Of course, change management and engagement of people is a huge barrier in the implementation of both lean and industry 4.0, especially for business already existing.

The problem of competences instead is manageable: people could be trained, or at least the expertise could be acquired, while leadership and the attitude to change must be present in order to propose a swing, both Lean or Digitization.

6.2.7 ABB Italia

ABB

Location: Dalmine (BG, Italy)

Industry: Power & Automation

At a glance: EUR 2.5 billion of turnover; +6,000 employees; 15 production plants

Reference: Fabio Golinelli (Supply Chain Management & Production Processes Manager)

ABB started to think about Lean in 2008, after a trip in Japan, visiting Toyota, Daikin, Mori Seiki and Honda. The pilot test was developed in Dalmine (Bergamo, Italy) and after some years the company decided to extend the model called "ABB Dalmine Lean Way" in all the other factories. Of course, the model was based on JIT and Jidoka pillars, together with a strong component of innovation, related to a new way of doing production, sustained by Kaizen pillar and a new concept of Daily Management. In ABB the results are monitored through only three KPIs: production efficiency, defect rate and delivery reliability. Lean was necessary because of the high degree of complexity: in ABB there are a lot of components and short delivery time to be managed with high flexibility. Once lean was enlarged to the whole organization, ABB decided to extend lean approach from its factory to the whole supply chain, helping each supplier in developing the same model and, after some months, sharing benefits and profits, keeping them monitored though the usage of Cloud platforms. The main barrier faced was the strong resistance to the change: people was engaged in an active and collaborative participation in order to foster the revolution and accept the approach.

ABB is already strong in Industry 4.0, because the company is currently selling more than 180 solutions 4.0 (with the brand ABB Ability), and has stipulated two important partnerships with Microsoft, for Cloud (Azure), and IBM, for Artificial Intelligence (Watson). ABB is trying to digitize all its plant, in order to create a real Smart Lean Factory. The plant manager, Fabio Golinelli, provided some examples: for example, a MES, internally designed in ABB, is used for a robust management of the factory, in a bi-directional way (instructions transferred to the workers which return feedbacks) and paper-less. The configuration of this MES is extremely simple: there is a dedicated engineer who develops every day new applications to foster the customization of the product for the clients, and enlarging the offer. Again with the MES, ABB implemented a genetic algorithm for managing the Hejiunka, which takes all the client orders and create the optimal sequence for the production. An X-Ray scanner controls smartly the goodness of each process phase, with Smart Testing that increases also the degree of real-time traceability. Furthermore, through an online layout it is possible to know the situation in every part of the factory. It was also implemented the Smart training for the operator, through virtual reality. The employees, worn their Smart Glasses, enter in the electric panel (or another product) and can learn better how to work with it.

Literally, Industry 4.0 for ABB could be translated in the digitization of Lean process, already existing and mandatory. ABB has a clear path to follow until 2020: it defined a clear investment plan called LightHouse, in which the company wants to create a Smart Lean Factory perfectly working in Dalmine for external audience. Moreover, a lot of R&D projects about new applications not existing in the market are still being developed. Of course, the first necessary step is approaching with lean, in order to create the culture, and then digitize the process, for all the applications. Furthermore, the automation seems to be a necessity in a high cost labour country like Italy, in which it is important to reduce the costs of workforce: according to Golinelli's point of view, Lean together with Automation leads to digitization, which is a natural path, not forced. Nevertheless, new employees were hired, but the mix has changed: instead of the traditional two-third workmen, today only one-third are workmen, while the other two-third are office workers. Therefore, in the factory workmen have changed their roles and started to supervise, control with tablet and analyse data.

Unfortunately, a lot of solutions are not ready to be applied. However, Golinelli underlined the opportunities that all the technologies together could have in gathering data and supporting the decision making process: he talked about collaborative table and wearable devices, real-time analysis of data, predictive maintenance and also artificial intelligence. Of course, higher the quantity of data, better the situation: in fact, IT systems allow to filter data and eliminate non-value-adding information. This is in line with the science of Cognitive Computing: analytics can use not-structured data in order to arrive at a solution absolutely acceptable. Through big data ABB thinks that the anticipation of the clients' needs will be possible. ABB does not agree with the concept of disruption according to Industry 4.0, because disruptive innovations have always been present: what changes is the speed of reaction. Modularity is not a requirement for 4.0, but from the interview emerged that interconnectivity and interoperability between products and machineries will become necessary: products and machines will be able to exchange information, fostering the creation of CPS that allow a higher flexibility and a better re-configuration of the plants. In the future, there will probably be also social networks between machineries through which they can talk each other and will decide alone, without human intervention.

Industry 4.0 will not influence too much the visibility across the Supply Chain, because with Lean suppliers were allowed to improve their performance through the sharing of information and management process. However, in the roadmap of 2020 it is inserted an ambitious project called "Dynamic & Digital Supply Chain", which will give the possibility to share all the information, from orders' portfolio to data over production capacities, and also about sales & operations daily planning, with a software that will nurture the collaboration between parties: it will support the integration of the supply chain, which lies also on trust between players, and of course tools to manage this new situation, leading on new business models.

6.2.8 Brembo

Location: Curno (BG, Italy)
Industry: Automotive
At a glance: EUR 2.3 billion of turnover; +9,000 employees; 16 production plants
Reference: Alberto Moro (Continuous Improvement Group Manager); Marco Santoni (Data Scientist)

Brembo is really robust in Lean practice and it started Industry 4.0 project in 2014 with a strong top commitment and some internal training courses, especially with German experts on 4.0. However, the situation presented seemed a bit utopic and so Brembo decided to start with its own path: at the beginning, it did not believe in the existence of a Digital Factory, but only in the presence of enabling technologies which could change the way of running business and production, tools that put together could lead to a radical and disruptive change. Initially, Brembo listed these technologies, in order to understand their areas of intervention, clustering them in group. Afterwards, they analysed these tools according to the impact on the factory and the implementation time: for those most promising, each BU decided to develop some pilot tests to grasp the potential benefits. The areas of intervention arose from the analysis were the following: data collection, IoT, AGV and internal movement, Smart planning and warehouse, virtual reality (both for training of the operators, remote control and assistance), simulation systems, co-bots. Each pilot test has a KPI, which is the maturity index, in order to understand if the project is in the right direction, but maybe in a few weeks the situation could change because a new enabling technology could emerge.
A lot of opportunities emerged: what was indisputable was that, as a basis, these tests need a strong knowledge of the process, which is possible to achieve only by a solid implementation of lean. Furthermore, Brembo prefers to keep separated Lean and 4.0 projects, because Lean is associated with the improvement of "classical" tools, while

Digital Factory deals with enhancement thanks to the intervention of technologies, even if it is correct to put them together: it is impossible to digitize without a lean approach as a basis. An interesting pilot test presented concerns the interconnection between machineries, which talk each other and coordinate autonomously the production, without inserting buffers within different phases of the process. Brembo depicts three possible steps to follow: first, the application of lean; second, the introduction of 4.0 technologies in line with lean tools, inducing a strong connection between digital tools and lean practices; third, the achievement of substantial improvements in *Lean 4.0*, a system which will be able to optimize alone. Another fascinating pilot involves the project of a plant that work in a complete autonomy: anyway, Brembo does not want to create a *black factory*, without the presence of operators, but a plant in which raw material will be automatically driven to the machine, for which a scanner collects the required information for starting a certain production phase, and in each of them every single element is registered and traced and it is able to control itself until the last phase of packaging, providing a continuous and reliable feedback through interconnected machines and cloud platforms. In this autonomous plant, Additive Manufacturing for supporting just-in-time techniques was inserted. Moreover, the interconnection between different departments provides the possibility to gather data which could be used in further phases, to increase the speed of reaction in facing new challenging situations: this will be only possible through the usage of software that are able to analyse a not-structured data automatically. Data collection is no more as with lean "naked-eye", but the level of detail will increase, like X-Ray: technologies will look beyond, and the Data will become atomic.

Finally, Alberto Moro highlighted also two main barriers related to Industry 4.0: cybersecurity and vulnerability of data, because for instance a hacker attack could block totally the factory. Furthermore, new roles for workmen will born and new skills will have to be acquired.

6.2.9 Fiat Chrysler Automobiles N. V.

Location: Turin (TO, Italy)

Industry: Automotive

At a glance: EUR 111 billion of turnover; +235,000 employees; 12 production plants

Reference: Luciano Massone (Head of WCM EMEA Region & WCM Development Center VP); Vincent Ruelle (Manufacturing Methods Specialist); Alessandro Lacalaprice (WCM Specialist)

The first idea that emerged after the last interview, the one with FCA in Turin, is related to the fact that Industry 4.0 will have an impact on the long-term: it needs a detailed investment plan with a precise roadmap with benefits achievable in the next future.

Moreover, FCA strongly believes that the link between Lean and Industry 4.0 is not unique: digital could be seen as an evolution of lean, but also as a way to support lean practices. Of course, lean is necessary before digitization in order to avoid the digitization of inefficiencies. Technologies allow to increase the number of projects for lean implementation and their impact respecting the continuous improvement approach, but they are really dynamic, because their costs and accessibility decrease over the time, and it is possible to use a technology after few months that in the previous business case was missing: this means *thinking out-of-the-box*, connected to what FCA calls *intangible benefits*, not applicable and computable at the moment, but concerning promising scenarios for the future.

FCA divides technologies divided in 2 main clusters: one related to digital twins and virtual factory, the other more technical and practical, related to the way a certain technology could be applied in the factory to improve performance. The implementation of 4.0 technologies is a step further: it enables to go ahead, once all the inefficiencies in the organization are eliminated.

The interview continues with a presentation of one of the ten technical pillars of WCM in FCA, which is the Cost Deployment (CD): it figures out the picture of the perimeter of costs sustained by a plant, considering also wastes and losses. It is possible to reduce a huge part of costs by implementing Lean. Moreover, it is possible to tackle other inefficiencies with the application of technologies (exoskeleton), whose impact could be evaluated precisely, and also another intangible part, thinking about new scenarios. To sum up, Industry 4.0 will be able to deal with problems already existing, increasing the area of intervention of lean project, and so the quantity of saving, and also to open an unknown world, tackling losses and wastes before invisible, thanks to the effective management of real-time and detailed information. The latter vision is deeply connected with the concept of radicalism and disruption owned by the fourth industrial revolution.

Technologies should satisfy production needs: however, value is not created by usage of technologies in itself, but in an element more analytical, whose core is on Data. Big Data and Analytics are connected with the previously mentioned intangible and unexplored benefits: of course, before doing a deep analysis it is necessary that lean approach is carried out. Moreover, cloud is the enabler of the integration: information is shared through Smart IT systems, and technologies foster a faster development and diffusion of value-adding projects.

Proactivity is an essential element: it is not enough being reactive, but companies have to be proactive, looking forward in the application of technologies and anticipate the clients' need. Indeed, companies should find the correct balance between external needs (business driven) and technologies (technology driven), in order to provide an alternative solution to satisfy the need. Traditional marketing will not exist anymore: through Big Data new unexplored trends will be discovered and solutions to these needs will be provided, in order to create quality and value.

FCA gives some hints in selecting the technology to use: it has to be user-friendly and functional; its reputation should be higher; it has to integrate within the process, providing an easy user-experience; lastly, it has to be integrated in the other existing systems. The concept of integration is strongly connected with visibility: digitization has to be extended along the whole supply chain, in a wider point of view., supporting just-in-time techniques with suppliers. Respecting Lean ecosystem, the degree of precision of information will be higher in Industry 4.0, increasing the level of detail and the traceability real-time. Nevertheless, FCA introduced an intriguing point of discussion according the IoT: Smart Devices will be able to show only the information that is needed, when it is needed, computing and analysing a huge quantity of data on remote, and pointing out only the required detail.

An interesting point of view emerged during the interview: digital could be subjected sometimes to a transposition of lean, namely a translation of lean principles and key concepts to digital context. It is common to refer to quality of software and data: lean is transferred from process to program and data analysis.

In addition, FCA thinks that machine learning, artificial intelligence and neural nets could disrupt the way in which problem solving is approached: decentralization of decision-making process towards Smart Machines will be no more an utopia.
In the last part of the interview it emerged that Industry 4.0 is not a black-box, but a system of integrated elements intertwined with the components of the factory. FCA stressed the importance and the necessity of digitization: companies are obliged to digitize, but it is important to understand the situation and follow the approach without shortcuts. Also for FCA the issue of competences required leads to a generational change. It is reasonable to think that it will be better finding an equilibrium between the acquisition of knowledge from extern (with new expertise, strategic partnerships, extending the network of know-how) and starting an outbound process (being helped by consultancy companies). As a result, new people have to be hired, more flexible and faster adaptable to the revolution. It is necessary focusing the attention on internal know-how, in the competences of Smart people, trained also with new HMI systems. However, in Industry 4.0 a soft part is missing: what is the essential part, the first investment, namely the training of the entrepreneur to deal and face with the radical change. This is because technology is available and accessible to everyone: what generates competitive advantage is people together with digital tools. The competitive barrier concerns the humans, the engineers that are able to provide Smart solutions with tools that others are not able in doing.

6.2.10 Conclusions after the interviews

After having interviewed the 9 partners selected, the draft of the model was refined. The approach to define the model followed a pure *keyword-based* method: in fact, for each principle and pillar (both sustaining, in blue box, and disruptive, in orange one) up to two keywords were selected and it was checked during each interview the level of intensity of a certain keyword in the speech, if it was present. This level is set up according to three qualitative score: *null* (blank space in the table, if the keyword and the part of the model was neglected), *questionable* (~, yellow box, in the table, if the part of the model is present but some doubts emerge, or if it is seen as a future scenario) and *indisputable* (↑, green box, in the table, if the interviewee is perfectly conformed with the model though). Once every keyword was analysed, the conclusion of the model thinking part was drafted, before going to the validation by the analysis of the 13 statements presented by the conceptual map.

Table 6.2: Results of the Interviews

			SEW	GALDI	TOYOTA	AGRATI	POLIFORM	LIUC	ABB	BREMBO	FCA
PRINCIPLES	CUSTOMER	*Anticipation Proactivity*	~	↑	↑	~			↑		↑
PRINCIPLES	VALUE STRAM	*VA information Filtering*	↑		~	~	↑		↑	↑	↑
PRINCIPLES	FLOW	*Real-time Interconnection Traceability of Data Flow*	↑		↑	↑	↑	↑	↑	↑	↑
PRINCIPLES	PRODUCTION	*Pull Servitization Product and Services*	↑	↑	↑	↑	↑	↑	↑	↑	↑
PRINCIPLES	APPLICATION	*Radical change Disruption*	~	~					~	↑	↑
PILLARS	STABLE AND STANDARDIZED PROCESSES	*Interoperability Interconnectivity*	↑	↑	↑			↑	↑	↑	
PILLARS	STABLE AND STANDARDIZED PROCESSES	*Servitization Cloud as a Service*	↑	↑	↑		~		↑		
PILLARS	VISUAL MANAGEMENT	*HMI Digital Twin*		~	↑		↑	↑	↑		↑
PILLARS	JUST IN TIME	*Cloud Computing Visibility*	↑	~	~		↑	↑	↑	↑	↑
PILLARS	JUST IN TIME	*Additive Manufacturing Faster Response & Shortest LT*	~				~	↑	~	↑	~
PILLARS	JIDOKA	*Collaborative Robots Advanced Automation*	↑	~	~			↑	↑	↑	↑
PILLARS	JIDOKA	*Autonomous Automation (CPS) Supervision*	↑		~		~		↑	~	
PILLARS	WASTE REDUCTION	*Analytics Big Data*	~	↑	↑	~	↑	↑	↑	~	↑

At first sight, almost from all the interviews the central thesis of this dissertation was validated: before implementing the paradigm of Industry 4.0, or in other terms before starting the process of digitization, Lean approach must be put into practice. A stable and standard process, without wastes and losses, is the first requirement for the application of Industry 4.0, in order not to incur in the digitization of inefficiencies. In general, it is a common opinion thinking that digitization is a mandatory step to follow after Lean, even if someone (like Agrati and Toyota) thinks that technologies have to be implemented in an essential way, only where it is needed, in order to create value for the company and the factory. In this sense, they do not look at industry 4.0 as a revolution, but more a possible evolution targeted just where it is required.

Related to the concept of *revolution*, two opinions came to light during the interviews, which allowed to draft the first and the fifth principles of the model, the two more *disruptive* in this sense respecting to Lean philosophy. In fact, some partners talked about anticipation and proactivity that could be pursued with Industry 4.0. This is an ambiguous point, that some interviewees did not agree with (like Poliform), but in some cases some interesting points of view arose. For instance, Toyota introduced a new vision of marketing, which is supported by FCA, according to which through Data and Analytics it will be possible to be proactive towards the market requests. However, it is important to find the correct balance between external needs (*created* with data collected and trends) and availability of new technologies and solutions. Another radical point was connected to the approach of application of Industry 4.0. Even if it was not explicitly said, the application of technologies and the creation of a Smart and interconnected Factory is in line with the aim of Industry 4.0, which aspires at transferring internet principles in manufacturing environment. Brembo is strongly convinced that the implementation of Indutry 4.0 is connected to a radical change of the factory (like also SEW) and it strongly believes that anyone has to pursue its own path. FCA linked the radicalism of the change to the intangible part of benefits achievable with Industry 4.0. Kaizen should remain the central attitude, even if it wants to obtain daily radical changes. Instead, even if ABB strongly put into practice the principle, it did not think that Industry 4.0 is connected to a disruptive change, but more to an idea of natural evolution: disruptive innovations have always been done.

Together with the disruptive part of the model, which was seen differently by different parties, for the central *developmental* part of the model almost all the interviewees agreed. Key was the concept of filtering the huge amount of information gathered: it was a common point to think that the selection of value-adding information will accelerate the decision-making process. Moreover, professor Battezzati introduced the interesting point of the evolution from *takt-time* to *real-time*. Almost all the parties agreed on the importance of real-time management of data, which became the core part of the paradigm, even if they stressed their relevance when it is necessary to react and supervise, not in the mere gathering process. Many partners, especially Poliform, underlined the change in concept of flow, which is no more a flow of physical element but a flux of data. It emerged also that real-time management is possible thanks only to the interconnection of machines throughout the factory. The traceability of production is another key concept arisen during the discussion, together with an increasing level of visibility: the situation is no more visible at *naked-eye*, but the analysis goes in deep like an X-Ray. According to this point, it is inserted the concept of remote control, “every time, everywhere”. Moreover, in this case some interviewees inserted the concept of *servitization*: customers are interested in products but also related services, which are enabled by data, and so companies must be able to afford this requests, by customizing and servitizing their offer.

