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Lean thinking in digital era: a systematic literature review and a case study

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Abstract (English Version)

In a context where companies must compete in an increasingly turbulent environment, most of them rely on Lean philosophy or on use of new technologies born with Industry 4.0 to survive and increase their productivity. Lean thinking and digitization have been successfully discussed, studied and applied in many contexts, but what are the challenges and opportunities for Lean thinking in the digital age? How does the concept of productivity change? What are the main enabling factors?

This thesis aims to investigate the relationship between these two elements, to understand if their simultaneous application within the company can bring real benefits and how it can do so. The methodology used for this study is the Systematic Literature Review, an in-depth analysis of the literature, which aims to identify, critically evaluate and integrate the results of all relevant, high-quality individual studies that address one or more research questions. Following a precise screening process of the existing literature, 150 relevant articles and publications were identified, on which the analyses were conducted.

From these analyses it is clear that Lean and new technologies can support each other positively and mutually, because Industry 4.0 technologies enhance the results of Lean practices, while the Lean philosophy implemented in the company is an excellent starting point for successful implementation of new technologies. Therefore, the digitalization and Lean principles and tools that present the greatest synergies, the ways in which business productivity is affected, the key factors for the success of this relationship, and the challenges and opportunities that a company faces to integrate these two elements have been investigated.

This theoretical analysis was completed by a case study at Cantine Quattro Valli. The project in this winery company aims to develop an innovative digital system and to use digital technologies in order to improve the management of the lifecycle of labels, following the principles of the Lean philosophy. In this project the two elements demonstrate to support each other to increase the company's productivity, acting on the reduction of waste, on the improvement of internal and external communication and working conditions of employees, and on the increase of the ability to meet customer needs

Abstract (Italian Version)

In un contesto in cui le aziende devono competere in un ambiente sempre più turbolento, la maggior parte di esse si affida alla filosofia Lean o all'uso di nuove tecnologie nate con l'Industry 4.0 per sopravvivere e incrementare la propria produttività. Il pensiero Lean e la Digitalizzazione sono stati discussi, studiati e applicati con successo in molti contesti, ma quali sono le sfide e le opportunità per il Lean thinking nell'era digitale? Come cambia il concetto di produttività? Quali sono i principali fattori abilitanti?

Questa tesi si pone l'obiettivo di indagare la relazione tra questi elementi, per capire se la loro simultanea applicazione all'interno dell'azienda può portare effettivi benefici e in che modo può farlo. La metodologia usata per questo studio è la Systematic Literature Review, ovvero un'analisi approfondita della letteratura, il cui scopo è identificare, valutare criticamente e integrare i risultati di tutti gli studi individuali rilevanti e di alta qualità che affrontano una o più domande di ricerca. A seguito di un preciso processo di screening della letteratura esistente, sono stati identificati 150 articoli e pubblicazioni rilevanti, su cui sono state condotte le analisi. Da queste analisi risulta evidente che Lean e nuove tecnologie si possono supportare positivamente e in maniera reciproca poiché le tecnologie dell'Industry 4.0 arricchiscono i risultati delle pratiche Lean, mentre la filosofia Lean implementata in azienda è un'ottima base di partenza per implementare nuove tecnologie con successo. Sono state indagate quindi le tecnologie e i principi e gli strumenti Lean che presentano maggiori sinergie, i modi in cui la produttività aziendale viene influenzata, i fattori chiave per il successo di questa relazione, le sfide e le opportunità che un'azienda deve affrontare per integrare questi due elementi. Questa analisi teorica è stata completata da un caso di studio presso l'azienda Cantine Quattro Valli. Il progetto in questa azienda vinicola ha l'obiettivo di sviluppare un sistema digitale innovativo e di utilizzare tecnologie digitali per migliorare la gestione del ciclo di vita delle etichette, seguendo i principi della filosofia Lean. In questo progetto i due elementi dimostrano di sostenersi a vicenda per aumentare la produttività aziendale, agendo sulla riduzione degli sprechi, sul miglioramento della comunicazione interna ed esterna e delle condizioni di lavoro dei dipendenti, e sull'aumento della capacità di soddisfare le esigenze del cliente.

Executive Summary

This thesis aims to deeply examine the relationship between Lean thinking and Digitalization, (represented by Industry 4.0), two fundamental concepts for the present and the future of industrialization. The integration and simultaneous application of these two concepts, which have been present in most companies for years, is subject of increasing attention and studies. However, the benefits and opportunities created by a simultaneous integration between Lean and Digital technologies have not been clarified, as well as the factors that favour this integration or the difficulties that companies may encounter. Trying to clarify these questions, the thesis makes use of a method, the systematic literature review (SRL). A SLR is an important research process that uses a pre-planned research strategy and not simply a review of previous research. This type of review aims to respond to specific research questions, build on existing studies, select and evaluate contributions, analyse and synthesize data, and report the evidence in such a way that allows the researcher to draw their own conclusions about what is known and unknown. The aim of the SRL is to provide an overview, synthesis and a critical assessment of previous research, challenge existing knowledge and identify and define novel research problems and research questions.

The first section of this work presents an introduction to the Lean thinking concepts that will be discussed, as well as the main lean practices and lean tools that will be recalled in the analysis. This introduction also mentions the reasons why the literature of recent years tends to combine these two elements.