Once revised the part of the five *actions*, the following step was defining clearly the pillars and foundations of the model, starting with Lean House (Liker, 2004), trying to understand which could be the *sustaining* elements and which the *disruptive* part. As the table shows, although the opinions for principles are quite homogeneous and clearly defined, in the area of pillars the situation is more jeopardized and also uncertain in some cases. In fact, for some points of the model the level of common agreement is much higher than for other parts, cited only by few of the interviewees.
Starting with the concept of Stability and Standardization of processes, it is interesting the opinion of Golinelli (ABB), according to which it is reasonable to introduce the concept of interoperability between machines, once a standard is created. According to this idea, Brembo has already implemented a pilot test. More ambitious is the link, proposed by ABB and also Toyota, of *Servitization*: the idea behind is that, once fixed a standard, the concept will radically change in favour of a "Service-oriented Architecture". For instance, ABB is proposing more than 180 solutions of industry 4.0 completely customizable through the introduction of new applications. Moreover, *Servitization* is perfectly in line with the trend of mass customization, emerged during the interviews.
The idea that arose behind the pillar of Visual Management was connected to the digitization of poka-yoke signals in order to increase the visibility within the factory. Another point was the change from paper-based to web-based signals (idea highlighted by Poliform), which fosters a higher traceability of the situation within the boundaries of the plant. Furthermore, FCA proposed an interesting point of discussion according to the decision-making process: in fact, Smart intertwined systems will be able to select automatically the necessary information to accelerate efficiently the process of taking decisions, while all the other non-value-adding information (for that specific situation) will remain latent. This point is strongly connected with the second principle of value-adding information, that also Agrati stressed a lot. Furthermore, almost everyone underlined the importance of HMI in the digitization of Visual Management practices. Human-Machine Interference will improve the ergonomic condition of workstation, fostering a job enrichment with the creation of new roles. This is in line with the doubts that emerge from certain interviews, related to the need of a generational change: new skills will be needed, because new roles will emerge. However, FCA and Brembo are convinced that these competences could be acquired externally or at least trained. However, it was decided to dedicate only a short paragraph for this topic, which is out of the dissertation, and leave it to further researches.

Every partner of the interviews agreed on the fact that Big Data are the core of the revolution. Almost everyone was aligned with the concept that Analytics and Business Intelligence will change the approach to problem solving, even if within each opinion different aspects according to the final goals of Big Data were present.
Interconnection which plays an important role in the evolution of the concept of Just-in-Time. Almost everyone was convinced that the real-time management of the factory will support the management of a flow without bugs. Moreover, the concept of Just-in-Time and interconnection has to be extended to the whole supply chain, shared between the partners: especially ABB and FCA stated that the extended intertwining will enhance a faster response and a higher visibility thanks to the usage of Cloud platforms. Timidly, Battezzati tried to introduced the concept of Additive Manufacturing in order to boost the performance of Just-in-Time techniques, whereas Brembo is already active in this way. However, it was a common opinion that technologies will allow a faster response and a shorter lead time, in order to change also radically the existing business and entrepreneurial models at the basis.
Finally, the pillar of Jidoka will be certainly modified thanks to the Human-Machine collaboration, that especially Battezzati underlined. Co-bots will definitely enter in the factory playing an essential role for the company, by a perfect integration with individuals: ABB already sells android self-made and SEW uses its own robots. The only sceptical remains Toyota, which stressed the importance of humans, and Agrati, that talked about automation as a support and not as fundamental. According to the more revolutionary idea of CPS, it seems like a work-in-progress. Only ABB and SEW are definitely convinced that a Smart Factory could be built on the interconnection of Cyber-Physical Systems. Moreover, especially Poliform and FCA introduced the idea of an incremental usage of Artificial Intelligence and neural nets as a support of the autonomy of CPS, that could totally take the job of individuals, who remain only as supervisors. However, it was a common opinion thinking that Smart machines will be important but the people are always at the centre, especially for Toyota, closer to the traditional Japanese philosophy. People are important not only for team-working, but also in writing the algorithm at the basis of these Smart Machines.

Apart from the already-cited problem of competences, another important issue emerged in every discussion: the dilemma of change management. In fact, not only in Lean, but also in applying concepts of Industry 4.0 it is important to create the culture within the

Organization, which is at the basis of every change. Also for this theme a single thesis could be write on, and it was decided to mention it in a little paragraph and keep the discussion opened for further follow-up (cf. *Section 7.3*).

To sum up, the interviews allowed to define more precisely the model thought at the beginning of the research, in the words in which it is written in this dissertation. As the table shows, some partners agree on most of the points of the model: this is the case of ABB and FCA, the two companies which seemed more *ready* to change, in which Industry 4.0 is already a consolidated reality (even if it is still object of deep studies). Also for SEW, Toyota and Brembo the same consideration could be advanced, even if with more question marks. On the opposite, there are still companies far from certain part of the model, or for which certain doubts remains regarding the real potentialities of Industry 4.0. This is the main reason why, once the model thinking phase was concluded, 13 statements were thought, in order to cover each part of the model and try to understand the level of *readiness* of the manufacturing industry in approaching the Fourth Industrial Revolution. The final outcome of the validation phase was trying to define which sides were widely accepted and which ones must be revised in other works.

6.3 Conceptual Map

Before the validation phase, a conceptual map was drafted in order to understand the number of necessary statements to be introduced in the Alpha test. The first idea, subsequently confirmed, was that at least 13 statements would have been mandatory, one covering each part of the model, starting from the first principle arriving at the last foundation of the House of Lean. In this sense, a four-level map was designed, in order firstly to understand the logic behind each part of the dissertation. The conceptual map is attached in *Attachment 9.2*. The starting point, of course, was the sentence expressing the main thesis of the work: namely, "Lean in the viewpoint of Industry 4.0 is composed by some principles and pillars that will be modified according to a sustaining perspective whereas others to a disruptive one".

Once having clear the main idea, the reasoning behind could be depicted. At the first level it was examined the reasons *why* it was decided to refer to *sustaining* and *disruptive* perspective of Industry 4.0 towards Lean. On the one hand, *sustaining* means that "Technologies of Industry 4.0 will improve the traditional Lean performance and the modalities of execution of Lean best-practices, overtaking some eventual limits". On the other hand, it was talked about *disruptive* because "Smart Technologies will radically change businesses (new business models, new services, new products, new entrepreneurial models), going beyond the traditional Lean paradigm".

The following step was understanding the way in which principles and pillars of the *old* Lean paradigm would have been modified by the intervention of Industry 4.0. The basic questions passed from *why* to *how* Industry 4.0 would have changed Lean philosophy. In the second level, two branches were developed, the first for the *sustaining* part of the model, the second followed the logic behind the *disruptive* rationale. Regarding the former, it was pointed out that "*operative* principles will be redefined towards a digital perspective", while foundations and pillars of Lean House "will be integrated progressively with the enabling technologies of Industry 4.0 in order to execute Lean best-practices in a more correct and efficient way". Regarding the latter, it emerged that principles and pillars will become *disruptive* in the sense that "*high-level* principles were radically modified towards a digital perspective" and "the usage of enabling technologies of Industry 4.0 would have completely changed the traditional way of carrying out the Lean best-practice".

Once the reasons behind and the methodologies according to which principles and pillars of the model referred to the words *sustaining* and *disruptive*, it could be possible to move to the third level, the most critical one. In fact, arriving at this point, it was necessary to define for each part of the model (no matter if principle or pillar) the construct which explained that specific part. For the sake of clarity, a construct is an absolute sentence which illustrates the concept behind a specific *abstract* idea. These constructs would have been the starting point for the creation of the statements used during the validation phase. As a matter of fact, a statement is the translation in *concrete* terms and actions of the idea expressed in the construct. It was worthy to think that at least one statement for each construct was necessary. The number of construct was set at 13, one for each part of the model: 5 for principles (value, value stream mapping, continuous flow, pull approach, attitude towards perfection) and 8 for foundations and pillars (stable and standardized processes, visual management, Just in time, Jidoka, waste reduction), respectively 5 *sustaining* and 3 *disruptive* (cf. *Table 5.1*). Of course, each of the two above-mentioned parts of the conceptual map was divided in another two sub-branches, one for principles and one for pillars.

Once the third level was composed, the fourth and last level could be tackled. It aimed at illustrating the way in which *abstract* ideas, namely the constructs, were translated in *concrete* actions and put in practice. The final objective of the fourth level was finding a series of unique and valid sentences for each construct, that put together would have formed a statement, that could explain the construct illustrated above in the third level. The composition of these sub-packages would have created the statement for the testing phase. As a matter of fact, each statement should have *lived* alone, in itself, without being overlapped with other statements or confused with other concepts in different branches. In fact, it was necessary to find statements which express one and only one construct, without leaving the possibility to refer to other constructs or branches. In the end, it was possible to shrink the reasoning in 13 statements only, one for each construct, which was the minimum number initially requested. This would have avoided the risk of having, for the same construct, two statement which could have been in opposition; in other words, it avoided the possibility to have two opposite opinions for two different statements linked to the same construct.

Once the map was revised, the 13 statements were finished and ready to be tested. However, they were sent to a little sample for Beta test. This phase helped to gather not only opinions but also feedbacks and comments regarding the clarity of the statements, in order to refine again them before the Alpha test. After the Beta test, the construct and the statement were presented in the way in which they are illustrated in *Section 6.4*.

6.4 Construct and Statement

The previous section describes the methodology behind the creation of the 13 statements inserted in the survey used to validate the dissertation model. The following one briefly presents what a construct and a statement are, in order to better understand the reason why they were necessary to confirm the dissertation thesis.

A *construct* is an idea, a mental abstraction that is used to express people, organizations, events, objects and/or thoughts. It is composed by a word, or a few of them, that could be explicable in a short sentence, in an abstract manner. They could be easy or difficult to understand and measure: the main issue is related to the fact that they could have more meanings and it is important to underline and communicate the meaning that has been given to it.

In order to validate and measure a construct, it is necessary to translate the construct into an operational definition, which is concrete and measurable in the form of variables (Laerd Dissertation, 2012, dissertation.laerd.com). Variables could be with category or levels, which for example defines the intensity of each factor, and ordinal, which can be ranked or ordinated. Likert Scale with 5 values (strongly agree…strongly disagree) could be considered an ordinal variable, and in this case it is requested the opinion regarding a certain part of the model (construct), which is the principle or the pillar (Likert, 1932). The final validation is only possible if a detailed analysis at conceptual level has been performed (cf. *Section 6.3*) and if each construct has been translated in concrete actions (measurable variables). Regarding the dissertation, these translations into concrete actions are what is previously called *statement*.

Beta Test was used for perfecting each statement before sending them in the survey. 5 experts were chosen in order to obtain feedbacks especially regarding their clarity, together with some suggestions for changing their form, in order to be more understandable for the final sample.

Continuing in the following sections, 13 constructs, followed by their specific statements, are showed, in the way in which they were inserted in the survey for Alpha test. The reference number (ID) of construct/statement is recoverable through the conceptual map present in *Attachment 9.2*. For the sake of clarity, Statements 1 to 5 refer to principles (1 and 5 are *disruptive*), while the others refer to foundations and pillars (7, 10 and 12 are *disruptive*).

Subsequently, for the Alpha Test it was selected an acceptable sample of 50 characters and collected answers for each statement in a scale between 1 (totally disagree) and 4 (totally agree), with the possibility to add also the option *I don't know*. To them, the statements are given following the number from 1 to 13, without putting in two separate sections the *sustaining* constructs and the *disruptive* ones. This allowed to foster the reasoning of the members of the sample, in order to avoid auto-correlation in their answers. In fact, no hints were given about the terms *sustaining* and *disruptive* in the survey.

6.4.1 Value

ID	Sustaining or Disruptive?	Construct (3rd level)	Statement (4th level)
1	Disruptive	Let the customer first, but it is necessary to anticipate his needs	Collection and sharing of Data and Information from customers through digital technologies (e.g. IT systems and Smart interconnected products) will allow companies to have a proactive approach towards the customers, aiming at not just "listening" to their requests, but "anticipating" their future trend and needs

6.4.2 Mapping the Value Stream

ID	Sustaining or Disruptive?	Construct (3rd level)	Statement (4th level)
2	Sustaining	Map the value stream, derived by information	Focus will be not only on searching obsessively operative activities which create value for the customer, but also on Data Stream, where information opportunely filtered will become value-adding, in order to improve the effectiveness of the decision-making process and fasten it

6.4.3 Continuous Flow

ID	Sustaining or Disruptive?	Construct (3rd level)	Statement (4th level)
3	Sustaining	Make not only Product Stream but also Data Stream Flow	There is not only a physical flow of "pieces", managed by takt-time logic, but it will be necessary to take into consideration also a flow of data, derived from IT and factory systems, which will create value once managed through a continuous and real-time flow

6.4.4 Pull approach

ID	Sustaining or Disruptive?	Construct (3rd level)	Statement (4th level)
4	Sustaining	Produce "everything" according to pull logic, not only products but also services	Traditional lean "pull" production will evolve through Industry 4.0 by the introduction of the concept of "services" enabled by Data Stream, available thanks to Smart Technologies

6.4.5 *Striving for Perfection*

ID	Sustaining or Disruptive?	Construct (3rd level)	Statement (4th level)
5	Disruptive	Modify traditional attitude towards continuous improvement (Kaizen) introducing radical (and not only incremental) changes by transferring internet principles in designing and managing industrial processes	Digital Factory is built upon the bedrock of CPS (Cyber Physical System): robust and well-tested internet principles such as Interoperability, virtualization, SoA, decentralization, modularity and real-time management will be opportunely transferred and adapted to industrial world, by introducing radical changes

6.4.6 *Stable and Standardized Processes*

ID	Sustaining or Disruptive?	Construct (3rd level)	Statement (4th level)
6	Sustaining	Foster standardization of processes and procedures by means of the interoperability of hardware and software	The topic of standardization will evolve in the concept of interoperability of machines and IT systems: interoperability fosters a better exchange of information, supporting the real-time management of the processes
7	Disruptive	Integrate stable and standardized processes with a new standard business architecture service-oriented	Standardization of process interfaces, product description and service-orientation (SoA) will be prerequisites which allow factories to use internet in order to share equipment and infrastructures

6.4.7 *Visual Management*

ID	Sustaining or Disruptive?	Construct (3rd level)	Statement (4th level)
8	Sustaining	Digitize traditional Visual Management practices in order to support workers in their workplace	Human-Machine Interface (HMI) will digitize the traditional Visual Management signals in the factory, by creating a paper-less environment; moreover, it will support workers by increasing the visibility over the whole processes and by improving the ergonomics of workplace

6.4.8 Just in Time

ID	Sustaining or Disruptive?	Construct (3rd level)	Statement (4th level)
9	Sustaining	Support Just in Time techniques thanks to the real-time sharing of Data	Data will be collected within the factory through tracking devices, by fostering their synchronization and real-time sharing in the supply chain through cloud platforms, in order to provide the right information, at right place and at right time
10	Disruptive	Reduce radically lead-time following one-piece flow logic, still keeping a higher product complexity without leaving aside the quality and the customization	Additive Manufacturing, designed for small product lots with a high level of customization and complexity in order to reduce product lead time, will allow to fasten the prototyping, the production and the maintenance, by fostering innovative logic of just in time and one-piece-flow

6.4.9 Jidoka

ID	Sustaining or Disruptive?	Construct (3rd level)	Statement (4th level)
11	Sustaining	Evolve the concept of Jidoka by inserting Collaborative robots in production line	Co-bots and humans will work together, in a balanced interaction, improving the work conditions, the productivity, the quality of production and the safety, without eliminating the need for the presence of workers for team-working
12	Disruptive	Allow individuals to be less operatively present in Gemba, thanks to a higher machine "autonomy" in the decision-making process	Individuals will play the role of supervisor in decision-making process, without the necessity of being necessarily physically present on Gemba for solving operative problems: as a matter of fact, a lot of process engineers and data scientists will design powerful and robust algorithms in order to allow CPS (Cyber Physical System) to be operationally autonomous

6.4.10 Waste Reduction: Problem Solving Approach

ID	Sustaining or Disruptive?	Construct (3rd level)	Statement (4th level)
13	Sustaining	Support the problem solving approach for a most effective waste reduction process	Traditional approach of Genchi Genbutsu will be supported by IoT and Tracking devices, which increase analytics capability to identify wastes

6.5 Beta Test and Expected Results

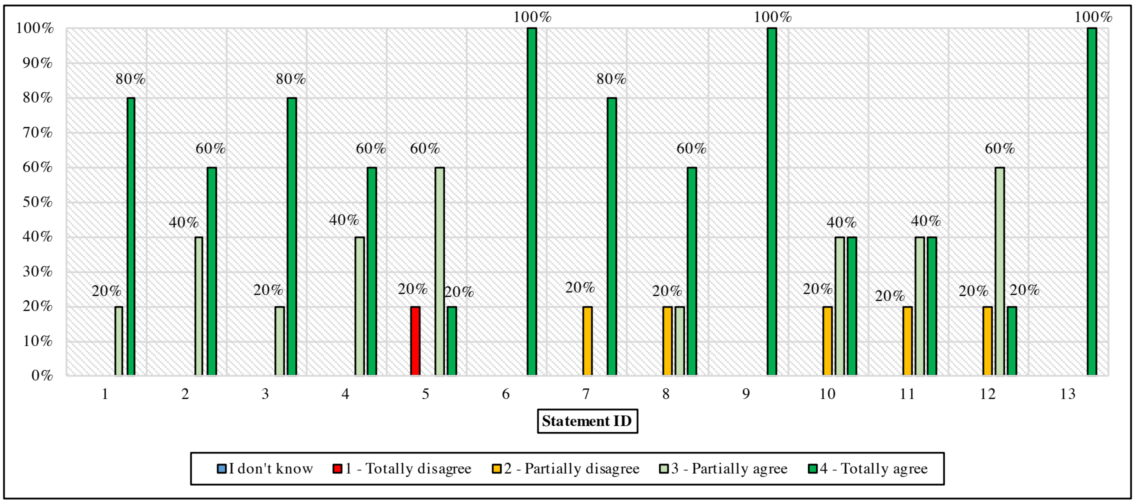
After the revision of the conceptual map, the 13 statements would have been ready to sent; yet a further analysis was performed. As a matter of fact, the statements presented above are the final outcomes of an intense work of a year made by personal researches and external interviews, where the broad dissertation topic was analysed according to different viewpoints. As a result, the statements grasped together different perspectives; anyway, they eventually express the point of view of the authors of this dissertation. In order to cope with this issue, it was deemed necessary to ask for another external point of view, in order to refine the statements, in terms of content and form, before sending them to the final selected sample.

Beta test was launched by selecting 5 people: 3 were taken from the bench of interviewees used for the brief case studies (cf. *Section 6.2*), while two were academic professors of Politecnico di Milano, keen on the topic of Lean and Industry 4.0. To be more precise, the 3 selected from the interviews were Fiat Chrysler Automobiles (reference: Alessandro Lacalaprice), Toyota Material Handling Systems (reference: Maurizio Mazzieri) and Liuc University (reference: Luigi Battezzati). The reasons behind this choice lies on the fact that the first two seemed, together with Brembo and ABB, the companies *readier* for embracing the digitization process; therefore, they could surely have given interesting insights if the statements were not clear. Moreover, professor Luigi Battezzati was chosen because of its deep both academic and professional expertise in this field: he could have provided interesting feedbacks regarding both viewpoints.
As already illustrated in *Section 6.1*, it was asked them to give their personal feedbacks for each statement. The primary intention of Beta test was completing the ultimate definition of the statements: it was built on a pure debate regarding the constructs, in which doubts emerged from the interviewed should have been solved. Some comments regarding the form of the statements were given, and they helped to refine the words used in order to reach the optimal level of the statement in terms of completeness and comprehension, to start the Alpha test (cf. *Section 6.4* and *Attachment 9.3*).
Moreover, at the same time, it was also asked to them their opinion, by providing a scale of agreement from 1 (totally disagree) to 4 (totally agree) and a *neutral* answer, labelled *I don't know*, in order not to force the answer in the case in which they were not able to respond or not sure about that particular topic. This was useful in order to understand

which could have been the trend behind the expected results, by considering this sample of experts, highly reliable.