The second section instead introduces the second element of study, Digitalization and Industry 4.0, highlighting the technologies behind the fourth industrial revolution, which are mentioned in the SRL. Among them stand out the Internet of Things and Cyber-Physical Systems, which are the basis of modern technologies, together with Big Data analysis and Cloud Computing.

In the third section is described the methodology of the systematic literature review and the fact that this SRL consists of two phases: first the research of the papers that will then be analysed, identified through a precise search process; then, through a bibliometric analysis, the data in the papers have been analysed with statistical methods to reach conclusions regarding the abovementioned objectives.

The search process in turn consists of four phases: 1) Selection of database, 2) Definition of keywords, 3) Articles Selection, 4) Bibliometric analysis.
The total number of documents selected e deeply analysed was 190. Subsequently, a second Screening phase was performed: All 190 papers were fully read to allow excluding the ones that were not aligned with the research topic. In total, 40 papers were disregarded resulting in a final bibliographic portfolio of 150 papers.
In the fourth section is presented the analysis of the papers, which is the heart of the thesis. The analysis was divided into two categories: basic (or bibliometric) and advanced variables. The basic variables analysed were: number of publications per year; countries where studies occurred; type of publication; methodology used in the study, authorship and co-authorship. With regards to the analysis of the advanced variables, the starting point is the analysis of the Keywords, while the other variables analysed are: the trends evident in the papers about the relationship between Lean and Digitalization; the Lean practices and the Industry 4.0 Technologies more cited and treated in the studies; how the improvement in productivity is reached by the two practices; what are the challenges in the integration.
From the analysis, first of all, result three well-defined trends: some authors (74) claim that Lean and Digitalization mutually support each other, improving their performance reciprocally, thus leading to an overall increase in productivity. A second part of papers (82), on the other hand, states that it is almost exclusively digitalisation, through industry 4.0 technologies, which improves the effectiveness and use of lean practices. Finally, a third part of authors (33) argues that lean practices are the foundation for the implementation of industry 4.0 technologies.
Regarding the first point, authors highlights that the methods of lean management use simplification and standardization in order to make complexity manageable prevalently at the expense of flexibility, while Digitalization has the ability to oppose this deficit. Digitalization, in turn, should be applied when lean principles are carried out and manufacturing processes are geared to each other. Moreover, some authors demonstrated that companies with higher levels of lean and digital maturity tend to perform better, have a better organizational culture, and have a better continuous Improvement process in place, enabling superior performance compared to a standalone implementation of lean or digital technologies.

The second trend, supported by most of the authors, is based on the assumption that in this mutual relationship it is mainly or only the use of Industry 4.0 technologies to improve the lean practices in the company. The technologies, if aligned with lean principles and concepts can, indeed, reduce non-value adding activities in organizations, improve the decision-making process, as well as, improving workers satisfaction. Moreover, the availability of up-to-date, high quality data increases transparency and facilitates the identification of waste. Furthermore, digitalization allows a higher degree of flexibility regarding to customer requirement (e.g., by enabling product customization or last-minute order changes).

The third trend identified refers to the authors who argue that having Lean in the company is essential to lay the foundations for the proper implementation of industry 4.0 technologies. Several authors indeed, sustain the theory that lean principles simplify the data collection required for digital projects by having streamlined processes, which can reduce the time to integrate digital solutions. Lean thinking moreover ensures a permanent focus on customer value and waste elimination, which facilitates the identification of technologies that support these objectives. In general, Lean is considered a facilitator of Digital implementation because it trains people as thinkers, simplifies processes and reduces/eliminates wastes so that they are not automated, reduces the possibility of compromising scarce resources, increases the transparency of work processes and organization.

Other trends identified in numerous publications regard: the reduction of wastes as consequence of the integration of the two paradigms (52 papers); the positive correlation between the use simulation and the lean thinking; the positive influence of new technologies on Value Stream Mapping. Regarding the first point, considering the effect of digitalization on lean, it is clear that different parts of the Industry 4.0 technologies have a positive impact on different types of waste in Lean Manufacturing, acting on all eight types of wastes. On the second point, 28 articles treat the use of simulation alongside with lean practices and lean thinking. Is showed that adding simulation into the Lean toolbox can strengthen, besides others, some of the main drawbacks of lean such as not considering variation, lack of dynamicity and the incapability of Lean standard tools of evaluating complex non-existing processes before implementation. Finally, 24 papers express the positive correlation between digitalization and Value Stream Mapping, highlighting that the main benefit of “VSM 4.0” is the improvement in transparency through a real-time display of value streams.

Following, a further analysis has been made in order to understand which are the most important and significant Lean practices and technologies of the industry 4.0, within the interaction between the two topics. In fact, for each article, it has been indicated which Lean practices and Technologies have been the subject of study. The reasons why these lean tools and new technologies are mentioned more often or less often have been explained in detail, as well as some direct applications of Lean and Digital integration have been presented.

Finally, have been investigated the possible productivity improvements given by the interaction between lean philosophy and modern technologies, the key factors enabling the successful implementation of the two, and the challenges that companies can face.

Analysing the improvements, identification and reduction of wastes is the most diffused. The reduction of waste is one of the main objectives of lean thinking, therefore digitalization, in its role of supporter of lean practices, get first of all to reduce wastes. The consequence on productivity is obvious, as this process allows company not to automate waste, improving the entire production process, increasing efficiency and reducing costs. Another important improvement is the improvement of decision-making process (14 authors), especially thanks to the integration of Simulation with VSM and lean tools in general. Moreover, the Real-time monitoring system enabled by IoT, Sensors and Cyber Physical Systems accelerates the data collection processes, leading to optimize the decision-making process. Another important improvement regards the WIP, lead time and inventory reduction (11 papers); Finally a very important improvement factor regards the human resources, since in the papers analysed lot of improvements regard better working condition and employee engagement, enhanced human capabilities and employees skills, better use of human resources and training, enhanced human machine cooperation. Actually, smart feedback devices, worker support systems and improved man-machine interface facilitates better empowerment and involvement of employees in the organisation.

Regarding Key factors influencing the successful integration between Lean philosophy and Digital world, human resource commitment and integration is identified by most papers to be fundamental. The employee indeed becomes the smart operator of production, able to use the connectivity offered by the network created by Iot and CPS to improve its performance of flexibility, efficiency and knowledge, but keeping as a guide the lean principles of team-work organization, multi-skill, high responsibility for work within their areas. As consequence, the training of the people who work in Industry 4.0 will be fundamental to succeed in the necessary cultural adaptation in this new environment, where man will work in a digital environment. In addition to human factor, Organisational culture and Leadership commitment are considered notable key factors, because the changes in the technologies just by themselves will not aid any gain in productivity, an organizational change will be needed to support the use of the new technologies included by Industry 4.0. Customer centricity and involvement is also considered a key factor by various authors. Is possible to affirm that in the integration of lean and digitalization will remain the concept stating that the customer is always right. Subsequently, the focused customer orientation of lean think will stay essential, or even become more important, in the time of digitalization.

Regarding the challenges, In addition to human factor, that is identified by the authors as a critical point in the company for the implementation of both Lean management and new Digital technologies, the lack of open innovation culture and lack of flexible organizational culture are other specific characteristics that hinders this transformation. Therefore, management needs a long-term holistic transformation plan of above-mentioned dimensions.

In the sixth section, to give an empirical value to some of the results achieved by the SRL, a case study in the winery Cantine Quattro Valli was analysed. The project’s aim is to develop an innovative digital system and to make use of digital technologies in order to improve the management of the life cycle of labels, a component of great importance for the oenological product. Thanks to Mural, a collaborative online platform, and thanks to the use of online calls using Teams, it has been mapped the process of labels’ lifecycle, with the collaboration of all actors. From this it was possible to understand what are the critical issues and the causes of recirculation in performing activities. Following, always thanks to the proposals and the help of the employees, various solutions have been conceived and chosen. This is an example of a process mapping and identification of wastes with a lean vision, enabled by use of digitalization. The solution ideated and chosen, that will be implemented during the following months, have been explained in detail, as well as the issues that they address. These solutions, made possible by the use of basic digital technologies, have been designed following lean thinking principles, with the aim to reduce waste, improve communication with customer and supplier, reduce non value added activities and lead times, increase internal communication and teamwork. In addition, the fact that these solutions solve problems proposed by employees and have been partly proposed and chosen by employees themselves, perfectly follows the lean principle of respect for people.

In general, it was possible to see from this case study how the principles of lean thinking can be applied with the help of digital technologies. In this project the two elements support each other to increase business productivity, acting on reducing waste (both related to time and inventory), improving internal and external communication and employee working conditions, and increasing the ability to fulfil client requirements.

1. Introduction

The industrial foundation of this study is to understand the importance of the lean philosophy and of the increasing digitalization within companies, trying to identify the opportunities that can be achieved by bringing the two concepts together. Lean thinking is still, after 30 years, the most powerful philosophy to optimize operations throughout the entire manufacturing enterprise, while Industry 4.0, of more recent origin, has revolutionized business productivity through the use of innovative technologies and is constantly expanding. Both concepts are widely used in modern companies and it's easy to think that they will be increasingly so in future. Hence arises the need to understand how they can be integrated simultaneously in a company, whether they can support each other, and how far they can cooperate, going to affect business performance. There is also the necessity, indeed, to understand how productivity can be improved by this relationship, understanding what factors are affected; in this context, it is also necessary to understand what will be the role of human resources in a future company where are present, in various forms, both Lean and Digitalization.

1.1 Lean thinking in digital era

Today, consciously or not, industries have to compete in a data-driven world, where the volume of available data is continuously increasing thanks to the development of technologies such as digital platforms, sensors, mobile phones, etc. In this context, the range of applications and opportunities has grown exponentially, provided that industries are able to capture data intrinsic value. The big challenge is ensuring that users get the most from the data, using it to increase the probability of making the right decisions, in the right context and for the right reasons. Indeed most companies are capturing only a fraction of the potential value of data and analytics and the biggest barriers companies face in extracting value from data are organizational, since companies struggle daily to incorporate data-driven insights into day-to-day business processes. [1]