As a matter of fact, after reviewing the conceptual map and especially this Beta test, it was clearer what would have been the expected answers gathered from the sample. As a matter of fact, some concepts would have been accepted undoubtedly with a strong level of agreement, almost taken for granted already since the first interviews; instead, others statements, voluntarily expressed through *aggressive* and *disruptive* sentences, would have created more heterogeneous answers. It was reasonable to think that for the former, the associated parts of the model could have been labelled as *validated*. Instead, for the latter, those model sections would have needed to be revised through other deeper further researches, in order to understand why the level of agreement was not so high, and why there was such heterogeneity in the answers.

Figure 6.1: Results of Beta Test



In this sense, an analysis of the answers for Beta test was done. The *Figure 6.1* shows the percentage associated to each of the 5 answers for the 13 statements of Beta test. As the graph points out, for all of them the percentage of agreement (by summing up the percentage obtained for score 3 or 4) is at least 80 %: it means that at least 4 interviewees out of 5 partially or totally agree with the statement. Furthermore, there are some statements that received 100% *totally agree* (such as the number 6, 9 and 13).

There were also statements in which more heterogeneous answers were given: for them, it could be expected more variety also in the Alpha test. This is the case of statements number 5 (striving for perfection), 7 (stable and standardized processes, *disruptive* viewpoint), 8 (visual management), 10 (just in time, *disruptive* point of view), 11 and 12 (jidoka, both *sustaining* and *disruptive* perspectives). For instance, since for these statements there were some answers which express a level of disagreement, these would have been taken into consideration in the final analysis of results as warning element. As a matter of fact, since the heterogeneity of the answers were significant, it meant that the opinions towards a statement voluntarily *aggressive* could have been different among a bigger sample, and this element would have been taken into account for the conclusions. In other words, together with *secure* statements, there are statements purely *challenging*, which were consciously written to foster doubts and reasoning, for whom was undoubtedly expected to find heterogeneous opinions. The latter is not only the case of *disruptive* statements, but also those concepts which may introduce elements difficult to understand from the *old* perspective of Lean paradigm.

7. CONCLUSIONS

7.1 Alpha Test

Once the Beta test was analysed and the expected results were presented, the Alpha test was launched. From a bench of 50 suitable addressees of the survey, 33 answers were collected. In addition, also the first 5 opinions were added, due to the fact that the content of each statements was similar to the one presented through Alpha test. In order to understand the level of reliability of the analysis, it was calculated the alpha coefficient (α) of Cronbach (Cronbach, 1951). It was decided to apply this method to measure the internal consistency of items providing answers with some alternatives; specifically, this method is considered useful where alternatives are related to the measurement of personal opinions. Moreover, this coefficient is considered beneficial when the characteristics that are being measured are susceptible to mutations, because related to perceptions or opinions that could change over time, as in this case. The reliability is considered according to the level of agreement between different items of the survey. Indeed, the alpha coefficient expresses the relationship between the sum of item variances and the total variance of the scale (i.e. the variance of the variable *Sum* obtained by summing up all the scores for each answer). Therefore, in order to obtain a good internal consistency (i.e. high α), it is necessary that the variance related to each item is low, in relation to the variance of the variable *Sum*.

Alpha coefficient (α) of Cronbach is obtained through the following formula:

$$\alpha = \frac{L}{L-1}\left[1 - \frac{\sum_{j=1}^{L}\sigma_j^2}{\sigma_\Sigma^2}\right] \qquad (1)$$

where L is the number of items, namely the 13 statements, σ_j^2 is the variance of each item and σ_Σ^2 is the variance of the variable *Sum*.
For each option, a score is associated, as the *Table 7.1* shows.

Table 7.1: Scores for Options in Alpha Test

Option Description	Score
I don't know	0
Totally disagree	1
Partially disagree	2
Partially agree	3
Totally agree	4

The tables with all the calculations is in *Attachment 9.4*. As a final result, a $\alpha = 0.75$ was obtained, which means that the sample chosen has a discrete and respectable level of reliability.

Table 7.2: Addresses for Alpha Test

Company or Person	Industry or Professional Activities
ABB Spa	Power and Energy
Agrati Group Fastener Solutions	Fasteners
Ansaldo Energia	Energy
Asperti Mario	Freelance Lean Consultant
Battezzati Luigi	Smart Factory Professor at LIUC
Beckhoff Automation	Industrial Automation
Bosch Rexroth Spa	Machinery Engineering and Factory Automation
Brembo Spa	Brake Components
Candy Hoover	Floor Care
Castel	Beverage
Cisco Systems	Networking Equipment
CNH Industrial	Agricultural and Construction Equipment
Considi	Lean and Industry 4.0 Consultancy
Dallara	Automotive
Electrolux	Home Appliance
Fiat Chrysler Automobiles	Automotive
Forgital Italy	Steel Production
Galdi	Food & Beverage Packaging
Gefran Spa	Automation & Electronics
Infor Group Spa	ICT Solutions
ICS Srl	Industrial Services
K.L.A.IN.robotics	Industrial Automation
Lamborghini	Automotive
Logital	Technology Integrator
Montagna Maurizio	Freelance Lean Consultant
Nr di Nisoli srl	Pneumatic Automation
Pietro Fiorentini	Oil & Gas
Poliform Spa	Furniture
Portioli Staudacher Alberto	Professor at Politecnico di Milano
Rulli Rulmeca Spa	Handling Systems
Same SDF	Mechanical Engineering
Sapio	Oil & Gas
Staufen.Italia	Lean and Industry 4.0 Consultancy
Terzi Sergio	Professor at Politecnico di Milano
Tesar Spa	IT Systems & Software Solutions
Tetrapak	Food & Beverage Packaging
Toyota Material Handling Systems	Automotive & Handling Systems
Whirlpool EMEA	Home Appliance

Table 7.2 shows the name of the interviewees (company or person) and their field of application (industry or professional activity).
As illustrated in *Table 7.2*, the sample is composed by accurately selected companies and people belonging to a huge variety of sectors: from Automotive to Home Appliance, from Energy to Oil & Gas, passing from ICT experts and consultancy companies keen on Lean and Industry 4.0. Moreover, also freelance consultants and university professors were added, due to their expertise on the topic. As a matter of fact, while in the empirical phase the 9 companies for the brief case studies were accurately selected within manufacturing industry (i.e. Lean companies that have already implemented Industry 4.0 projects), the sample of the Alpha test was intentionally wider. In fact, the validation must have been widespread gathering different perspectives: the only driver considered was an intense knowledge of the theme. For this reason, also consultancy companies or IT Providers were considered, due to their partnerships with Lean companies regarding the topic of Industry 4.0 and their strong awareness of the subject.
The way in which the survey was presented has been already shown in *Section 6.1*. Just to briefly sum up, the survey was sent in a *google.doc* format through webmail. It was asked to answer to each statement by providing an opinion from 1 (totally disagree) to 4 (totally agree). If the subject did not feel confident with a specific theme, there was the possibility to select the option *I don't know*. A *pdf* format of the survey is attached in the *Attachment 9.3*, together with the link for the *google.doc*.

Finally, the 38 answers were gathered and analysed, and they are illustrated below.

7.2 Analysis of Results: Validation or Rejection?

The analysis was performed separately for the two parts of the model, *sustaining* and *disruptive*, as illustrated in the conceptual map (cf. *Section 6.3*). For each statement, the percentage of the answers of different types was analysed, and it was computed a numerical Index of Agreement, by giving a positive or negative score to each of the single answer (cf. *Table 6.3*). Moreover, an explanation of the results is performed, for each statement, in order to interpret each Index of Agreement. Finally, two combined indexes were calculated, one for *sustaining* parts (*Average Sustaining Index*) and the other for *disruptive* statements (*Average Disruptive Index*), and they were compared, in order to understand how the two parts of the model were perceived by external viewpoints.

Figure 7.1: Results of Alpha Test – *Sustaining* Perspective

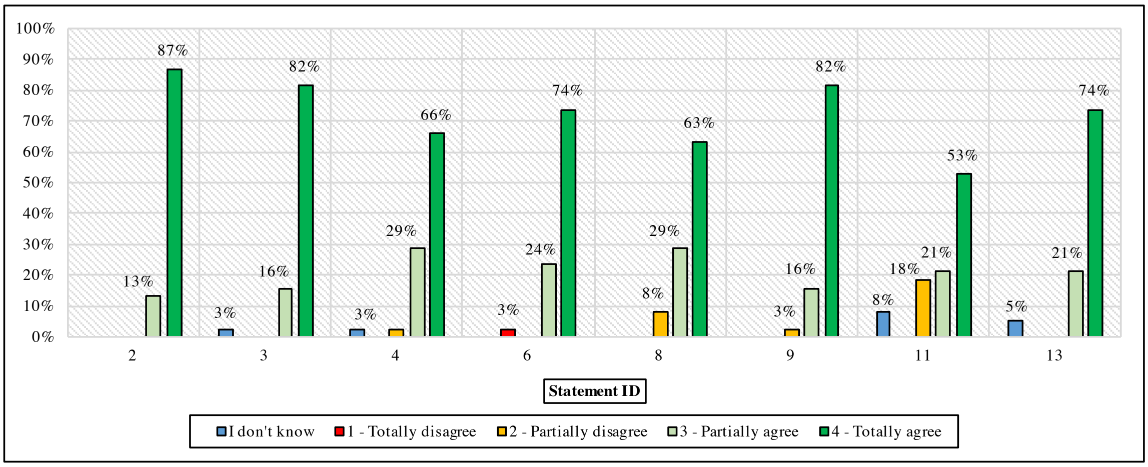
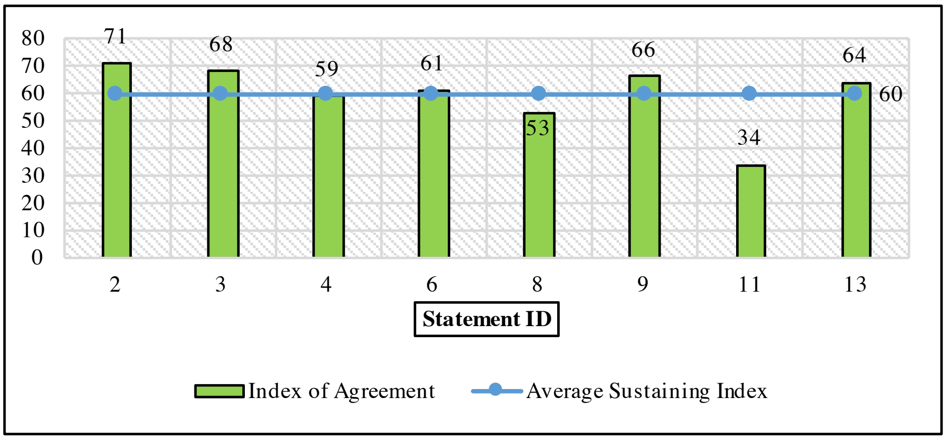


Figure 7.2: Index of Agreement – *Sustaining* Perspective



Starting from *sustaining* perspective, *Figure 7.1* shows that the level of agreement is always higher than 92% (by summing up score 3 and 4) (a part for statement 11 (74%)), reaching also a percentage of 100% for statement 2. Considering the *Figure 7.2*, the Index of Agreement for each statement is computed: it stays between 34 (statement 11) and 71 (statement 2). Then, by computing the *Average Sustaining Index* among the 8 *sustaining* statements, it shows a value of 60: in five cases, the Index of Agreement of a statement is higher than the *Average Sustaining Index*, whereas in three cases is lower. As it was expected, statements number 2 (mapping the value stream), 3 (continuous flow), 6 (stable and standardized processes), 9 (just in time), 13 (waste reduction) are those for which the Index of Agreement is higher than 60. Also the statement number 4 (pull approach), can be clustered in this group: in fact, its Index of Agreement is 59, almost similar to the average index. By summarizing, for number 2, 3 and 9 the percentage of answer *totally agree* overcomes 80%. Only in one case, the answer *I don't know* was chosen (3% for statement 3); the same happening for the answer *partially disagree* (3% for statement 3). Furthermore, for statement 4, 6 and 13 the percentage of answers *totally agree* is higher than 65% (up to 74% for statements 6 and 13), while the answer *I don't know* is always present, even if with a non-significant percentage. Considering the remaining *sustaining* statements, namely number 8 (visual management) and 11 (Jidoka), their Indexes of Agreement are far less the *Average Sustaining Index* (i.e. respectively 53 and 34), especially for what concerns the latter. Regarding the former, the percentage of answer *totally agree* is higher than 63%, while the level of agreement (total or partial) is more than 90%, even though 8% of the answers are *partially disagree*. This could be due to the fact that the concept of transformation of a Lean factory, typically paper-based, in a paper-less and completely digital environment, could be seen as strongly in opposition with the *old* paradigm of Lean. Moreover, the problem behind this statement could be due to the fact that no practical examples were provided, and it was explained in general terms: in this sense, subjects of the survey could have interpreted the statement subjectively; hence, heterogeneity in the answers was created. Moving to the most critical statement for this part, the number 11, even though the level of agreement is 74% and the percentage for answer *totally agree* corresponds to 53%, the most crucial part is connected to the fact that the answer *partially disagree* represents 18% of the total opinions. Moreover, 8% of the subjects preferred not to express a point of view. The reason could be that people did not see Co-bots as a huge innovation. As a matter of fact, talking about collaborative robots, without underlining the most important concept of *interconnectivity* in the statement, it could have been seen as less innovative than what expected. Nevertheless, the problem was related to a statement which can be considered "poor of contents" compared to the part presented in the *Section 5.3.4* where the idea behind was very detailed. Expressing this statement in general terms could have been created ambiguity in the interviewees.

In general, it is worth to conclude that the level of agreement for *sustaining* part of the model is in line with what was expected: the higher majority of subjects agreed on what is stated in the model. Basically, this could be translated in the fact that all these statements were quite well-understood and accepted among the interviewees: as a consequence, they could be considered as valid.

Figure 7.3: Results of Alpha Test – *Disruptive* Perspective

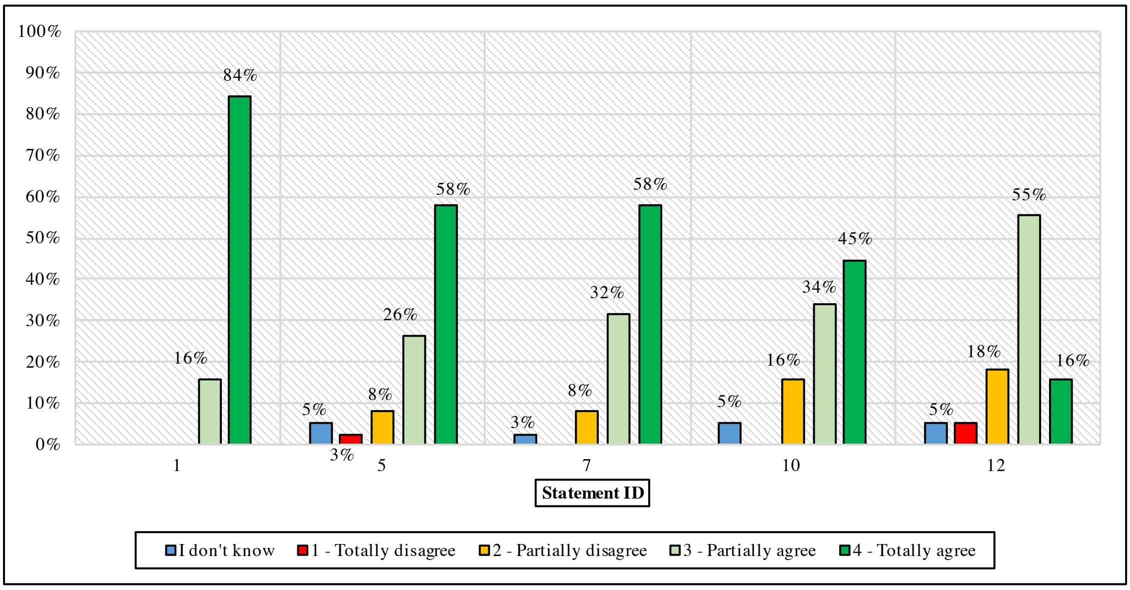
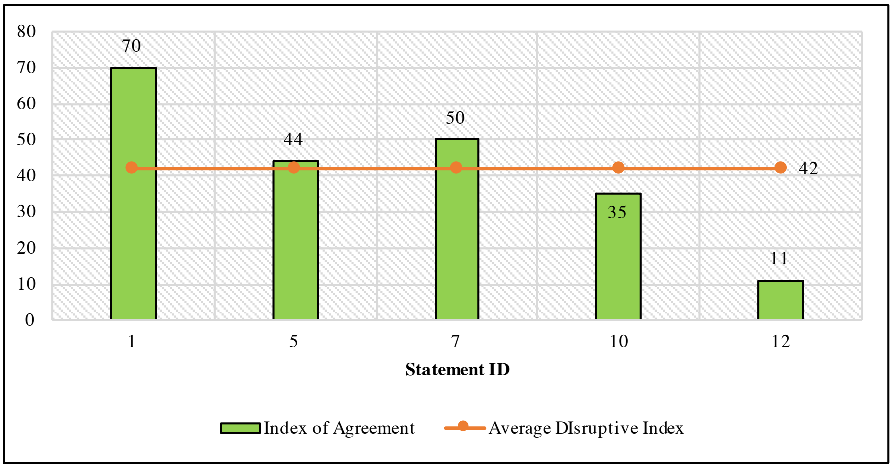


Figure 7.4: Index of Agreement – *Disruptive* Perspective



The analysis of *disruptive* statements is less promising (cf. *Figure 7.3*). In fact, apart from the first statement (value), for which the percentage of answers 3 or 4 is 100%, for the others it goes from 90% of statement 7 (stable and standardized processes) to 71% of statement 12 (Jidoka). Moreover, if the Index of Agreement is computed for each statement, it is possible to outline that it goes from 70 (statement 1) to 11 (statement 12). Due to this heterogeneity in the answers, as it was expected after the first 5 interviews, for this part of the model the *Average Disruptive Index* gets a score of 42. While 3 statements have a value of the index higher than average, the other two, namely statement number 10 (just in time) and 12, present a value far less than the average, especially the latter.