Moreover, In the current turbulent world, it is necessary to react quickly and to see the competitiveness of the business in its customized products and services. The application of digital engineering techniques and technology to industrial practice creates the prerequisites for gaining market leadership and ensuring long-term sustainability for the future. [2]
The capability to manufacture individual and personalized products is another key for success in a globalized and digitally connected world. The high customer expectations lead to an increase in variant diversity and intensify the complexity of the production environment. One solution to this issue that reduces complexity within the industrial area is the Lean thinking or Toyota Production System (TPS). This production philosophy developed by the Toyota Motor Corporation in the last century aims to reduce waste in the value chain in order to minimize lead time. By applying this ideology and permanently focusing on customer value in a continuous improvement process, Toyota was able to gain a world leading position in the automotive industry. Nowadays, the TPS is well known as lean management (LM) or lean manufacturing and widely deployed as a standard in various industries. Another possibility to handle the increasing complexity in manufacturing is given by the relatively new research field Industry 4.0 (I4.0). It aims to improve transparency through the digital linkage of each element involved in the production. It is based on cyber-physical systems (CPS) which organize the value creation process by themselves. Another key feature of Industry 4.0 is the realization of an internet of things (IoT) which allows a worldwide data communication in real time. Both production paradigms are promising to solve future challenges in manufacturing. [3]
These two concepts therefore, although with different origins and moments of appearance, seek the same: to reduce costs and to increase productivity for companies. Lean Thinking prefers to focus on waste reduction, while I4.0 focuses on the use of new technologies powered by IoT. Although with different approaches, they can be complementary, since the implementation of Lean will encourage a company to promote thinkers who will be fundamental in implementing the changes required by I4.0. [4]

Before now, companies have often used Lean Management methods to increase the productivity in value-added processes and to optimize the organization. It can generally be considered as an organizational-personal approach which pursues an increase in value through organizational changes and active employee engagement, and attempts to do so by means of continuous employee development.

On the contrary, Industry 4.0 represents a technology-driven approach and represents the networking of the real world and the cyber world. As can be seen, the differences between Industry 4.0 and lean management are enormous, since they are fundamentally different approaches. But at the same time the shared goal, an increasing added value, is identical. At this point, the question arises as to whether the two approaches can be combined and, if so, how?

Historically, lean manufacturers have been intentionally slow to introduce new technology and IT systems. Instead, the lean philosophy focuses on human learning, with the purpose of “developing every employee into a scientist” who can continuously improve the work processes that have been tested and proven in the past. Although digitalizing manufacturing processes allow for much better and accurate data collection, in near real time it risks to alienate the human being from the problem-solving process and, thereby, reduces the ability to innovate. Lean management emphasizes the reduction of complexity, leveled flow, visual control, and standardization as enablers for process innovation. Digitalization, in contrast, enables the handling of high complexity in manufacturing processes. Scholars and practitioners still struggle to understand how the two paradigms of lean and digitalization influence each other. It is still a question of how digitalization and lean will coexist in the future. [5]

In few words, Lean thinking and digitalization have been discussed, studied and successfully applied in many contexts, but which are the challenges for Lean thinking in the digital Era? How the concept of productivity change? Which are the main enablers?

The aim of this work is to merge these two concepts answering to the abovementioned research questions.

1.2 Lean Thinking

Lean thinking or management is one of the most widely used business strategies in the last three decades.[6]

Before entering into Lean Thinking effectively, a brief introduction outlines the history and reasons for this line of thought, as well as why it is so fundamental within business. The Lean philosophy emerged in Toyota company, Japan, in 1940s, after the WorldWar II. Japan, a country that had been devastated by the war and companies were at a much lower stage compared to the factories in the United States. However, unlike American factories, the Toyota Production System (TPS) model was based on the fact that only a small percentage of the time and effort was employed in order to add value to the product. It was in the early 1990s that Lean philosophy began to expand out of Japan. The main and first written book on the methodology employed at Toyota, comparing it with North American production lines was “The Machine that Changed the World” (Womack et al. 1990).

The use of the Lean philosophy is intrinsically linked to the reduction of waste; however, the philosophy is something that goes beyond this. The principles of the Lean philosophy serve to identify among all the activities of the process, those that add and those that do not add value to the final product, aiming to reduce or, even, eliminate activities that do not add value. The philosophy is based on production according to customer demand, which is called pull production, always having as main goal the continuous improvement of production, in order to reduce activities that increase the monetary value, but do not aggregate in quality or are not essential within the manufacturing. The current and increasingly competitive market has led most companies to adopt Lean Production tools in order to minimize production costs and thus increase profitability.[7]

Nowadays, Lean thinking is still the most powerful philosophy to optimize operations throughout the entire manufacturing enterprise, focusing on continuous process improvements driven by customer demand, on rooting out production inefficiencies and engaging all the employees in the application of lean principles and actions like value creation, waste elimination, respect for people and continuous improvement. Specific attention should be paid to product and process development where lean thinking promotes the creation, use and reuse of knowledge for learning purposes.

The lean principles of doing what is needed, how it is needed, when it is needed seem to translate here into enabling a system to provide the information that is needed, when it is needed, where it is needed, and in the right format (how it is needed).[1]

Lean 5 Principles

In literature, numerous approaches explain lean management by different “principles”, “guidelines”, or “rules”. Based on the values of the Toyota Production System, Womack & Jones derive five general principles: (a) value, (b) value stream, (c) flow, (d) pull, (e) perfection. These can be supplemented by the principle (f) Respect for People, which the founders of the Toyota Way regard as a fundamental basis for a trusting cooperation of all employees.

(a) Value: according to Womack & Jones, the definition of value must always be made from the customer's point of view. All customer requirements must be satisfied.

(b) Value Stream: the value stream comprises all steps that are necessary for a product’s creation, from customer order to delivery. The identification of the value stream significantly increases the understanding of the process and hence, helps to disclose problems that previously were undetected.

(c) Flow: the flow principle fundamentally fulfils the Toyota Production System's guiding principle of customer orientation by shortening the time from order entry to delivery with clear value stream based production layout.

(d) Pull: the Pull Principle implies on-demand service delivery. Customer orders trigger manufacturing processes.

(e) Perfection: perfection through continuous improvement (kaizen) is the guiding principle of lean thinking and is therefore the core of lean management. The prerequisite for continuous improvement in small steps (Kaizen) is the existence of standardized, stable and transparent processes.

(f) People & Teamwork: respect for the employees is a central aspect of the lean philosophy. By focus on teamwork, the available potential of employees is developed. [8]

Eight wastes

The greatest enemy of competitiveness is waste, typically of time, money and resources (materials). In manufacturing, waste is any expense or effort that does not transform raw materials into an item the customer is willing to pay for, so 'value' from the perspective of the customer. The Lean philosophy basically distinguishes the 3 MUs, namely the fluctuation (Mura), the overload (Muri) and the 8 essential wastes (Muda). We can state that the muri and the muda can result in all cases muda, therefore a lot of literature speaks only from the muda's elimination. [9]

There are generally considered to be eight types of waste in Lean Manufacturing. The first seven of these eight identified wastes being production process oriented,

- Defects: Repair or rework of a product or service to fulfill customer requirements.
- Over-Production: Producing more than is needed, faster than needed or before needed.
- Transportation: Any material movement that does not directly support immediate production.
- Wait-time: Idle time that occurs when co-dependent events are not synchronized.
- Inventory: Any supply in excess of process or demand requirements.
- Motion: Any movement of people which does not contribute added value to the product or service.
- Processing: Redundant effort (production or communication) which adds no value to a product or service.
- Unused Employee Creativity: Losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to your employees.

Essentially this is the waste of the talent of those directly employed and is related to management's ability to utilize personnel (and was originally considered by Ohno) but has been better understood more recently.

The idea behind Lean production stems from seeking to eliminate waste or Muda, so any activity which involves wasted effort, materials and time at every stage in the supply through the design of, and constant improvement to the manufacturing system. [10]

1.3 Lean Practices and tools

Employees influence the organization culture by means of their practices thereby each organization possess its own characteristics and dimensions. Thus, LM tools and practices are influenced by the organizational culture and varies between different business contexts. This diversity led to creation of different versions of lean Models. To provide a common and widely accepted source, the Toyota Production System Lean House was chosen as it is the base for LM tools and techniques in practice. [11]

Based on the TPS-House, the following Lean practices have been selected as the most representatives and used in production.

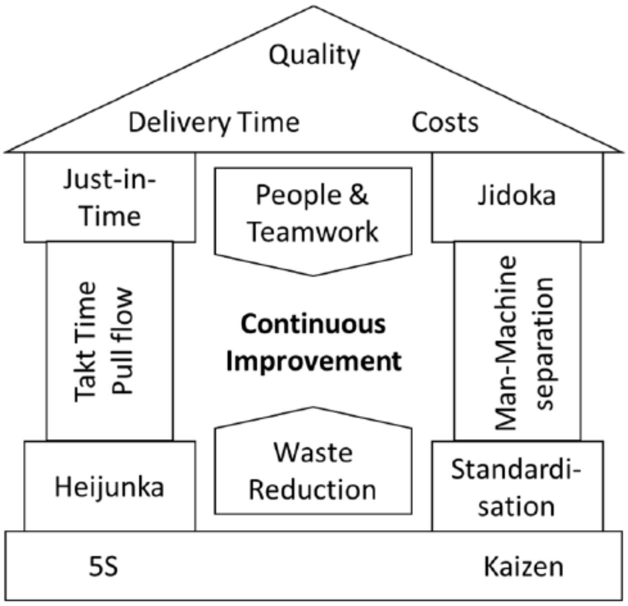

Figure 1: TPS-House

- Continuous improvement / Kaizen: The philosophy of the continuous improvement (CI) process aims at improving process stability and performance whilst increasing employees' competencies at the same time[12]. The CI process for lean implementation and assessment can be divided into four steps: problem identification, lean implementation, leanness assessment and report preparation. [13]

- Heijunka and production planning: The objective of heijunka is to level the production program to a constant rate. By solely producing the customer demand, waste in the form of overproduction is reduced.
- Jidoka / Autonomation: Jidoka means automation with human touch. It describes a set of automation systems' design principles that aim to separate human activity from machine cycles in order to allow a human operator to attend multiple-machines, preferably in different types of working in sequence**.**[14]
- Just-in-time (JIT): A system where a customer initiates demand, and the demand is then transmitted backward from the final assembly all the way to raw material, thus ‘‘pulling’’ all requirements just when they are required
- Andon: can be defined as a ‘Sign’ or ‘Signal’ that provides visual management aid when highlighting an issue, as it occurs, which helps to introduce countermeasures immediately so as to avoid re-occurrence
- Kanban: Kanban is a tool for pull production system that manages the movement of materials from one operation to another, by using a kanban card or a digital kanban signal. Each kanban signal is a manufacturing order for a specific product and It triggers the performing of a work only when it is necessary.[15]. Is a signaling system for implementing JIT production.
- VSM: is a visual representation of processes within a pathway and can be considered as a visual map of all the activities, illustrating how they linked to each other, and information such as timing and resources. It aims identifying all the value-added and non-value-added (waste) activities, as an opportunity to remove non-value-add steps and eliminate waste through problem solving, to standardise and improve value-added processes but mainly to eliminate waste. [16]
- Total quality management (TQM): A system of continuous improvement employing participative management that is centred on the needs of customers. Key components are employee involvement and training, problem-solving teams, statistical methods, long-term goals, and recognition that inefficiencies are produced by the system, not people.