To be more precise, nothing needs to be added for the first statement: even though it is a *disruptive* element, the level of agreement is comparable with a *sustaining* statement.
Regarding statement number 7, the same considerations made for statement 8 could be applied: as a matter of fact, the absence of practical examples to better explain a complex concept could have caused ambiguity in interpreting the sentence. Moreover, in this case, it is worth to think that the idea expressed by MaaS could be seen as too much *disruptive* nowadays, generating heterogeneous opinions. Indeed, not all the interviewed completely agreed about this disruptive idea connected to the concept of standardization. The main reason could be seen in a sort of scepticism and abstraction about this future scenario, in which a new standard business architecture service-oriented will overwhelmingly enter in manufacturing industry.
The statement number 5 (striving for perfection), which was expected to be the one most *disruptive*, obtained a level of agreement of 84% (58% *totally agree* and 26% *partially agree*). Although disagreement answers are present, their incidence is not too evident: 3% of the subjects answered *totally disagree* while 8% responded *partially disagree*. This concept must be tackled with caution since it states that a strong principle of Lean (Kaizen) will be modified by considering radical and not only incremental changes; anyway more than 80% of the interviewees agree on this point. Its Index of Agreement is 50, quite higher than the *Average Disruptive Index*. In other words, these 84% could be labelled as companies with a high level of *readiness* for putting in practice this Industry 4.0 radical attitude.
Finally, the results gathered from statement 10 and 12 were, as expected, the most critical. Although the level of agreement is higher than 70%, the percentage for answer *totally agree* corresponds respectively to 45% and 16%. The most critical part is connected to the fact that the answer *partially disagree* represents on average 17% of the total opinions for both the two statements. Moreover, for statement number 12, 5% of the answer refers to *totally disagree*, while other 5% to *I don't know*. Almost the same order of magnitude is visible for the statement 10. Although the level of agreement is quite high, these concepts cannot be comparable with the other statements: in fact, while the others could be labelled as *validated*, for these last three statements the opinions are really heterogeneous. It is reasonable to conclude that these two statements are those for which further researches will be needed; maybe, it could be useful to start with these constructs partially validated and elaborate more detailed concepts that can be shared almost by everyone, like the previous statements. To be more specific, the *disruptive* perspective

regarding just in time could have created some troubles, due to the fact that Additive Manufacturing is a concept for which people did not feel already confident: their scepticism regarding this Smart Technology is much higher in this case than for the *disruptive* scenario of Maas (statement 7). Furthermore, the opinion regarding the *disruptive* part of Jidoka was the most critical one, because the answer *totally agree* was present only 16% of the time, registering the minimum level between the 13 statements. The cause could be identified in the fact that the sentence of the statement seems to release the individual from the responsibility to go to Gemba and decide. This idea is strongly in opposition with Lean paradigm: however, in Industry 4.0 the individual will remain central in the decision-making process, since he writes the algorithms for supporting it. Nevertheless, associating this strong concept of a less physical presence in Gemba with the *new* concept of CPS, resulted in generating the the most heterogeneous opinions of this analysis.
At the end, despite the presence of these two critical statements, which lowered a lot the *Average Disruptive Index*, also the results obtained in this part are not so negative.

As it was expected at the beginning, some parts of the model were widely accepted, whereas others not. As it is figured out from the comparison between the *Average Indexes*, they are both quite high (60 for *Sustaining* versus 42 for *Disruptive*). It is reasonable to conclude that experts were more inclined towards continuity than disruption: the *sustaining* model is widely accepted, while the *disruptive* parts created more heterogeneity. In fact, some subjects agreed about these concepts, but they were not commonly accepted: sometimes, the absence of practical examples could have created ambiguity; moreover, probably some scepticism towards a possible enabling technology or a future uncertain scenario emerged. Hence, in further works, these will be the concepts to be better investigated and explained, trying to find a way for solving criticalities (briefly described in *Section 7.3*) and refining the model in order to obtain a shared opinion also towards them.

In the end, although there are parts of the model not widely accepted, both the *Average Indexes* are quite high. In particular, the *Average Disruptive Index* obtained is higher than expected, confirming that the Fourth Industrial Revolution has in its pure essence a seed of radicalism. To conclude, the main intuition behind this dissertation is shared: it is

reasonable to assume a balance between *sustaining* and *disruptive* elements, considering Lean in the viewpoint of Industry 4.0.
In this sense, since it is a research, the results obtained can be considered acceptable, paving the way for promising further improvements.

7.3 Criticalities

The Alpha test allowed to establish which parts of the model could be validated and which ones need further researches to illustrate better the concept behind. As a matter of fact, the analysis pointed out results which are affected by different factors, that can be summarized as criticalities around the model and the dissertation.

Firstly, an important criticality, emerged especially during the Beta test, was the complete absence of examples supporting the statements. As a matter of fact, the statements were written voluntarily in general terms, in order to be as much absolute as possible for external parties. In this sense, the absence of examples explaining the real meaning behind each of them, could have created misalignments between different actors, and more heterogeneous answers. Nevertheless, it is important to point out that in this dissertation, for each part of the model, a detailed list of concrete examples is illustrated (cf. *Section 5.2* and *Section 5.3*). However, the choice of writing statements in general terms was mandatory, due to the fact that each concept has multiple aspects to be tackled; hence, it was difficult to write a comprehensive statement, whether not in its general form.

In addition, another criticality could be seen in the way in which concepts were developed. In fact, the starting point of this dissertation was the comparison between *sustaining* and *disruptive* perspectives, considering the interaction between Lean Manufacturing and Industry 4.0. Sometimes, it could have been difficult to understand how Smart Manufacturing Technologies sustain or disrupt Lean best-practices, clearly comprehending the difference at the basis. Moreover, sometimes it might have seemed, especially in *sustaining* statements, that not too much innovation was considered around certain concepts. It was the case, for instance, of the *sustaining* statement of Jidoka (i.e. statement 11), for which it could have been tricky to understand how Industry 4.0 might actually provide a step forward, considering that the mere introduction of co-bots is an innovation dated 15-years ago. This criticality could be strictly connected to the fact that for Industry 4.0 there is not a clear definition to explain what it really is: some publications associate the concept of *evolution* to Industry 4.0, while others talk about *revolution*. This means that, sometimes, it could be considered as only a mere application of technologies without taking into consideration the topic of *Data* and *Interconnectivity*, key concepts of the revolution. By looking at the whole work according to this *new* perspective, it is reasonable to think that new ideas are present in each sentence of the statements. Instead, if it is taken the wrong perspective of just the mere application of technologies, a lot of misalignments could emerge in reading and analysing the work behind the dissertation. This could be translated in the fact that, sometimes, subjects were not so confident with some concepts: this is the case of Co-bots, Additive Manufacturing, MaaS and CPS.

Lastly, a criticality emerged in the way in which statements were presented. Even though they were dispatched in a random sequence, mixing up *sustaining* and *disruptive* constructs in order to avoid the risks of auto-correlation from one answer to the other, they were presented in positive terms. It is reasonable to think that the presence of agreement answers would have been higher than the disagreement ones.
Therefore, it was thought to assign a scale of scores to each answer, giving more weight to negative ones (i.e. *disagree*) than to those positive (i.e. *agree*).

7.4 Follow-up: Open Points for Discussion

It has already been written that the topic of this dissertation was quite huge to tackle completely. In fact, the aspects of Lean paradigm to analyse towards a digital viewpoint are a lot, and so also how they are reflected in different forms in Industry 4.0.
In order to cope with this issue, it was decided to start with principles and pillars of the Lean model as a basis, by analysing only those *operative* aspects that would have given a concrete perspective to the topic. Instead, those *high-level* aspects of the model were left on a side: regarding principles, a huge analysis was made by providing a practical viewpoint, considering how the value is created in practice (first principle) and how changes are tackled following Industry 4.0 ultimate aspiration (fifth principle). However, cultural aspects connected to these *high-level* principles were only introduced. Furthermore, the same reflections were made for pillars and foundations. As a matter of fact, only some elements of the Liker's House of Lean were analysed, whereas the themes

of change management and people (and related skills) were only introduced, without going deeply in the analysis of how Industry 4.0 will change the perspective. In other words, change management and people, core starting points for Lean implementation, would have requested an analysis on *higher level* perspective, more theoretical than practical, in which Smart Manufacturing Technologies would have played a secondary role. In addition, a huge topic of cybersecurity, connected to Big Data, came to light during the case studies with the 9 selected partners. However, also this is a huge theme to be tackled, and a single dissertation could be written around it.

Therefore, these topics are briefly presented in this last section, in order to leave a general overview. They are let for further researches and academic works, in order to be understood according to a digital viewpoint.

7.4.1 Change Management

As the House of Liker shows, the bedrock at the basis of the Lean paradigm is a strong philosophy to be instilled in people within all the organization (Liker, 2004).

For years, companies have decided to apply Lean thinking to manufacturing and operations in order to increase in productivity. However, inefficient change management might result in a failed transformation. As a matter of fact, the right culture (conditions and circumstances) is the foundation for implementing a change. The main issue is that Lean is often perceived as a toolbox of concepts and methodologies that are forced to be implemented in an organization, rather than tailored to; Lean is not just a matter of cost reduction. Probably, the most important thing to underline is that "The organizational culture determines the success of Lean or any other change initiative" (Atkinson, 2010). Pushing Lean, rather than Pulling it, is considered a big mistake. Culture change can be defined as "driving performance across the organization to exceed customer expectations". Lean, of course, cannot exist in an organization where the culture is against it. Generally, nothing changes until behaviour changes internally. In fact, Lean requires a high degree of cross functional working, a culture where change is the norm, resistance is lower than support and in which going to work is a joy, since the workplace is a site to think how to improve all the factory.

The same reasoning could be made for Industry 4.0, where the biggest challenge is not technology, rather than people. Digital technologies are fast becoming a commodity, therefore success largely depends on how well the leaders define Lean and communicate the transformation. It is worth to underline that radical disruption is not often accepted by people who make it happen: therefore, also in this case change management is critical. For example, in Industry 4.0 digital trust is fundamental and the right culture must be pursued.

"The pattern of basic assumptions that a given group has invented, discovered or developed in learning to cope with its problems of external adaptation and internal integration and that have worked well enough to be considered valid, and, therefore, to be taught to new members as the correct way to perceive, think and feel in relation to those problems."

(Definition of Culture, Edgar Schein)

In both cases, as it has been highlighted by Edgar Schein, there is a common denominator for achieving the desired outcomes of the initiative: the creation of the right culture and, consequently, a structured approach to support the individuals to align with the new mind-set. Schein, in its famous book "Organizational Culture and Leadership", explained in detail why organizational culture is essential (Schein, 1985). Lean and Industry 4.0 bring with them a complex background of concepts and principles; for this reason, it is advisable to create the right culture and then implementing actions. In the end, change management is essential to move individuals to the expected futures state.

7.4.2 Skills and People

"The biggest challenge for Industrial leaders isn't technology – it's people"

(PWC 2016 Global Industry 4.0 Survey)

The above-mentioned issue of change management is strongly in connection with people within the organization. They have to be inspired by a strong culture and a shifting mind-set is required also in Industry 4.0. As a matter of fact, generally, every big change starts from changing people mind-set and it may require new and different skills. Also in this case, the huge innovation associated to the Fourth Industrial Revolution needs to introduce new skills and abilities. The aim of this paragraph is to briefly explain the new skills required to deal with Industry 4.0.

In particular, Industry 4.0 could be considered skill-intensive, since it requires a high variety of skills. For example, the adoption of mobile and handheld devices obliges operators to make them as an integral part of their daily profession. Skills like understanding GPS coordinates or using tracking systems are basic to enter into many professions. Recently, in the manufacturing industry, new skills are becoming essential such as guiding a robot or operating a simulated assembly line. Radical changes with the digitization are happening in various functions. For example, most products in B2B or B2C are sold with a service component that adds the digital element to it. Following this pattern, analytical skills, attention to details and problem solving form the core of a digital enterprise. The World Economic Forum (WEF) believes that in some years, almost 35% of the skills considered essential in today's workforce will have changed. This may be great, since all experts think that routine jobs will disappear first and Creativity, Problem Solving and Critical Thinking will become key skills workers need to have.

It is also true that complete automation is not realistic, human labour will not be completely replaced (e.g. humans will still be needed to supervise the robots). New job profiles may rise, like *robot coordinator* proposed by BCG which should oversee robots on the shop floor and responds to malfunctions or error signals (The Boston Consulting Group, 2015). Another new role could be the *industrial data scientist*, who has to prepare data, conducting advanced analysis applying the knowledge to improve products or production.

Companies should increase the in-house training, because several skills can be learned. People should be encouraged to be open to new things, create and be curious in a dynamic and challenging environment.

7.4.3 Data Security

The last topic not tackled in details which emerged during this research is Data Security: it is one of the major operational risks connected with the rise of the Fourth Industrial Revolution. As a matter of fact, the interconnected nature of Industry 4.0 based on analytics makes cyber attacks more frequent; they can generate more extensive effects than before. The problem could be that manufacturers and their whole supply networks might be not prepared for the risks. Therefore, cybersecurity strategies must be adopted and they have to be secure, vigilant and, above all, fully integrated into organizational

and information technology strategy from the beginning. On the one hand, Smart and connected technologies allow to innovate, transform and modernize the business model. However, tactical or strategic business decisions could be affected by cyber risks. According to the main purpose of Industry 4.0, it aims at combining the digital world with physical one, enabling advanced manufacturing. Sometimes, Industry is unprepared to face cyber risks; developing a fully integrated approach to deal with cyber risk is fundamental to pursue the marriage between OT and IT. This is considered essential since the moment in which supply chains, factories and operations are fully connected, and, therefore, cyber-threats become all greater and dangerous.
As it was previously highlighted, the core of a Smart Factory relies on the exploitation of real time data, also in cloud between the different parties of the supply chain. For this reason, one of the main challenges is to find the right balance between transparency and security.

According to an important research made by Deloitte in 2017, by 2020 it is estimated that over 20 billion IoT devices will be deployed around the world (Waslo et al., 2017). Many of these objects might remain into the factories but many others are expected to be directed to B2B or B2C. That's why IoT manufacturers should take into consideration the creation of more secure software development practices to face the increasing cyber risk related to the new Smart Devices. In practice, their vulnerability should be considered especially when they perform the most critical and sensitive tasks in industry.

In conclusion, this topic is very interesting and it has surely to be investigated more in depth. In particular, the new trend argued by many consulting groups clearly provides the necessity of incorporating secure coding practices by IoT manufacturers. Therefore, cybersecurity leading practices should be incorporated from the beginning and throughout the hardware and software development lifecycle. For example, the vast amount of information collected through Smart Devices must be protected and any conditions or activities that could jeopardize the security of those data should promptly emerge.

8. BIBLIOGRAPHY

Abdi F., Shavarini S., Hoseini S., (2006) *Glean Lean: How to Use a Lean Approach in Services Industries*, Journal of Services Research, Vol. 6, pp. 191-206

Abele E., Bauerdick C. J. H., Strobel N., Panten N., (2016), *ETA Learning Factory: A holistic Concept for teaching Energy Efficiency in Production*, Procedia CIRP, Vol. 54, pp. 83-88

Agethen P., Otto M., Mengel S., Rukzio E., (2016) *Using Marker-less Motion Capture Systems for Walk Path Analysis in Paced Assembly Flow Lines*, Procedia CIRP, Vol. 54, pp. 152-157

Ahuja I. P. S., Khamba J. S., (2008) *Total productive maintenance: literature review and directions*, International Journal of Quality & Reliability Management, Vol. 25 (7), pp. 709-756

Anand G., Ward P. T., Tatikonda M. V., Schilling D. A., (2009) *Dynamic capabilities through continuous improvement infrastructure*, Journal of Operations Management, Vol. 27, pp. 444-461

Ancora M., Vendola G., *Lean Manufacturing – Principi e Metodi dell'Organizzazione Snella*, Auxo s.r.l.

Armbrust M., Fox A., Griffith R., Joseph A., Katz R., Konwinski A., Lee G., Patterson D., Rabkin A., Stoica I., Zaharia M., (2010) *A view of cloud computing*, Communications of the ACM, Vol. 53(4), pp. 50–58

Atkinson P., (2010) *Lean is a cultural issue*, Management Services, Vol. 54, pp. 35-44

Auschitzky E., Hammer M. C. Rajagopaul A., (2014) *How big data can improve manufacturing*, Insight and Publications, Available online at www.mckinsey.com/insights/operations/how_big_data_can_improve_manufacturing

Austenfeld R.B. Jr, (2006) *Toyora and Why It Is So Successful*, Research Society of Commerce and Economics, Vol. 47 (1), pp. 109-173

Baheti R., Gill H., (2011) *Cyber-physical systems*, The impact of control technology, pp. 1-6

Batalha A. D. V., Parli A. L., (2017) *Industry 4.0 with a Lean perspective – Investigating IIoT platforms' possible influences on data driven Lean*, Upsala University, Master's Thesis, Department of Business Studies

Bauer W., Schlund S., Marrenbach D., Ganschar O., (2014) *Industrie 4.0 – Volkswirtschaftliches Potenzial für Deutschland*, Fraunhofer IAO

Baur C., Wee D., (2015) *Manufacturing's next act*, available at www.mckinsey.com

Begam M. S., Swamynathan R., Sekkizhar J., (2013) *Current Trends on Lean Management – A review*, International Journal of Lean Thinking, Vol. 4 (2), pp. 15-21

Behrendt A., Muller N., Odenwalder P., Schimtz C., (2017) *Industry 4.0 demystified – lean's next level*, available at www.mckinsey.com/business-functions/operations/our-insights/

Beilke R., (2015) *What are Human Machine Interfaces and Why Are They Becoming More Important?*, Beckhoff Automation point of view, article written by Gonzalez C., available online at http://www.machinedesign.com/iot/what-are-human-machine-interfaces-and-why-are-they-becoming-more-important

Bell S., (2006) *Lean enterprise systems: using IT for continuous improvement*, Hoboken, Wiley

Bell S., Orzen M., (2011) *Lean IT: enabling and sustaining your lean transformation*, Boca Rotan, CRC Press

8. Bibliography

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

Bhuiyan N., Baghel A., (2005) *An overview of continuous improvement: from the past to the present*, Management Decision, Vol. 43 (5), pp. 761-771

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

Bicheno J., (2004) *The New Lean Toolbox: Towards Fast, Flexible Flow*, Buckingham, Production and Inventory Control, Systems and Industrial Engineering Books (3rd edition)

Blöchl S. J., Schneider M., (2016) *Simulation Game for Intelligent Production Logistics – The PuLL® Learning Factory*, Procedia CIRP, Vol. 54, pp. 130-135

Bonfiglioli R., (2001) *Pensare Snello – Lean-thinking alla maniera italiana. Come costruire l'impresa snella e produrre di più con minori sprechi: 3 casi italiani di successo*, Franco Angeli Edizioni.