- Lean Six Sigma: Lean Six Sigma is a managerial concept that combines the Lean production philosophy and the quality management program, Six Sigma, a program that aims to eliminate eight types of waste/ muda and an 'increased performance capacity. The term "Six Sigma" is statistically based on the supply of goods and services at the highest level.
- Total Productive/Preventive Maintenance (TPM): Workers carry out regular equipment maintenance to detect any anomalies. The focus is changed from fixing breakdowns to preventing them. Since operators are the closest to the machines, they are included in maintenance and monitoring activities in order to prevent and provide warning of malfunctions.
- Poka yoke: literally means "Mistake proofing", is a simple technique that developed out of the Toyota Production system through Jidoka and Autonomation. It is normally a simple and often inexpensive device that prevents defects from being made or highlights a defect so that it is not passed to the next operation.
- SMED: Changing the production sequence from one product to another requires usually significant time for machines setup. SMED arises from the need to have a Quick Changeover. This procedure consists in converting as much as possible the IED (Inside Exchange of Die) in OED (Outside Exchange of Die), practically minimizing setup activities that require downtimes.[17]
- 5S: Focuses on effective work place organization and standardized work procedures.[18]
- Cellular manufacturing: Organizes the entire process for a particular product or similar products into a group (or ''cell''), including all the necessary machines, equipment and operators. Resources within cells are arranged to easily facilitate all operations.

To conclude, generally the characteristics of the organization where lean production has been implemented, can be as follows:

- Team-work organization performed by operators who are flexible, multi-skilled and their responsibility for work within their areas is high.
- Active shopfloor problem-solving structures, central to kaizen or continuous improvement activities.

- Lean manufacturing operations, where problems are exposed and corrected by low inventories, quality management, prevention rather than detection and correction, small number of direct workers and small batch, just in time production.
- High commitment of human resource policies emphasizing a shared destiny within the organization.
- Closer relations with suppliers.
- Cross-functional development teams.
- Retailing and distribution channels liable for close links to customers.[19]

1.4 Thesis' structure

The thesis is structured in this way: section 2 is a background that introduces the concepts related to digitalization and industry 4.0, which together with lean thinking are the basis of this study. Section 3 presents the research designs, objectives and methodologies used, in particular it presents a description of the main method used, the Systematic Literature Review, and describes in detail the search process used to select the papers that will be the subject of the research.

Section 4 exposes the bibliometric analysis, with the real analysis of the papers, expressed through basic variables and advanced variables. In this phase the trends and the main results regarding the analysis of the integration between lean thinking and digitalization are expressed.

Section 5 is a discussion which summarises the findings of the analysis of the study objective in question; in this section conclusions and suggestions for future study are drawn.

Section 6 presents a case study in a winery company, Cantine Quattro Valli. The project aims to develop an innovative digital system to improve the management of the life cycle of labels, a component of great importance for the oenological product. The case study aims to demonstrate the positive effect of digitalization on the reduction of wastes and inefficiencies, as well as demonstrating the possible increase in productivity due to integration of digitalization and lean thinking.

Section 7 presents the final discussion with the conclusions reached.

2. Background: Digitalization and Industry 4.0

What is digitalization in the context of manufacturing? Besides being a technological trend digitalization is an approach to react to rising dynamization and complexity with digital technologies. Manufacturing companies seek to generate high quality goods with the aim of low cost and less time. Digitalization offers tremendous potential regarding the improvement of quality, flexibility and productivity. It represents a new level of organization and control in manufacturing landscapes by using digital technologies. Relevant information needs to be available at any time in order to deduce an optimal value flow for producing individualized products down to batch size one. The use of such real time information enables to conjunct objects, systems and humans in order to provide dynamic and self-organizing digital production systems, which can be optimized regarding costs, efficiency or resources.[20]

Over the last years, the global industrial landscape has deeply changed due to the emergence of several disruptive technologies that have resulted from successive developments and innovations. Consequently, with growing advancements in manufacturing processes, the Industry 4.0 concept has emerged, becoming an increasingly relevant global topic in the last few years. [21]

This term has been coined at the 2011 Hannover Fair by Siegfried Dais (Robert Bosch GmbH) and Henning Kagermann (Acatech) and it represents a politically established target for the production industry, intending to apply the principles of Cyber-Physical Systems (CPS), internet and future-oriented technologies and smart systems, with enhanced human-machine interaction paradigms.

The technological basis for the Industry 4.0 is the Internet of Things (IoT), first proposed in 1999 by the MIT. In IoT, physical objects (i.e. the "things") are remotely sensed and controlled for a tighter integration between the physical and digital worlds, creating networks of “things” able to autonomously collect and flow data to other objects through the internet thanks to an embedded connectivity at electronic and software level.[1]

Moreover, this new industrial paradigm will bring together the digital and physical worlds through the use of CPS technology, allowing the improvement of productivity and efficiency among the companies that are adopting this new manufacturing paradigm.[21]

Thus, the concept of Industry 4.0 can be perceived as a strategy for being competitive in the future. It is focused on the optimization of value chains due to autonomously controlled and dynamic production. It covers the design and implementation of competitive products and services, the administrative powerful and flexible logistics and production systems.[19]

According to the results of a study “Industry 4.0” published by the Fraunhofer Institute, it is possible to indicate three future-relevant themes related to it such as: dealing with complexity, capacity for innovation and flexibility.

Moreover, it is possible to derive six design principles from its components: interoperability, virtualization, decentralization, real-time capability, service orientation and modularity. Interoperability ensures the connection and communication between physical components, humans and Smart Factories, whereas virtualization is realized as virtual copy of physical objects.[19]

2.1 Three paradigms

The Industry 4.0 can be further described by three paradigms: the *Smart Product*, the *Smart Machine* and the *Augmented Operator*.

The main idea of the *Smart Product* is to change the role of the work piece from a passive to an active part of the system. In such a system the products have a memory to store operational data and requirements individually and are able to request for the required resources and coordinates the production processes for its completion.

In the paradigm of the *Smart Machine* a traditional production hierarchy is replaced by descriptions allow to communicate the autonomic components and local control intelligence communicates with other devices, production modules and products what makes the production line flexible and modular.

Finally, the *Augmented Operator* addresses the automation of knowledge which makes it the most flexible and adaptive part in the production system. Such a worker is supposed to be faced with a large variety of jobs such as specification, monitoring and verification of production strategies. In the same time he may manually interfere in the autonomously organized production system. [19]

2.2 Horizontal, Vertical, End-to-end engineering integration

Three types of integration can lead industry 4.0's goals: (1) horizontal integration making interconnected collaborations, (2) Vertical integration inside the production plant and (3) end to end engineering integration in entire chain to support product improvement. The corporative integration and inside factory collaboration are the pillars for end to end engineering integration.

Horizontal integration: Horizontal integration refers to a generation of value-creation networks involving integration of different agents such as business partners and clients, and business and cooperation models. [19] An efficient eco system could be created for the different organizations, in which information, material can be shared. Hence, new business models can be merge.

Vertical integration: A production plant has several systems which could be physical or virtual (information). All the systems or subsystems driven and controlled by a set of actuators, sensors, production and organizational planning need to be integrated across different levels of the plant till ERP. It makes production much configurable and flexible. The machines can make a self-organized system, which make it possible to reconfigurable for much diverse product. The sharing of information among all actors will make the system much transparent and accusable.

End to end engineering integration: A production plant, where all the processes are converged to develop, redesign, market demand, maintenance, producing and reengineering. It makes it essential that, all the processes need to be inter-connected for future use in product design. [22]

The manufacture enabled for the IoT refers to an advanced principle in which typical production resources are converted to the manufacture of intelligent objects capable of detecting, interconnecting and interacting with one another to automatically and adaptive manufacturing logic.

2.3 Technology Enablers in Industry 4.0

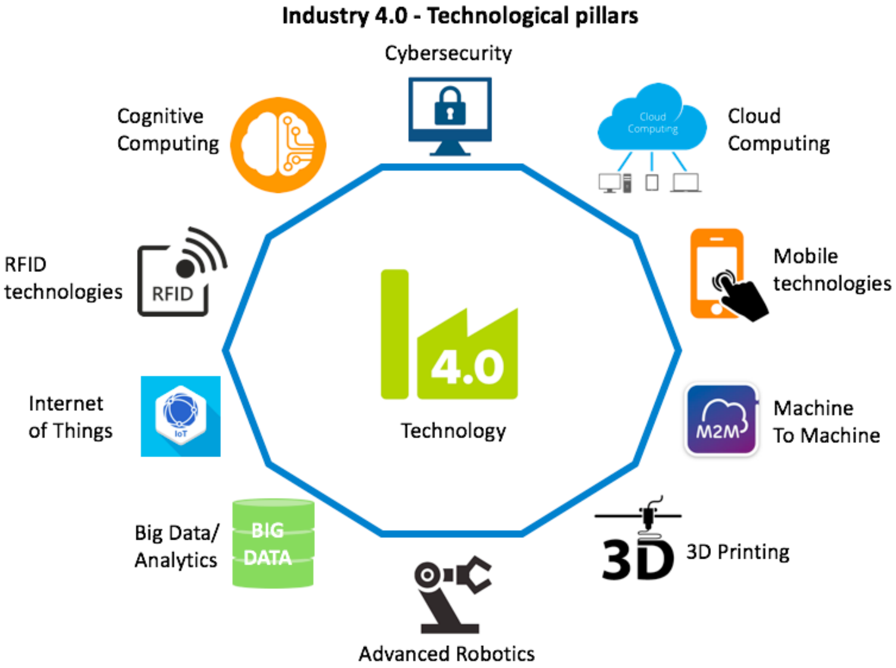

Figure 2: Technologies for Industry 4.0

The Industry 4.0 is the union of several technologies that allow seamless integration between physical space and virtual space. The virtual space will use information collected directly from the physical space, through sensors.

Cyber-Physical Systems (CPS): The CPS refers to a new generation of systems that enables the integration of computational and physical capacities with human ones[23]. CPS corresponds to the union of the physical and digital environment, and can be defined as the integration of physical processes with computing, where physical processes are controlled and monitored by computers and embedded networks.