Boschi F., De Carolis A., Taisch M., (2017) *Nel cuore dell'Industry 4.0: I Cyber-Physical System*, available at https://www.industriaitaliana.it/nel-cuore-dell-industry-4-0-i-cyber-physical-systems/

Boud A. C., Haniff D. J., Baber C., Steiner S. J., (1999) *Virtual Reality and Augmented Reality as a Training Tool for Assembly Tasks*, International Conference on Informatics and Visualization

Boyer S., (2004) *SCADA: Supervisory Control and Data Acquisition*, Instrumentation, Systems and Automation Society, Research Triangle Park, North Carolina

Brenner B., Hummel V., (2016) *A seamless convergence of the digital and physical factory aiming in personalized Product Emergence Process (PPEP) for smart products* *within ESB Logistics Learning Factory at Reutlingen University*, Procedia CIRP, Vol. 54, pp. 227-232

Brøtan V., Berg O. A., Sørby K., (2016) *Additive Manufacturing for enhanced performance of molds*, Procedia CIRP, Vol. 54, pp. 186-190

Brøtan V., Fahlström J., Sørby K., (2016) *Industrialization of metal powder bed fusion through machine shop networking*, Procedia CIRP, Vol. 54, pp. 181-185

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), pp. 906-917

Broy M., Kargermann H., Achatz R., (2010) *Agenda Cyber Physical Systems: Outlines of a new Research Domain.acatech*, Berlin, Germany

Buxmann P., Hess T., Ruggaber R., (2009) *Internet of Services*, Business & Information Systems Engineering, Vol. 5, pp. 341 – 342

Buyya R., Yeo C. S., Venugopal S., Broberg J., Brandic I., (2009) *Cloud computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility*, Future Generation Computer Systems, Vol. 25(6), pp. 599–616

CamuffoA., (2016) *Rolling out lean production systems: a knowledge-based perspective*, International Journal of Operations & Production Management, Vol. 36 (1), pp. 61-85

Capellan A., Roulet-Dubonnet O., (2016) *Handling of Frequent Design Changes in an Automated Assembly Cell for Electronic Products*, Procedia CIRP, Vol. 54, pp. 175-180

Capgemnini Consulting (2014), *Industry 4.0 - The Capgemini Consulting View*

Cardon N., Bribiescas F., (2015) *Respect for people: the forgotten principle in lean manufacturing implementation*, European Scientific Journal, Vol. 11 (13), pp. 45-61

8. Bibliography

Carminati B., (2016) *La fabbrica snella nell'era della quarta rivoluzione industriale*, Venice, Presentation at Fabbrica Future (2016, Novembre 24th)

Christensen C. M., Rosenbloom R., (1995) *Explaining the attacker's advantage: Technological paradigms, organizational dynamics, and the value network*, Research Policy, Vol. 24(2), pp. 233-257

Christensen C. M., (1997) T*he Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Boston, Harvard Business School Press

Christensen C. M., Raynor M. E., (2003) *The innovators solution: Creating and sustaining successful growth*, Harvard Business Press

Christensen C. M., (2013) *We are living the capitalist's dilemma*, special to CNN (2013, January 21st), available at http://edition.cnn.com/2013/01/21/business/opinion-clayton-christensen/index

Coleman R. J., Vaghefi M. R., (1994) *Heijunka (?): A Key to the Toyota Production System*, Production and Inventory Management Journal, Vol. 35 (4), pp. 31-35

Colgate J. E., Wannasuphoprasit W., Peshkin M. A., (1996) *Cobots: Robots for collaboration with human operators*, Journal of Dynamic Systems, Measurement and Control, Vol. 58, pp. 433–440

Columbus L., (2017) *Roundup of cloud computing forecasts and market estimates*, in Forbes Magazine, available at www.forbes.com

Comstock B., (2016) *Minds&Machines*, San Francisco, General Electric

Creswell J. W., (2009) *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*, Thousand Oaks, SAGE Publications Inc. (3rd edition)

Cronbach L. J., (1951) *Coefficient alpha and the internal structure of tests*, Psychometrika, Vol. 16, pp. 297-334

Crabtree R., Astall C., (2006) *Lean manufacturing and IT – it's not an Oxymoron!*, available at www.cincom.com/pdf/CM050210-2.pdf

Cusumano M. A., (1985) *The Japanese Automobile Industry: Technology and Management at Nissan and Toyota*, Boston, Harvard University Press

Cusumano M. A., (1994), *The limits of lean*, Sloan Management Review, Vol. 35 (4), pp. 27-32

Deming W. E., (2000) *Out of the Crisis*, Cambridge, MIT Press (2nd edition)

Di Stefano T. F., (2012), *3D Printing: A New Dimension for Manufacturing*, in E-commerce Times, available at https://www.ecommercetimes.com/

Diekmann J. E., Krewedl M., Balonick J., Stewart T., Won S., (2004) *Application of lean manufacturing principles to construction*, Austin, Report to The Construction Industry Institute

Doh S. W., Deschamps F., Pinheiro De Lima E., (2016), *Systems Integration in the Lean Manufacturing Systems Value Chain to Meet Industry 4.0 Requirements*, from Borsato M. et al. (eds) Transdisciplinary engineering: crossing boundaries, pp. 642-650

Dolak J., Lathrop B., (2004) *Standardized Work*, Presentation for ESD. 60 – Lean/Six Sigma Systems, MIT Leaders for Manufacturing Program

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

Drath R., Horch A., (2014) *Industrie 4.0 – Hit or Hype?*, IEEE Industrial Electronics Magazine, Vol. 8 (2), pp. 56-58

Ducharme C., Ruddick T., (2004) *Takt Time*, Presentation for ESD. 60 – Lean/Six Sigma Systems, MIT Leaders for Manufacturing Program

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), pp. 95-102

Ebert C., (2015) *Product development in the era of Industry 4.0*, Lecture at University of Stuttgart (2015, January 8th)

Eichhorn C., Jõema J., Kolk A., Tomberg H., (2016) *Industry 4.0 in practice*, Tallin, from the International Conference at Spacex Event Centre (2016, June 2nd and 3rd)

Erichsen J. A. B., Pedersen A. L., Steinert M., Welo T., (2016) *Prototyping to Leverage Learning in Product Manufacturing Environments*, Procedia CIRP, Vol. 54, pp. 233-238

Erol S., Jäger A., Hold P., Ott K., Sihn W., (2016) *Tangible Industry 4.0: a scenario-based approach to learning for the future of production*, Procedia CIRP, Vol. 54, pp. 13-18

Ezzel S., Swanson B., (2017) *How Cloud Computing Enables Modern Manufacturing*, American Enterprise Institute, Information Technology & Innovation Foundation (2014, June), pp. 1-33

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

Fitts P. M., (1954) T*he information capacity of the human motor system in controlling amplitude of movement*, Journal of Experimental Psychology, Vol. 47, pp.381-391

Fjeldaas S., Furevik M. L., (2016) *The principle of the stored program applied to servo motors*, Procedia CIRP, Vol. 54, p. 71-76

Ford H., Crowther S., (1922) *My Life and Work*, New York, Garden City

Found P., Harrison R., (2012) *Understanding the lean voice of the customer*, International Journal of Lean Six Sigma, Vol. 3 (3), pp. 251-267

Francis D. E., (2014) *Lean and the learning organization in higher education*, Canadian Journal of Educational Administration and Policy, Issue 157

Gardner D., Gardner T., (1994) *The Motley Fool Investment Guide*, New York, Simon and Schuster

Garg A., Deshmukh S. G., (2006) *Maintenance management: literature review and directions*, Journal of Quality Management Engineering, Vol. 12 (3), pp. 205-238

Gassner W., (2016) *3D EXPERIENCE: The communication platform for industry 4.0*, Electronically available at http://blogs.3ds.com/germany/3dexperience-diekommunikationsplattform-fur-industrie-4-0

Gåsvaer D., von Axelson J., (2012) *Kaikaku – Radical Improvement in Production*, International Journal of Industrial and Manufacturing, Vol. 6 (9), pp. 1914-1921

Ghillani G., Muttoni P., (2015) *Lean Thinking*, Lean Enterprise Centre

Gilpin L., (2014) *3D printing: 10 companies using it in ground-breaking ways*, available at www.techrepublic.com/article/3d-printing-10-companies-using-it-in-ground-breaking-ways/

Gjeldu, N., Mladineo M., Veza I., (2016) *Transfer of Model of Innovative Smart Factory to Croatian Economy using Lean Learning Factory*, Procedia CIRP, Vol. 54, pp. 158-163

Goldratt E. M., (1990) *Theory of Constraints*, New York, North River Press

Graham S. G., Baliga, Kumar P. R., (2009) *Abstractions, Architecture, Mechanism, and Middleware for Networked Control*, IEEE Transactions on Automatic Control, Vol. 54 (7), pp. 1490-1503

Gräßler I., Pöhler A., Pottebaum J., (2016) *Creation of a Learning Factory for Cyber Physical Production Systems*, Procedia CIRP, Vol. 54, pp. 107-112

Gräßler I., Taplick P., Yang X., (2016) *Educational Learning Factory of a holistic Product Creation Process*, Procedia CIRP, Vol. 54, pp. 141-146

Green S. A., Billinghurst M., Chen X., Chase J. G., (2008) *Human–robot collaboration: A literature review and augmented reality approach in design*, International Journal of Advanced Robotics System, Vol. 5 (1), pp. 1-18

Grewal C., (2008) *An initiative to implement lean manufacturing using value stream mapping in a small company*, Journal of Manufacturing Technology and Management, Vol. 15, pp. 404-417

Gupta S., Iyengar C., (2014) *The tip of the (Inventory) Iceberg*, Supply Chain Management Review, Vol. 18 (6), pp. 28-35

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), pp. 444-473

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

Hambach J., Kummel K., Metternich J., (2017) *Development of a digital continuous improvement system for production*, Procedia CIRP, Vol. 63, pp. 330-335

Haschemi M., Roessler M. P., (2017) *Smart Value Stream Mapping: An Integral Approach Towards a Smart Factory*, Malaysia, 3rd International Congress on Technology, Engineering & Science (2017, February 9th -10th), pp- 273-280

Heckel M., (2017) *Are you ready for Industry 4.0?*, Issue 1, available online at http://www.delivered.dhl.com/en/articles/2017/02/skills-for-industry-4-0.html

Hecklau F., Galeitzke M., Flachs S., Kohl H., (2016) *Holistic approach for human resource management in Industry 4.0*, Procedia CIRP, Vol. 54, pp. 1-6

Hermann M., Pentek T., Otto B., (2016) *Design Principles for Industrie 4.0 Scenarios: A literature Review*, Technische Universität Dortmund, from the 49th Hawaii International Conference (2016, January 5th-8th)

Holweg M., (2007) *The genealogy of lean production*, Journal of Operations Management, Vol. 25, pp. 420-437

Howell V. W., (2013) *Value stream mapping*, Ceramic Industry, Vol. 163 (8), pp. 24-26

Hura M., McLeod G., Schneider J., Gonzales D., (2000) *Interoperability: A continuing challenge in coalition air operations*, Chapter Two, Santa Monica, RAND Monograph Report

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), pp. 501–507

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

Isdale J., (1998) *What is Virtual Reality? A Web-Based Introduction*, Version 4 – Draft 1 (1998, September), available online at: http://www.isdale.com/jerry/VR/WhatIsVR.html

Ishikawa K., (1976) *Guide to Quality Control*, Tokyo, Asian Productivity Organization

Jadhav J. R., Mantha S. S., Rane S. B., (2014) *Exploring barriers in lean implementation*, International Journal of Lean Six Sigma, Vol. 5 (2), pp.122-148

Jayaram A., (2016) *Lean Six Sigma Approach for Global Supply Chain Management using Industry 4.0 and IIoT*, Contemporaty Computing and Informatics (IC3I), 2nd International Conference on, pp. 89-94

Jenses M. B., Sole Semb C. C., Vindal S., Steinert M., (2016) *State of the Art of Makerspaces - Success Criteria when Designing Makerspaces for Norwegian Industrial Companies*, Procedia CIRP, Vol. 54, pp. 65-70

Jeschke S., Brecher C., Meisen T., Özdemir D., Eschert T., (2017) *Industrial Internet of Things and Cyber Manufacturing Systems*, New York, Springer

Johansson P. E. C., Mattson S., Moestam L., Fast-Berglund A., (2016) *Multi-Variant Truck Production – Product Variety and its Impact on Production Quality in Manual Assembly*, Procedia CIRP, Vol. 54, pp. 245-250

Jones D., (2012) *How can IT support a lean transformation*, Presented at European Lean IT Summit (2012, November 22nd-23rd), available at http://www.slideshare.net/LeanUK/lean-and-it

Jones D., (2016) *Stepping up to the Factory of the Future*, Quality Magazine, available at www.qualitymag.com/articles/93484-stepping-up-to-the-factory-of-the-future

Juran J. M., (1991) *Juran's New Quality Road Map: Planning, Setting, and Reaching Quality Goals*, New York, Free Press

Kagermann H., (2015) *Change through digitization – Value creation in the age of industry 4.0*, Management of Permanent Change, pp. 23–45

Kagermann H., Wahlster W., Helbig J., (2013) *Recommendations for implementing the strategic initiative Industrie 4.0*, Final report of the Industrie 4.0 Working Group

Karre H., Hammer M., Kleindienst M., Ramsauer C., (2017) *Transition towards an Industry 4.0 state of the LeanLab at Graz University of Technology*, Procedia Manufacturing, Vol. 9, pp. 206-213

Kemény Z., Nacsa J., Erdos G., Glawar R., Sihn W., Monostori L., Ilie-Zudor E., (2016), *Complementary research and education opportunities—a comparison of learning factory* *facilities and methodologies at TU Wien and MTA SZTAKI*, Procedia CIRP, Vol. 54, pp. 47-52

Kemény Z., Beregi R. J., Erdos G., Nacsa J., (2016), *The MTA SZTAKI Smart Factory: platform for research and project-oriented skill development in higher education*, Procedia CIRP, Vol. 54, pp. 43-58

Kolberg D., Zühlke D., (2015), *Lean Automation enabled by Industry 4.0 Technologies*, International Federation of Automatic Control, Vol. 48 (3), pp. 1870-1875

Kopetz H., (2011) *Real-time systems: design principles for distributed embedded applications*, Part of the Real-Time Systems Series book series (RTSS), New York, Springer

Koudate A., (2003) *Il management della progettazione*, ISEDI (Translated from Japanese to Italian by Manisera R. and Giovannuzzi R.)

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

Küber C., Westkämper E., Keller B., Jacobi H. F., (2016) *Method for configuring product and order flexible assembly lines in the automotive industry*, Procedia CIRP, Vol. 54, pp. 215-220

Kuka, (2017) *Human-robot collaboration (HRC)*, available at https://www.kuka.com/en-us/technologies/human-robot-collaboration

Kumar C. S., Panneerselvam R., (2007) *Literature review of JIT – KANBAN system*, International Journal of Advanced Manufacturing Technology, Vol. 32, pp. 393-408

Lanza G., Minges S., Stoll J., Moser E., Harfner B., (2016) *Integrated and Modular Didactic and Methodological Concept for a Learning Factory*, Procedia CIRP, Vol. 54, pp. 136-140

Lee J., Bagheri B., Kao H. A., (2014) *A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems*, Manufacturing Letters, Vol. 3, pp. 18-23

Lee J., Kao H. A., Yang S., (2014) *Service innovation and smart analytics for Industry 4.0 and big data environment*, Procedia CIRP, Vol. 16, pp. 3-8

Li B. H., Zhang L., Wang S. L., Tao F., Cao J. W., Jiang X. D., Song X., Chai X. D., (2010) *Cloud manufacturing: a new service-oriented networked manufacturing model*, Computer Integrated Manufacturing Systems, Vol. 16(1) , pp. 1–7

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

Likert R., (1932) *Technique for the measure of attitudes*, Archives of Psychology, Vol. 22 (140)

Lind M., Morset E., Bredeli M., (2016) *EtherCAT-integrated processing machine with full local task redundancy*, Procedia CIRP, Vol. 54, 204-209

Linstone H. A., Turoff M., (1975) *The Delphi Method: Techniques and Applications*, Reading, Addison-Wesley

Loch C. H., Kavadias S., (2007) *Handbook of New Product Development Management*, Burlington, Butterworth Heinemann-Elsevier

Lodgard E., Ingvaldsen J. A., Gamme I., Aschehoug S., (2016) *Barriers to lean implementation: perceptions of top managers, middle managers and workers*, Procedia CIRP, Vol. 57, pp. 595-600

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

Magruk A., (2016) *Uncertainty in the sphere of the industry 4.0 – potential areas to research*, Business, Management and Education, Vol. 14 (22), pp. 275–291

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 Organisations Today*, Understanding the Lean Enterprise, Springer, pp. 31-60

Malcolm J., (2016) *Lean 4.0 and lean equipment*, available at the-lmj.com/category/article/

Manyika J., Dobbs R., Chui M., Bughin J., Bisson P., Woetzel J., (2015) *The internet of things: mapping the value beyond the hype*, McKinsey Global Institute, McKinsey & Company

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), pp. 3-13

Martinez F., Jirsak P., Lorenc M., (2016) *Industry 4.0. The End Lean Management?*, Prague, from the 10th International Days of Statistics and Economics (2016, September 8th-10th), pp. 1189-1197

Matt D. T., Rauch E., Fraccaroli D., (2016) *Smart Factory for SMEs,* ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, Vol. 111 (1-2), pp. 52-55

Maxwell J. A., (1996) *Qualitative research design: An interactive approach*, Thousand Oaks, SAGE Publications Inc.

Mazali T., (2014), *Factory of the future – Tecnologia, competenze e fattore umano nella fabbrica digitale*, available in www.torinonordovest.it

Mazzieri M., (2015) *The Toyota Way*, Koster Publishing, curated by Il Giornale della Logistica with the collaboration of Toyota Material Handling Italia

McKinsey Global Institute (2015), *Industry 4.0 – How to navigate digitization of the manufacturing sector*, McKinsey Digital

McKinsey Global Institute (2016), *Industry 4.0 after the initial hype – Where manufacturers are finding value and how they can best capture it*, McKinsey Digital

McKinsey Global Institute, (2015) *The internet of things: Mapping the value beyond the hype*,: McKinsey Digital

Meissner H., Ilsen R., Aurich J. C., (2017) *Analysis of control architectures in the context of Industry 4.0*, Procedia CIRP, Vol. 62, pp. 165-169

Melton T., (2005) *The benefits of lean manufacturing: what lean thinking has to offer the process industries*, Chemical Engineering Research and Design, Vol. 83 (A6), pp. 662-673

Meudt T., Metternich J., Abele E. (2017) *Value stream mapping 4.0*, CIRP Annals [accepted for publication], Vol. 66(1)

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), pp. 211-214

Moen R., Norman C., (2006) *Evolution of the PDCA Cycle*, Tokyo, Paper presented at the 7th ANQ Congress

Moldavska A., Abreu-Peralta J. V., (2016) *Learning factories for the operationalization of sustainability assessment tools for manufacturing: bridging the gap between academia and industry*, Procedia CIRP, Vol. 54, pp. 95-100

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)

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

Monostori L., (2014) *Cyber-physical production systems: Roots, expectations and R&D challenges*, Procedia CIRP, Vol. 17, pp. 9-13

Mora J. N. C., Bribiescas F., (2015) *Respect for people: The Forgotten Principle in lean Manufacturing Implementation*, European Scientific Journal, Vol. 11 (13), pp. 45-61

Moreau C., (2016) *The Factory of the Future is Here. Are you ready?*, available at www.fabbaloo.com/blog/2016/11/2/the-factory-of-the-future-is-here-are-you-ready

Mork O. K., Hansen I. E., Strand K., Giske L. A., Kleppe P. S., (2016) *Manufacturing Education- Facilitating the Collaborative Learning Environment for Industry and University*, Vol. 54, pp. 59-64

Moyne J., Iskandar J., (2017) *Big Data Analytics for Smart manufacturing: Case Studies in Semiconductor Manufacturing*, in http://www.mdpi.com/2227-9717/5/3/39/htm

Mrugalska B., Wyrwicka M. K., (2017), *Towards Lean Production in Industry 4.0*, Procedia Engineering, Vol. 182, pp. 466-473

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

Nass C., Steuer J., Tauber E. R., (1994) *Computers are social actors*, Boston, Proceedings of the CHI'94 Conference on Human Factors in Computing Systems, (1994, April 24th-28th), Published by ACM (New York)

Nafais S., (2017) *Automated Lean Manufacturing*, Kingston University London, Master's Thesis, available at https://www.researchgate.net/publication/317042141_Automated_Lean_Manufacturing

Nee A. Y. C., Ong S. K., Chryssolouris G., Mourtzis D., (2012) *Augmented Reality Applications in Design and Manufacturing*, CIRP Annals Manufacturing Technology, Vol. 61(2), pp. 657–679

Netland T., (2015) *Industry 4.0: Where does it leave lean?*, available at www.leanmj.com (April 2015), pp. 22-23

Nicoletti B., (2015) *Optimizing Innovation with the Lean and Digitize Innovation Process*, Technology Innovation Management Review, available at timreview.ca/article/879

Ninive P. H., (2016) *Atomistic modelling of interfaces in cold welded joints*, Procedia CIRP, Vol. 54, pp. 197-203

NISO (National Information Standards Organization), (2004) *Understanding metadata*, Bethesda, NISO Press, available at www.niso.org/standards/resources/UnderstandingMetadata.pdf

Nordskogen K., Sterten J., (2016) *Case study: Development of social relations for management, learning and creation of social learning models*, Procedia CIRP, Vol. 54, pp. 164-169

Novàk V., Krajcovic M., (2011) *Warehouse Management System*, Zilina, Transcom 2011: 9th European Conference of Young Research and Scientific Workers (2011, June 27th-29th), pp- 23-26

Nyen P. A., Polanscak E., Roulet-Dubonnet O., Lind M., (2016) *Distributed, autonomous control in production of jet turbine parts*, Procedia CIRP, Vol. 54, pp. 35-40

Ogorodnyk O., Granheim M. V., Holtskog H., (2016) *Preconditions for Learning Factory: a case study*, Procedia CIRP, Vol. 54, pp. 191-196

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

Ohno T., (1988) *Toyota Production System: Beyond Large-scale Production*, Portland, Productivity Press

Okur A., (2015) *Lean thinking is perfectly compatible with digitalization*, available at planet-lean.com/lean-thinking-is-perfectly-compatible-with-digitalization

Oracle Help Center, (2017) *JD Edwards EnterpriseOne Tools Interoperability Guide*, available at docs.oracle.com/cd/E17984_01/doc.898/e14711/interoperability.htm

Oriani G., Pellegrini L., Veschi C., *Industria 4.0 – Survey 2017: Uno studio di Staufen Italia*, Milano, Staufen.Italia

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

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

Pavnaskar S. J., Gershenson J. K., Jambekar A. B., (2003) *Classification scheme for lean manufacturing tools*, International Journal of Production Research, Vol. 41 (13), pp. 3075-3090

Peterson J., Smith R., (2001) *The 5S Pocket Guide*, New York, Quality Resources

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

Piszczalski M., (2000) *Lean versus information systems*, Automotive Manufacturing & Production, Vol. 112 (8), pp. 26-28

Plenert G., (2012) *Lean management principles for information technology*, Boca Raton, CRC Press

Politecnico di Milano, (2017) *Augmented & Virtual Reality: Industrial Perspectives*, Observatory Industry 4.0 (2017 Research), Business Scenario

Politecnico di Milano, (2011) *Cloud & ICT as a Service: fuori dalla nuvola!*, Observatory Cloud & ICT as a Service (Report 2011, May), available at osservatori.net

Politecnico di Milano, (2015) *La competitività della manifattura passa dal digitale*, Observatory Industry 4.0 (Report 2015, July), available at osservatori.net

Politecnico di Milano, (2016) *La digitalizzazione dell'industria: Italia, Work in Progress*, Observatory Industry 4.0 (Report 2016, June), available at osservatori.net

Politecnico di Milano, (2017) *L'interoperabilità nella Fabbrica 4.0: standard, architetture e approcci per interconnettere macchinari e processi*, Observatory Industry 4.0 (Report 2017, May), available at osservatori.net

Poñe C., (2014) *Connecting the world – Industry 4.0*, from ABB contact 3/14

Poonpakdee P., Koiwanit J., Yuangyai C., (2017) *Decentralized Network Building Change in Lean Manufacturing Companies towards Industry 4.0*, Procedia Computer Science, Vol. 110, pp. 46-53

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

Posselt G., Böhme S., Aymans S., Herrmann C., Kauffeld S., (2016) *Intelligent learning management by means of multi-sensory feedback*, Procedia CIRP, Vol. 54, pp. 77-82

Prinz C., Kreimeier D., Kuhlenkötter B., (2017) *Implementation of a learning environment for an Industrie 4.0 assistance system to improve the overall equipment effectiveness*, Procedia Manufacturing, Vol. 9, pp. 159-166

Prinz C., Morlock F., Freith S., Kreggenfeld N., Kreimeier D., Kuhlenkötter B., (2016) *Learning Factory modules for smart factories in Industrie 4.0*, Procedia CIRP, Vol. 54, pp. 113-118

Rauch E., Dallasega P., Matt D. T., (2015) *Axiomatic Design based Guidelines for the Design of a Lean Product Development Process*. Procedia CIRP, Vol. 34, pp. 112-118

Rauch E., Dallasega P., Matt D. T., (2017) *Critical Factors for Introducing Lean Product Development Small and Medium sized Enterprises in Italy*, Procedia CIRP, vol. 60, pp. 362-367

Rauch E., Dallasega P., Matt D. T., (2016) *The way from Lean Product Development (LPD) to Smart Product Development (SPD)*, Procedia CIRP, vol. 50, pp. 26-31

Regli W., (2016) *Data and Manufacturing Innovation*, Mechanical Engineering, Vol. 138 (9), pp. 40-45

Robo Global, (2015) *Industrial Internet of Things: cobots and connectivity*, available at http://www.roboglobal.com/industrial-internet-of-things-cobots-and-connectivity

Roland Berger, (2016) *The Industrie 4.0 transition quantified – How the fourth industrial revolution is reshuffling the economic, social and industrial model*, Think *Act:* Beyond Mainstream (Roland Berger)

Roland Berger, (2014) *Industry 4.0*: *the new industrial revolution – How Europe will succeed*, Think *Act:* Beyond Mainstream (Roland Berger Strategy Consultants)

Rose A. M. N., Deros B. M., Rahman M. N. A., Nordin N., (2011) *Lean manufacturing best practices in SMEs*, Kuala Lumpur, Proceeding of the 2011 International Conference of Industrial Engineering and Operations Management

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

Russom P., (2011) *Big Data Analytics*, TDWI Best Practices Report, 4th Quarter

Russell R. S., Taylor B. W., (1999) *Operations Management*, Hoboken, John Wiley & Sons (3rd edition)

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

Rybski C., Jochem R., (2016) *Benefits of a learning factory in the context of lean management for the pharmaceutical industry*, Procedia CIRP, Vol. 54, pp. 31-34

Saenz de Ugarte B., Artiba A., Pellerin R., (2009), *Manufacturing execution system: a literature review*, Production Planning & Control, Vol. 20 (6), pp. 525-539

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

Sanders A., Subramanian K. R. K., Redlich T., Wulfsberg J. P., (2017), *Industry 4.0 and Lean Management – Synergy or Contradiction?*, Journal of Industrial Engineering and Management, Vol. 9 (3), pp. 811-833

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*, IFIP Advances in Information and Communication Technology, Vol. 514

Satoglu S., Ustundag A., Cevikcan E., Durmusoglu M. B., (2017) *Lean Transformation Integrated with Industru 4.0 Implementation Methodology*, Istanbul Technical University, Department of Industrial Engineering

Schein E. H., (1985) *Organizational Culture and Leadership*, Jossey Bass, translated in Italian by Guerini e associati, Milano

Schlaepfer R. C., Koch M., (2014) *Industry 4.0 – Challenges and Solutions for the digital transformation and use of exponential technologies*, from a research of Deloitte

Schlick J., Stephan P., Loskyll M., Lappe D., (2014): *Industrie 4.0 in der praktischen Anwendung*, In Industrie 4. 0 in Produktion, Automatisierung und Logistik: Anwendung, Technologien und Migration, edited by Bauernhansl T., ten Hompel M., Vogel-Heuser B., pp. 57–84

Scholz M., Kreilein S., Lehman C., Böhner J., Steinhilper R., (2016) *Integrating Intralogistics into Resource Efficiency Oriented Learning Factories*, Procedia CIRP, Vol. 54, pp. 239-244

Schreiber S., Funke L., Tracht K., (2016), *BERTHA – A flexible learning factory for manual assembly*, Procedia CIRP, Vol. 54, pp. 119-123

Schumacher A., Erol S., Sihn W., (2016) *A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises*, Procedia CIRP, Vol. 52, pp. 161-166

Schumacher A., Hummel V., (2016) *Decentralized control of logistic processes in cyber-physical production systems at the example of ESB Logistics Learning Factory*, Procedia CIRP, Vol. 54, pp. 19-24

Shah R., Ward P. T., (2007) *Defining and developing measures of lean production*, Journal of Operations Management, Vol. 25, pp. 785-805

Shimokawa K., Fujimoto T., (2009), *The Birth of Lean: Conversations with Taiichi Ohno, Eiji Toyoda, and other figures who shaped Toyota management*, Cambridge, The Lean Enterprise Institute (version 1.0 – translated by Miller B., with Shook J.)

Shingo S., (1989) *A Study of the Toyota Production System: From an Industrial Engineering Viewpoint*, New York, Productivity Press (newly translated by Dillon A. P.)

Sibatrova S. V., Vishnevskiy K. O., (2016) *Present and Future of the Production: Integrating Lean Management into Corporate Foresight*, National Research University Higher School of Economics, Basic Research Program – Working Papers

Sileoni S., (2017) *L'industria 4.0 distrugge posti di lavoro? – Analisi del discusso fenomeno con Serena Sileoni, vicedirettore dell'Istituto Bruno Leoni*, from Italia Oggi – Economia e politica (2017, February 1st), p. 11

SmartFactory^KL (2014), *Keyfinder production line*, available at http://smartfactory.dfki.uni-kl.de/en/content/demo/technological-demo/plant-industry4

Sobek D. K., Smalley A., (2008) *Understanding A3 Thinking: A Critical Component of Toyota's PDCA Management System*, New York, Productivity Press

Soder J., (2014) *Use Case Production: Von CIM uber Lean Production zun Industrie 4.0*, In , In Industrie 4. 0 in Produktion, Automatisierung und Logistik: Anwendung, Technologien und Migration, edited by Bauernhansl T., ten Hompel M., Vogel-Heuser B., pp. 85-102

Sperman M. L., Zazanis M., (1992) *Push and pull production systems: issues and comparisons*, Operations Research, Vol. 40 (3), pp. 521-532

Stark J., (2004) *Product lifecycle management: 21st century paradigm for product realization*, New York, Springer

Staufen A. G., (2015) *Industry 4.0 Index 2015: Industry 4.0 and Lean Study*, Köngen

Sterten J., Nordskogen K., Verlan A., (2016) *Adaptation and Implementation of Modern Learning Techniques in Master of Sustainable Manufacturing: Cultural Challenges, Effects and Potential for Improvement*, Procedia CIRP, Vol. 54, pp. 170-174

Sterten J., Ogorodnyk O., (2016) *Application of modern educational methods through implementation of the ambulance simulator at a clinic laboratory (NTNU Gjøvik)*, Procedia CIRP, Vol. 54, pp. 41-46

Stock T., Seliger G., (2016) *Opportunities of Sustainable Manufacturing in Industry 4.0*, Procedia CIRP, Vol. 40, pp. 536-541

Streitzig C., Oetting A., (2016) *Railway operation research centre – a learning factory for the railway sector*, Procedia CIRP, Vol. 54, pp. 25-30

Sugimori Y., Kusunoki K., Cho F., Uchikawa S., (1977) *Toyota production system and Kanban system: materialization of just-in time and respect-for-human system*, International Journal of Production Research, Vol. 15 (6), pp. 553-564

Synnes E. L., Welo T., (2016), *Enhancing Integrative Capabilities through Lean Product and Process Development*, Procedia CIRP, Vol. 54, pp. 221-226

Taleghani M., (2010) *Key factors for implementing the lean manufacturing system*, Journal of American Science, Vol. 6 (7), pp. 287-291

Tapping D., Luyster T., Shuker T., (2002) *Value Stream Management: Eight Steps to planning, mapping, and sustaining lean improvement*, New York, Productivity Press

Tavola G., (2016), *Industry 4.0*, Presentation for A.Y. 2016-2017 of Politecnico di Milano, Course of Advanced and Sustainable Manufacturing

Taylor A., (2004) *The Organization of Information*, Westport, Libraries Unlimited (2nd edition)

The Boston Consulting Group, (2015) *Industry 4.0 – The Future of Productivity and Growth in Manufacturing Industries*

The Boston Consulting Group, (2015) *Man and Machine in Industry 4.0 – How Will Technology Transform the Industrial Workforce Through 2025?*

The Boston Consulting Group, (2016) *Time to Accelerate in the Race Toward Industry 4.0*

Thiede S., Juraschek M., Herrmann C., (2016) *Implementing cyber-physical production systems in learning factories*, Procedia CIRP, Vol. 54, pp. 7-12

Tiraboschi M., Seghezzi F., (2016), *Il Piano nazionale Industria 4.0: una lettura lavoristica*, Labour & Law Issues, Vol.2 (2)

Todd P., (2000) *Lean manufacturing: building the lean machine*, Advance Manufacturing (2000, September 12th), available at www.advancemanufacturing.com/leanmanufacturing/part1.htm

Toyota Motor Corporation (2003), *Environmental & Social Report*, p. 80

Tvenge N., Martinses K., Kolla S. S. V. K., (2016) *Combining learning factories and ICT-based situated learning*, Procedia CIRP, Vol. 54, pp. 101-106

Uhlemann T. H. J., Schock C., Lehmann C., Freiberger S., Steinhilper R., (2017) *The Digital Twin: Demonstrating the potential of real time data acquisition in production systems*, Procedia Manufacturing, Vol. 9, pp. 113-120

Veloso M., Biswas J., Coltin B., Rosenthal S., Kollar T., Mericli C., Samadi M., Brandao S., Ventura R., (2013) *CoBots: Collaborative Robots Servicing Multi-Floor Buildings*, in Intelligent Robots and Systems (IROS), pp. 5446-5447

Venkatesh J., (2007) *An Introduction to Total Productive Maintenance (TPM)*, The Plant Maintenance Resource Center

Villalba-Diez J., Ordieres-Meré J., Rubio-Valdehita S., (2016) *Lean Learning Patterns. $(CPD)_n$A vs. KATA*, Procedia CIRP, Vol. 54, pp. 147-151

Wagner T., Hermann T., Thiede S., (2017) *Industry 4.0 impacts on lean production systems*, Procedia CIRP, Vol. 63, pp. 125-131

Walker D., (1990) *Customer first: A strategy for quality service*, Chapter 10 of the book *Handbook for Management*, edited by Lock D., Brookfield, The Gower

Wank A., Adolph S., Anokhin O., Arndt A., Anderl R., Metternich J., (2016) *Using a learning factory approach to transfer Industrie 4.0 approaches to small- and medium-sized enterprises*, Procedia CIRP, Vol. 54, pp. 89-94

Waslo R., Lewis T., Hajj R., Carton R., (2017) *Industry 4.0 and cybersecurity – Managing risk in an age of connected production*, A Deloitte series on digital manufacturing, Deloitte University Press

Weber C., Konigsberger J., Kassner L., Mitschang B., (2017) *M2DDM – A Maturity Model for Data-Driven Manufacturing*, Procedia CIRP, Vol. 63, pp. 173-178

Weeber M., Gebbe C., Lutter-Günther M., Böhner J., Glasschroeder J., Steinhilper R., Reinhart G., (2016) *Extending the scope of future learning factories by using synergies through an interconnection of sites and process chains*, Procedia CIRP, Vol. 54, pp. 124-129

Weyer S., Schmitt M., Ohmer M., Gorecky D., (2015) *Towards Industry 4.0 – Standardization as the crucial challenge for highly modular, multi-vendor production systems*, International Federation of Automatic Control, Vol. 48 (3), pp. 579-584

Whittemore R., Melkus G., (2010) *Design Decisions in Research*, available at http://www.esourceresearch.org/eSourceBook/DesignDecisionsinResearch/1LearningObjectives/tabid/662/Default.aspx

Whittemore R., Chase S. K., Mandle C. L. (2001) *Validity in qualitative research*. Qualitative Health Research, Vol. 11(4), pp. 522-537

Wiegand B., (2016) *Lean and Industry 4.0 – Opposites or Complements?*, In Michel Baudin's Blog: Idea from manufacturing operations, available at michelbaudin.com/2015/10/11/lean-and-industry-4-0-opposites-or-complements-wiegands-watch

Williamson G., (2012) *Case Study: Implementing Visual Management*, in Kangan Institute of TAFE

Wilmott P., (1994) *Total Productive Maintenance – The Western Way*, Oxford, Butterworth-Heinemann

Wilson K., Doz Y. L., (2011) *Agile Innovation: A Footprint Balancing Distance and Immersion*, California management Review, Vol. 53 (2), pp. 6-26

Wireman T., (2004) *Total Productive Maintenance*, New York, Industrial Press Inc

Witkoski K., (2017) *Internet of Things, Big Data, Industry 4.0 – Innovative Solutions in Logistics and Supply Chains Management*, Procedia Engineering, Vol. 182, pp. 763-769

Womack J. P., Jones D., (1996) *From Lean Production to the Lean Enterprise*, Harvard Business Review, Vol. 72 (2) pp. 93-103

Womack J. P., Jones D., (2005) *Lean Solutions: how companies and customers can create value and wealth together*, New York, The Free

Womack J. P., Jones D., (1996) *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*, New York, Free Press

Womack J. P., (2007) *Respect for People*, e-mail to the Lean community, available at bptrends.com

Womack J. P., Jones D., Roos D., (1990) *The machine that changed the world: The story of Lean production – Toyota's secret weapon in the global car wars that is revolutionizing world industry*, New York, Free Press

Wong K. V., Hernandez A., (2012) *A Review of Additive Manufacturing*, International Scholarly Research Network Mechanical Engineering, Vol. 2012, pp. 1-10

Wyrwicka M. K., Mrugalska B., (2017), *Mirages of Lean Manufacturing in Practice*, Procedia Engineering, Vol. 182, pp. 780-785

Xia F., Yang L. T., Wang L., Vinel A., (2012) *Internet of Things*, International Journal of Communication Systems, Vol. 25, pp. 1101-1102

Xu X., (2012) *From cloud computing to cloud manufacturing*, Robotics and Computer-Integrated Manufacturing, Vol. 28, pp. 75-86

Yamamoto Y., (2010) *Kaikaku in production*, Licentiate thesis at Mälardalen University of Eskilstuna, School of Innovation, Design and Engineering

Yoo I. S., Braun T., Kaestle C., Spahr M., Franke J., Kestel P., Wartzack S., Bromberger J., Feige E., (2016) *Model Factory for Additive Manufacturing of Mechatronic Products: Interconnecting World-Class Technology Partnerships with Leading AM Players*, Procedia CIRP, Vol. 54, pp. 210-214

Zhang Q., Cheng L., Boutaba R., (2010) *Cloud computing: state-of-the-art and research challenges*, Journal of Internet Services and Applications, Vol. 1, pp. 7-18

Zhang Y., Xie F., Dong Y., Yang G., Zhou X., (2013) *High fidelity virtualization of cyber-physical systems*, International Journal of Modeling, Simulation and Scientific Computing, Vol. 4 (2), pp. 1-26

9. ATTACHMENT

9.1 Questionnaire for Case Studies

The figures below illustrate the questionnaire used for the 9 interviews for the case studies in the model thinking phase. It is important to underline that the questionnaire was used as a guideline and not all the questions were asked to all the interviewees. It is composed of four main parts: a brief introduction of the subject, Lean manufacturing, Industry 4.0 and the final part regarding the model *Lean 4.0*.
The language of the questionnaire is the Italian.

INTERVISTA LEAN + INDUSTRIA 4.0

Gentilissimo,

Siamo due studenti del Politecnico di Milano e stiamo affrontando il tema della Lean Manufacturing nel nuovo ecosistema della quarta rivoluzione industriale.
Il nostro obbiettivo è quello di cercare eventuali punti di contatto e discrepanze tra i due mondi, cercando di definire un modello qualitativo che stia alla base di quella che vorremmo definire "Lean 4.0".
Il seguente questionario ci aiuterà a raccogliere informazioni per la scrittura di case studies a supporto della nostra tesi e abbiamo identificato in voi un esempio interessante per la nostra analisi.
Vi ringraziamo anticipatamente per la vostra disponibilità.

0. INTRODUZIONE DELL'AZIENDA

0.1. Qual è il settore in cui l'azienda opera?

0.2. Quali sono le caratteristiche del portfolio di prodotti che offrite sul mercato?

0.3. E' possibile avere qualche dato attestante le dimensioni dell'azienda, come ad esempio il fatturato, il numero di dipendenti, il numero di plant produttivi, l'investimento annuo in R&D…?

0.4. Come l'IT (la parte software e di programmazione) comunica con le operations (OT, la parte attiva sul campo)? Se e come negli ultimi anni questo legame è cambiato, con l'ingresso prepotente delle nuove tecnologie e della digitalizzazione?

0.5. Cosa c'è alla base del vostro vantaggio competitivo?

<table>
<tr><th colspan="2">PRESTAZIONE</th><th>IMPATTO ALTO</th><th>IMPATTO MEDIO ALTO</th><th>IMPATTO MEDIO BASSO</th><th>IMPATTO BASSO</th></tr>
<tr><td rowspan="2">EFFICIENZA</td><td>Produttività
(Lavoro, Capitale fisso, Capitale circolante, Materiali)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Flessibilità
(di mix, di volume, di piano, di prodotto)</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">EFFICACIA</td><td>Servizio
(Prontezza, Completezza, Accuratezza, Puntualità, Disponibilità)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Qualità
(di targa, di conformità on field)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>ALTRO</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

0.6. Qual è il vostro posizionamento sul mercato? Siete i leader nel vostro settore? Qual è il vostro market share?

0.7. Riguardo al concetto di sviluppo e innovazione, che tipo di azienda ritenete di essere? Qual è il vostro approccio riguardo a questi temi?

1. **LEAN *MANUFACTURING***

1.1. In quale anno è iniziata l'implementazione della Lean?

1.2. A che grado di implementazione siete arrivati? Scegliere una fase e fornire ulteriori argomentazioni se possibile:
- o Fase 1: introduzione processi Kaizen
- o Fase 2: creazione del valore orientata ai principi Lean
- o Fase 3: anche le funzioni indirette seguono i principi Lean
- o Fase 4: la strategia e l'organizzazione adottano la filosofia Lean

1.3. Alla base della Lean è richiesto un forte cambiamento culturale nelle persone e nel modo di concepire l'organizzazione dell'azienda. Dopo quanto tempo avete potuto osservare un cambiamento culturale?

1.4. Cosa è cambiato nella mentalità dei dirigenti e dei dipendenti?

1.5. Quali strumenti avete adottato? (SMED, TPM, Kanban, Hoshin Kanri, 5S…)

1.6. E' stato necessario un cambiamento organizzativo e strutturale dopo l'implementazione della Lean?

1.7. Quali sono state le barriere e le difficoltà che avete riscontrato nell'implementazione?

1.8. Quali sono i motivi che vi hanno spinto ad adottare la Lean?

1.9. Come definireste il processo di innovazione in un ambiente puramente Lean?

1.10. Quali benefici avete maggiormente raggiunto con l'implementazione della Lean (anche in percentuale 0-100 %)? Sono in linea con gli obbiettivi pianificati prima dell'implementazione del progetto?
- o Riduzione degli sprechi
- o Riduzione dei costi di produzione
- o Riduzione del tempo totale di attraversamento
- o Riduzione del lavoro e della fatica
- o Riduzione di scorte e magazzini
- o Aumento della capacità produttiva …

1.11. Credete che la filosofia Lean abbia dei limiti intrinsechi? Parlando di problematiche “endogene” ed “esogene”, quali di queste difficoltà nell’implementazione della filosofia avete riscontrato? (Nell’elenco definiti ambito e dettaglio)

- Feedback dei fornitori: limitata esperienza e risorse, differenti modelli di business e pratiche
- Consegne JIT dei fornitori: report incompleti sullo stato delle consegne, ritardi inaspettati, mancata corrispondenza nelle quantità richieste
- Sviluppo dei fornitori: inadeguate risorse e competenze
- Coinvolgimento del cliente: scarsa flessibilità, acquisizione delle corrette informazioni sui bisogni e le richieste
- Produzione *pull*: scarsa tracciabilità dei materiali, cambi nello scheduling di produzione
- Flusso continuo: errori nell’inventario, problemi di capacità, control system centralizzato
- Riduzione del set-up
- Manutenzione: scarso controllo dei breakdown
- Coinvolgimento dei dipendenti: improprio sistema di feedback, monotonia nel lavoro …

1.12. Avete mai sentito parlare di Lean Automation?

2. *INDUSTRIA 4.0*

2.1. Potete darci una vostra definizione di Industria 4.0?

2.2. Quali sono secondo il vostro punto di vista gli obbiettivi di questa nuova rivoluzione e i principi alla base di essa (in maniera filosofica, qual è la vera essenza dell’industria 4.0)?

2.3. Quanto ha influito il Piano Calenda sul vostro processo di cambiamento? Quanto avete investito o pensate di investire complessivamente sfruttando le agevolazioni del governo?

- 0 – 300.000 €
- 300.000 – 500.000 €
- 500.000 – 1.000.000 €
- 1.000.000 – 3.000.000 €
- Più di 3.000.000 €

2.4. Quali di queste soluzioni 4.0 avete applicato e in quali progetti (da inserire nelle note)?

SOLUZIONE		**PROGETTO**
Industrial Internet of Things	Radio Frequency Identification (RFId)	
	Near Field Communication (NFC)	
	Wireless Sensors & Actuators Networks (WSN)	
	Machine to Machine (M2M)	
	Bluetooth Low Energy	
	Cyber Physical System	
	Sensors / Meters	
	altro	
Industrial Analytics	Predictive Analytics	
	Failure pattern recognition	
	Supply Chain Analytics	
	Cloud computing	
	Virtualization technologies	
	altro	
Cloud Manufacturing	Cloud Computing	
	Virtualization Technologies	
	altro	
Additive Manufacturing	SLS, FDM, EBM, DMLS, SLA, …	
	altro	
Advanced Automation	Cognitive	
	Collaborative	
	Reconfigurable	
	altro	
Advanced Human Machine Interface	Realtà aumentata	
	3D Scanner	
	Visori	
	Wearable	
	Touch Display	
	altro	

2.5. Se e come queste pratiche hanno risolto (o potrebbero risolvere secondo voi) le problematiche nell'implementazione (e mantenimento) della Lean precedentemente identificate?

2.6. Se consideriamo le tecnologie come strumenti per il cambiamento, quanto reputate importanti le persone, i loro comportamenti e lo stile di leadership in questa rivoluzione?

2.7. Quali sono i motivi che vi hanno spinto ad implementare queste tecnologie (ad esempio, una rivoluzione spinta dall'aumento di produttività, o sempre volta alla creazione del valore per il cliente…)? Avete sentito necessario e obbligatorio il cambiamento?

2.8. Da quanto la vostra azienda implementa queste tecnologie nei vostri impianti produttivi?

2.9. Quanto impattano secondo il vostro punto di vista queste difficoltà d'implementazione?

DIFFICOLTÀ D'IMPLEMENTAZIONE		**ALTA**	**MEDIO ALTA**	**MEDIO BASSA**	**BASSA**	**NULLA**
TECNOLOGIA	Indisponibilità di infrastrutture (esterne/interne)					
	Limiti di prestazioni					
	Velocità evoluzione tecnologia/tecnologie concorrenti					
	Costi					
STANDARD	Indisponibilità di standard (assenti/poco chiari)					
OFFERTA INDUSTRIA 4.0	Basso livello tecnico dei fornitori					
	Incapacità dei fornitori di comprendere il Vostro business					
	Assenza di System Integrator di qualità					
CHANGE MANAGEMENT	Problemi di gestione dell'informazione					
	Resistenze interne					
	Problemi di Privacy					
	Problemi di comunicazione di fabbrica					
KNOW HOW	Personale interno non sufficientemente preparato ad affrontare il cambiamento					
ALTRO	*(specificare)*					

3. LEAN 4.0

3.1. Se dovessimo coniare la parola "Lean 4.0" (Lean in ottica 4.0), quale potrebbe essere una definizione? Quali obiettivi potrebbe porsi questa nuova filosofia?

3.2. Anche nell'implementazione della "Lean 4.0", avete riscontrato necessità di un cambiamento culturale?

3.3. L'implementazione e l'integrazione nei sistemi aziendali dei Cyber Physical Systems e delle nuove tecnologie richiede tempo e si tratta di un processo complesso: come viene visto questo processo in ottica Lean, che invece si basa sull'approccio "Quick and dirty" al cambiamento?

3.4. Credete che un'azienda possa implementare le nuove tecnologie nei loro processi senza una base Lean? Se si, come e con quali benefici?

3.5. In aggiunta, la quarta rivoluzione industriale potrebbe rendere superflua l'implementazione e i benefici dati dalla Lean?

3.6. Avete ottenuto risultati migliori dei precedenti applicando la "Lean 4.0"?

3.7. Quanto sono importanti i seguenti principi Lean quando si implementa la 4.0?

- Organizzazione orientate al flusso del valore per la produzione e lo sviluppo del prodotto
- Utilizzo di processi e tecnologie standard nella produzione e nello sviluppo del prodotto
- Riduzione del lead time e del tempo di attrezzaggio
- Gestione dei materiali
- Gestione della varietà e della complessità

3.8. Come viene influenzata la Lean dalla 4.0?

- La Lean soddisfa qualunque requisito per una efficace implementazione del 4.0
- L'industria 4.0 potenzia la Lean grazie a una maggiore attenzione ai processi
- La Lean (basata sul flusso orientate al valore) e l'industria 4.0 (orientata agli aspetti tecnici) si completano a vicenda in maniera ideale

3.9. Qual nuove competenze si sono rivelate necessarie nel processo di implementazione?

3.10. Come è cambiata la figura dell'operatore? Quali nuove skills sono richieste?

3.11. Come cambia il processo decisionale?

3.12. Come viene potenziata la Lean leadership (stile di leadership comunque da conservare e far progredire per implementare in maniera corretta le tecnologie) grazie ai dati in tempo reale e i cosiddetti "digital twins"?

3.13. Come viene vista la metodologia Hoshin Kanri (fondata sui pilastri del MBO, Management by Objectives, e TQM, Total Quality Management) nel nuovo ecosistema basato sulla digitalizzazione?

3.14. Riguardo al trend ormai consolidato della mass customization, è esso legato alle pratiche Lean? Come la "Lean 4.0" ha soddisfatto questa esigenza?

3.15. Pensate che la modularizzazione sia un elemento chiave per la "Lean 4.0"?

3.16. In che modo i Big Data e l'analisi di tutte queste informazioni è importante per la creazione del valore? Tutte le informazioni ricevute sono importanti e utilizzabili o si parla anche in questo caso di value e non value adding information (come per la Lean, value e non value adding activities)?

3.17. Pensando a un pilastro della Lean quale la standardizzazione, se e in che modo pensate che evolva in questo nuovo contesto?

3.18. Riguardo al processo del miglioramento continuo legato alla Lean, credete che il processo di miglioramento e l'idea di innovazione alla base del 4.0 sia la stesso o venga concepito in maniera differente (da un processo "step by step" ad un'innovazione forte e "disruptive")? Se ci focalizziamo sulla creazione del valore per il cliente, verranno creati nuovi business model innovativi?

3.19. Pensate che la proattività nei confronti del mercato, ottenuta grazie alle tecnologie 4.0, sia un key success factor oggi?

3.20. Ritenete che avere una maggiore visibilità della catena del valore sia necessario oggi? Se sì, come lo state ottenendo?

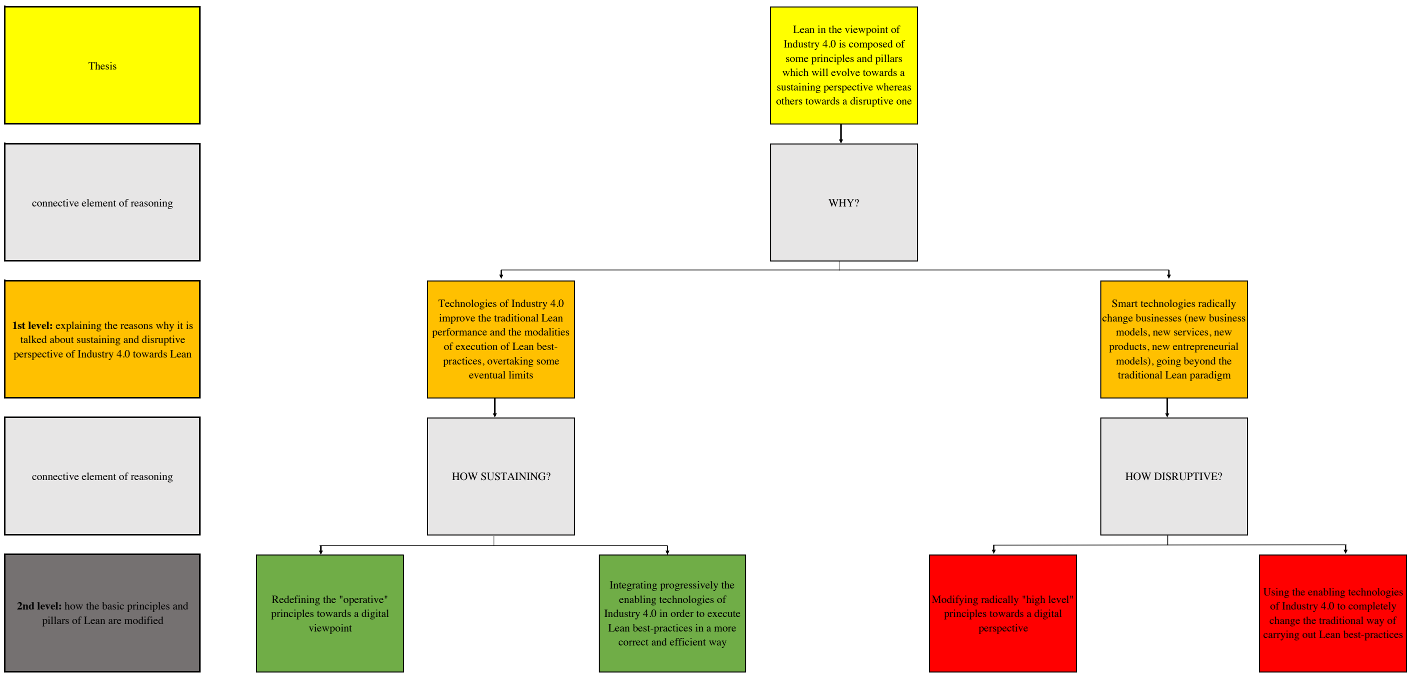
3.21. Quali benefici ha portato l'implementazione del Lean applicando le tecnologie dell'industria 4.0?

- Virtualizzazione
- Interoperabilità
- Modularità
- Informazioni e analisi real-time
- Tracciabilità
- Orientamento ai servizi
- Decentralizzazione

9.2 Conceptual Map

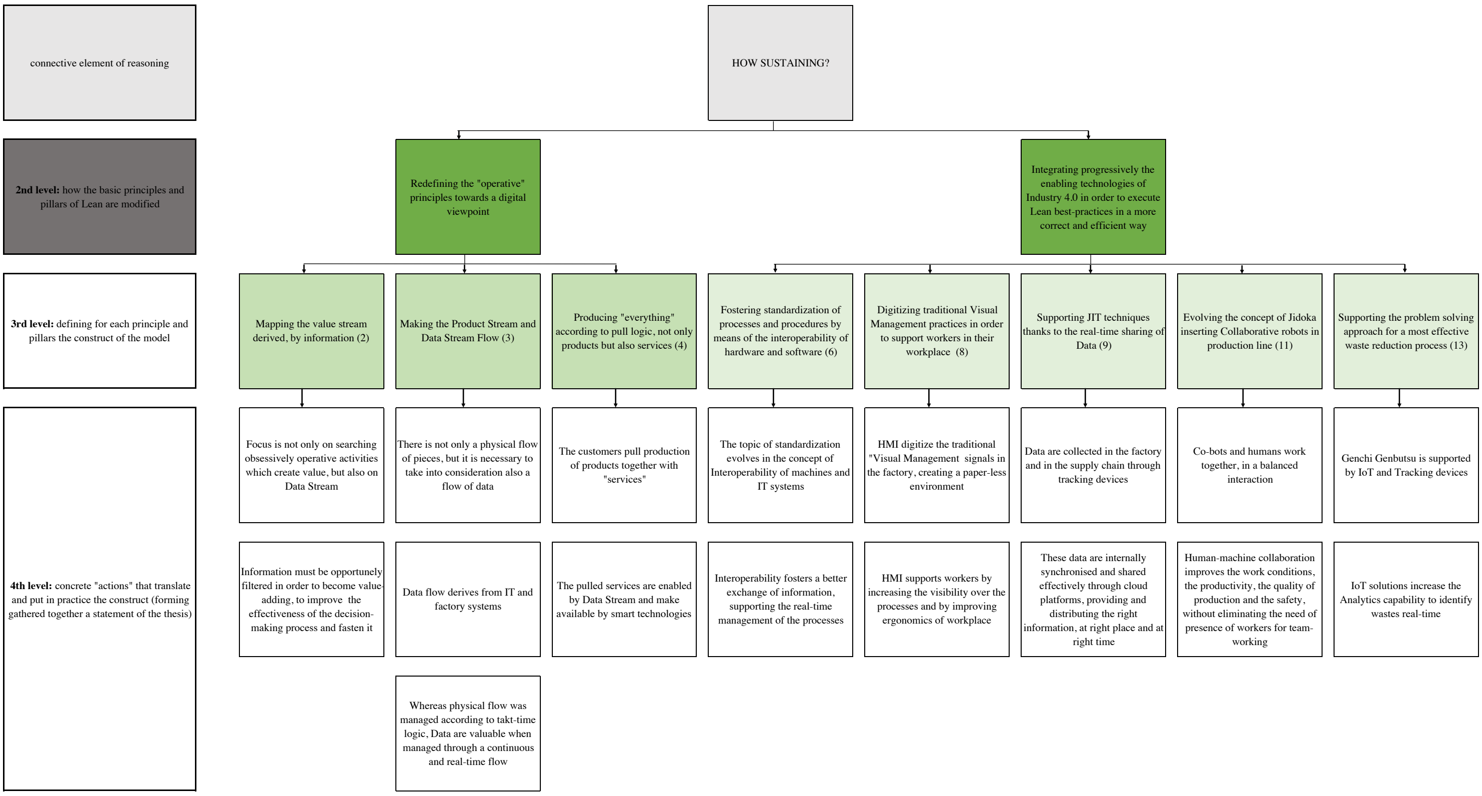
In the three figures below the conceptual map in which the reasoning behind the work of this dissertation is illustrated. Since it is a four-level map, it was preferable to show it in different figures, illustrated as the following.

The first figure shows the first two levels of the map. Starting with the thesis, the reasons behind the usage of the words *sustaining* and *disruptive*, the core of the dissertation, and *how* the principles and pillars were modified is illustrated.



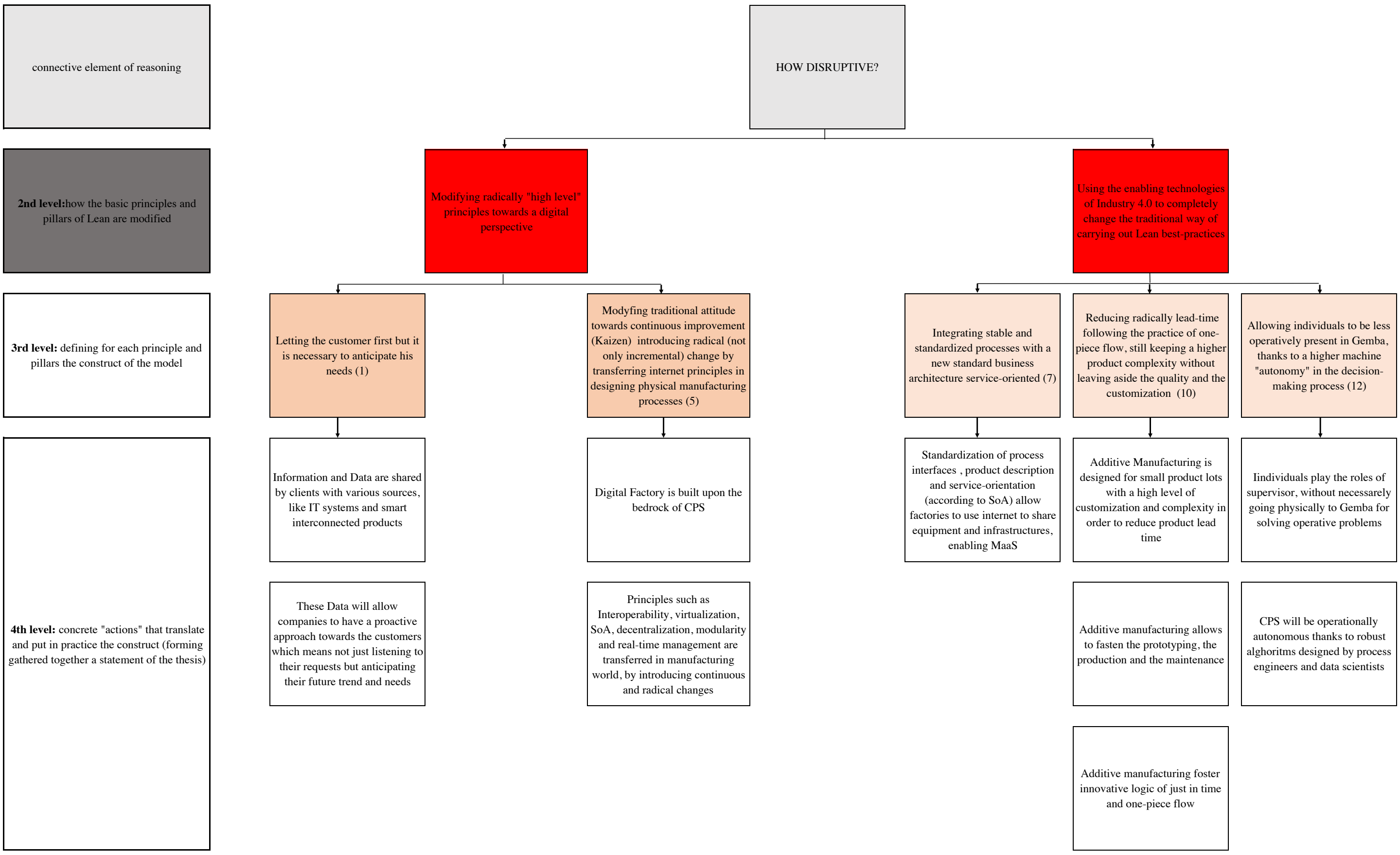
9. Attachment

The second figure shows the third and the fourth levels of the map, regarding the *sustaining* part of the model, both in terms of principles and pillars. *sustaining* constructs and statements are showed below.



9. Attachment

The last figure shows the third and the fourth levels of the map for the *disruptive* part of the model, in the way in which they are presented in the figure above.



9.3 Survey for Alpha Test

The *pdf* format of the Alpha Test is illustrated above: it was delivered in Italian. Since also partners of Industry 4.0 Observatory of Politecnico di Milano were used for the validation, the survey was presented as proposed by it, to achieve sure collaboration. The name of the two dissertation's authors were put only in the final thanksgiving.

Lean e Industria 4.0

Gentilissimo/a,

L'Osservatorio "Industria 4.0" del Politecnico di Milano sta affrontando una ricerca sul tema della Lean Manufacturing nel nuovo ecosistema della quarta rivoluzione industriale.
L'obbiettivo è quello di individuare eventuali punti di contatto e discrepanze tra i due mondi, definendo un modello qualitativo che stia alla base di una potenziale Smart Lean Factory.

Per concludere una prima ricerca abbiamo elaborato il seguente breve questionario che ha lo scopo di validare tale modello, nel quale le si chiede di esprimere un grado di accordo/disaccordo riguardo a 13 affermazioni, divise in 2 sezioni. Tali affermazioni, denominati STATEMENT, sono la spiegazione a livello concreto della frase scritta all'inizio di ogni domanda.

Per essi, dovrà esprimere il suo grado di accordo/disaccordo, scegliendo una e una sola tra le 4 possibilità: 1 se totalmente in disaccordo, 2 se parzialmente in disaccordo, 3 se parzialmente in accordo, 4 se totalmente in accordo con l'affermazione. Inoltre, nel caso in cui lo statement non fosse chiaro e fosse difficile prendere una posizione di accordo/disaccordo, è possibile selezionare la casella "Non saprei".
In caso di dubbio in relazione a questi statement e/o al loro contenuto, o qualora desideri farci avere un suo commento al riguardo, le chiediamo di contattare via e-mail Gabriele Schenetti (gabriele.schenetti@mail.polimi.it) oppure Mila Malavasi (mila.malavasi@mail.polimi.it).

La ringraziamo anticipatamente per la sua disponibilità e per il tempo prezioso dedicatoci.

Nome Azienda

____

Lasciare il cliente al primo posto, ma è necessario anticiparne i bisogni

STATEMENT: La raccolta e la condivisione di Dati e informazioni dai clienti attraverso le tecnologie digitali (e.g. sistemi IT avanzati e Smart interconnected Products) permettono alle aziende di avere un approccio proattivo nei confronti di essi, non più solo "ascoltando" le loro richieste, ma anticipandone trend e bisogni futuri.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Mappare il flusso del valore, che deriva dalle informazioni

STATEMENT: Il focus non è più solo nella ricerca ossessiva delle attività operative che creano valore per il cliente, ma anche nelle informazioni, le quali opportunamente filtrate diventano a valore aggiunto, migliorando l'efficienza e la velocità del processo decisionale.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

.

Creare un flusso continuo non solo di prodotto ma anche di Dati

STATEMENT: Non esiste più solo un flusso fisico di "pezzi", gestito da logiche di takt-time, ma è necessario prendere in considerazione anche il flusso dei dati che deriva dai sistemi IT e di fabbrica, il quale viene gestito attraverso un flusso continuo e real-time per creare valore.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Produrre con logica "pull" non solo prodotti ma anche servizi

STATEMENT: La tradizionale logica "pull" production in ottica lean evolve attraverso l'Industria 4.0 con l'introduzione del concetto di "servizi" abilitati dal flusso di valore dei dati e delle informazioni, disponibili grazie alle tecnologie digitali.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Modificare la tradizionale attitudine al miglioramento continuo (Kaizen) mettendo in atto cambiamenti radicali (e non solo incrementali) attraverso il trasferimento dei principi internet nel disegno e nella gestione dei processi industriali

STATEMENT: La Digital Factory pone le fondamenta nei CPS (Cyber Physical System): i ben funzionanti principi internet quali l'interoperabilità, la virtualizzazione, la SoA, la modularità e la gestione real-time vengono opportunamente trasferiti e adattati al mondo industriale, apportando cambiamenti continui e radicali.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Favorire la standardizzazione dei processi e delle procedure attraverso l'interoperabilità di hardware e software

STATEMENT: Il tema di standardizzazione evolve nel concetto di interoperabilità delle macchine e dei sistemi informativi: l'interoperabilità favorisce un miglior scambio di informazioni, supportando la gestione real-time dei processi.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Integrare processi stabili e standardizzati con una nuova architettura standard di business service-oriented

STATEMENT: La standardizzazione delle interfacce di processo, delle descrizioni di prodotto e dell'orientamento ai servizi (SoA) sono i requisiti che permettono alle fabbriche di condividere equipaggiamenti e infrastrutture attraverso internet.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Digitalizzare le tradizionali pratiche di Visual Management per supportare l'operatore nel posto di lavoro

STATEMENT: Lo Human-Machine Interface (HMI) digitalizza i segnali tipici del Visual Management presenti nella fabbrica, creando un ambiente paper-less; inoltre, esso favorisce una migliore visibilità di tutto il processo fabbrica e migliora l'ergonomia del posto di lavoro.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Migliorare tecniche Just-in-Time attraverso la condivisione real-time delle informazioni

STATEMENT: Le informazioni sono raccolte internamente alla fabbrica, favorendo la loro sincronizzazione e condivisione real-time in tutta la supply chain attraverso piattaforme cloud, per fornire le informazioni giuste, nel posto giusto, al momento giusto.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Ridurre radicalmente il lead-time di produzione secondo la logica one-piece flow, mantenendo comunque un alto grado di complessità del prodotto, senza rinunciare alla qualità e alla customizzazione

STATEMENT: L'Additive Manufacturing, disegnata per lotti piccoli di produzione con un alto livello di customizzazione e complessità, permette di ridurre il lead-time di produzione, velocizzando le fasi di prototyping, produzione e manutenzione, favorendo logiche innovative di just-in-time e one-piece flow.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Evolvere il concetto di Jidoka inserendo CoBots nelle linee di produzione

STATEMENT: I Co-bots e gli umani lavorano insieme, in una bilanciata interazione, migliorando le condizioni di lavoro, la produttività, la qualità del prodotto e la sicurezza, senza eliminare il bisogno della presenza dell'operatore stesso per il teamwork.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Permettere all'uomo di essere operativamente meno presente nel Gemba, grazie ad una maggiore autonomia delle macchine nel processo decisionale

STATEMENT: L'uomo riveste un ruolo di supervisore nel processo decisionale, senza più dover necessariamente presenziare fisicamente nel Gemba per risolvere i problemi operativi: infatti, molteplici ingegneri di processo e da data scientists programmano potenti algoritmi per permettere ai CPS (Cyber Physical System) di essere autonomi nell'operatività.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Supportare l'approccio al problem solving per una più efficiente riduzione degli sprechi

STATEMENT: L'approccio tradizionale del Genchi Genbutsu è supportato dagli IoT e dai Tracking devices, che rendono visibili gli sprechi real-time e aumentano le capacità di Analytics di renderli più facilmente identificabili.

- 1 - Totalmente in disaccordo
- 2 - Parzialmente in disaccordo
- 3 - Parzialmente in accordo
- 4 - Totalmente in accordo
- Non saprei

Il questionario è finito... Grazie per la sua disponibilità!

Il suo contributo sarà prezioso per la conclusione della nostra ricerca.
Ricordiamo che le risposte rimarranno in forma anonima e verrà citato il nome della sua azienda soltanto nel caso in cui lei lo voglia (in caso contrario, ci avvisi).
Grazie ancora della sua disponibilità!

Rimaniamo a disposizione per eventuali chiarimenti o dubbi.
Gabriele Schenetti (gabriele.schenetti@mail.polimi.it)
Mila Malavasi (mila.malavasi@mail.polimi.it)

Furthermore, *google.doc* format, in the way in which it was delivered for alpha test, is available in the following link:
https://docs.google.com/forms/d/e/1FAIpQLSeBMScuDjTy52ou6GSdxi4XddkOwREG cLlGKQQqcA_JsuJCow/viewform?c=0&w=1

9.4 Alpha Coefficient of Cronbach

For estimating the level of reliability, it was used the formula to calculate the alpha coefficient of Cronbach (Cronbach, 1951):

$$\alpha = \frac{L}{L-1}\left[1 - \frac{\sum_{j=1}^{L}\sigma_j^2}{\sigma_\Sigma^2}\right] \quad (1)$$

Where L is the number of variable, namely the 13 statements, and σ_Σ^2 is the variance of the variable *Sum*, which is computed by summing up all the scores of different options.

The first table shows the scores of associated to each variable, for the 38 answers. A variable *Sum* was also considered, in which the sum of different scores for the same respondent was computed. The scores associated to each option refer to *Table 7.1*.

		ITEM (L)													SUM
		1	2	3	4	5	6	7	8	9	10	11	12	13	
ANSWERS	1	4	3	4	4	4	4	4	4	4	0	4	4	3	46
	2	4	4	4	3	4	3	4	4	4	3	4	3	4	48
	3	4	4	4	2	4	4	4	4	4	4	4	2	4	48
	4	4	4	4	4	3	4	3	4	4	4	4	3	4	49
	0	4	4	4	4	4	4	4	4	4	3	4	4	4	51
	6	4	4	4	3	3	2	3	3	3	2	2	2	3	38
	7	4	4	4	4	0	4	3	4	4	4	4	3	4	46
	8	4	4	4	3	4	4	4	4	4	3	4	4	4	50
	9	3	4	4	3	2	4	3	3	2	2	2	2	4	38
	10	4	4	4	3	4	3	4	4	4	3	3	3	4	47
	11	4	4	4	4	4	3	3	4	4	3	2	3	4	46
	12	4	4	3	3	4	3	4	4	4	4	3	1	4	45
	13	4	4	3	3	2	3	3	2	3	3	4	2	2	38
	14	4	4	4	4	4	4	4	4	4	4	4	3	4	51
	15	4	4	4	4	4	4	4	4	4	4	4	4	4	52
	16	3	4	3	4	0	3	0	4	3	0	0	0	4	28
	17	3	4	0	3	4	4	2	4	4	3	3	3	4	41
	18	4	4	4	4	3	4	4	4	4	4	4	2	4	49
	19	4	4	4	4	4	4	4	4	4	4	4	3	4	51
	20	3	4	4	4	4	4	3	3	4	4	4	3	4	48
	21	4	4	4	4	4	4	4	3	4	4	4	3	3	49
	22	4	4	4	4	4	4	4	4	4	3	3	3	4	49
	23	4	3	3	3	3	3	3	3	3	3	2	3	3	39
	24	4	4	4	4	4	4	3	3	4	2	0	3	4	43
	25	4	3	4	4	2	3	3	3	3	4	2	1	3	39
	26	3	4	4	4	4	4	4	4	4	4	4	3	3	49
	27	4	4	4	4	3	4	3	3	3	2	2	3	3	42
	28	4	4	3	4	3	4	2	2	4	2	3	2	2	39
	29	4	4	4	4	4	4	4	4	4	3	3	3	4	49
	30	4	4	4	4	4	4	4	4	4	4	0	0	4	44
	31	4	4	4	0	3	3	3	3	4	3	4	3	3	41
	32	4	4	4	4	4	4	4	3	4	4	4	3	4	50
	33	4	4	4	4	4	4	4	4	4	4	4	4	4	52
	34	3	4	4	3	3	4	4	4	4	4	4	3	4	48
	35	4	4	4	4	3	4	2	2	3	4	3	4	4	45
	36	4	4	4	4	1	4	4	4	2	4	4	4	4	47
	37	4	3	3	3	3	4	4	3	3	4	2	3	4	43
	38	4	3	4	4	4	4	4	4	3	4	3	2	4	47

The second table refers to average and variance of each variable (considering the formula for computing the variance of the sample) and of the variable *Sum*

	1	2	3	4	5	6	7	8	9	10	11	12	13	SUM
AVERAGE	3.84	3.87	3.74	3.55	3.29	3.71	3.42	3.55	3.66	3.24	3.11	2.74	3.68	45.39
VARIANCE	0.14	0.12	0.52	0.63	1.18	0.27	0.74	0.42	0.34	1.10	1.45	1.01	0.33	26.79

Finally, the alpha coefficient of Cronbach was calculated as the following:

$$\alpha = \frac{13}{13-1}\left[1 - \frac{8.24}{26.79}\right] = 0.7499$$