The CPS is developed any three phases, first generation when RFID was introduced, gives us much faster and accurate identification, kept stored by centralized memory service. Second generation when sensors and actuators are made available. Third generation was more towards data storage and analysing it [22].

Internet of Things (IoT): refers to the integration and connectivity between machines, devices, humans and resources through a network of sensors and software for industrial and operations purposes. What differentiates IoT from machine to machine (M2M) is that in IoT this communication is intelligent and autonomous, enabling systems to feel, decide and act. The manufacture enabled for the IoT refers to an advanced principle in which typical production resources are converted to the manufacture of intelligent objects capable of detecting, interconnecting and interacting with one another to automatically and adaptive manufacturing logic.

IoT and CPS technologies have enabled unprecedented industry integration, with CPS as the backbone for IoT implementation.

As a result, manufacturing control systems have become capable of processing a large amount of data, information, and knowledge in real time, taking these systems from an intensive information model to an intensive knowledge model [23].

Sensors: Sensors are essential devices for the existence of IoT, as they allow the digitization of the physical aspects inherent to each system. These have evolved from basic sensors to intelligent sensors, causing a revolution in how these physical aspects are collected, analyzed and distributed to intelligent systems [23]

Big Data: The big data become an integral part of the manufacturing paradigm recently. It can optimize the service quality as well as production quality, greener as energy savings. The big data is helpful in case of making real time decisions in the whole production management since it stores a set of comprehensive evaluated data and its easy to go through it for any solution in future.[22] Big Data allows us to quickly and efficiently manage and use a constantly growing database and would be applied to provide the necessary database and required performance.

Cloud Computing (CC): Cloud systems allow for a shared platform of diversified Supply Chain, where exploit demand access, creating efficiency, optimizing resource allocation in response to different customer demands. Therefore, the characteristics of cloud-based systems generate agile, unlimited access by shared information through partners, virtualization, resource pooling
and everything as service[24]. The reaction time in cloud computing is changed to milliseconds, hence the machine data can fly through number of systems, enabling faster services for the data driven production systems. Different suppliers also have implemented cloud with their customer's companies in order to perform much better services [22].

Augmented Reality: Augmented Reality (AR) technology derived from the interaction of human and computer as wearable devices as well as the regular interaction such as voice, gestures, tactile and visual. Augmented Reality technology is based on the relevant information provided by the smart components attached to human. The performed tasks are visualized and animations overlaid on demonstrator. By using this technology, the time is utilized by reducing wasteful activities; by doing so, tasks could be performed with minimum errors, enhancing maintenance efficiency and less time required to achieve the same tasks of maintenance. [24]

Additive Manufacturing: Additive manufacturing technology, mostly known as 3D printing, allows for value creation processes and business models of Supply Chains based on customer centric logic. 3D machines are simply conducted in optimizing the production layouts and offering process accuracy.

Autonomous Robots: They are robots which can performs behaviours or tasks with a high degree of autonomy (without external influence). Autonomous robots collaborate with humans in a working environment due to the ease of the tasks, reducing human errors and implement the efficiencies in process flow.[24]

Thus, the concept of Industry 4.0 can be perceived as a strategy for being competitive in the future. It is focused on the optimization of value chains due to autonomously controlled and dynamic production. It covers the design and implementation of competitive products and services, the administrative powerful and flexible logistics and production systems". In order to achieve the increased automation, the technological concepts of Cyber Physical Systems (CPS) can be used to work autonomously and interact with their production environment via microcontroller, actuators, sensors and a communication interface.

According to the results of a study "Industry 4.0" published by the Fraunhofer Institute, it is possible to indicate three future-relevant themes related to it such as: dealing with complexity, capacity for innovation and flexibility.

3. Research design, objectives, methodologies

The present study aims to deeply examine the relationship between Lean thinking and Digitalisation, (represented by Industry 4.0), two fundamental concepts for the present and the future of industrialization.

The objective is to understand how data, analytic tools and any form of digitalisation could support lean thinking (and vice versa), in order to ultimately deliver customer value centric products, by fulfilling customer requirements and increasing industry productivity.[1].

As a first contribution to such a debate, this work starts the illustration of the current research status on lean thinking and Industry 4.0, through a Systematic Literature Review, in order to provide an overview, synthesis and a critical assessment of previous research, challenge existing knowledge and identify and define novel research problems and research questions. The findings of the systematic literature review are supported by a case study, which presents a direct application of digitalisation and lean thinking to improve the productivity and the working conditions in a company.

The relationship between lean and digitalization (industry 4.0 in particular) has been addressed many times in the literature, being two topics of great importance in the current industrial landscape. Therefore, the best way to analyse this integration and arrive at useful conclusions, is to perform a Systematic Literature Review which allows to find an order in the multitude of information regarding these two subjects.

More specific objectives concern to understand if the integration between the two productive systems always brings positive results, or if instead there are some challenges and issues that the companies must face; this work also aims to investigate how corporate productivity is increased by this relationship, and which role have human resources in this change.

3.1 Systematic literature review

A systematic literature review (SLR) is the research methodology used to explore the literature relating Lean thinking and Industry 4.0 and the interaction between both systems.

A SLR is an important research process that uses a pre-planned research strategy and not simply a review of previous research. This type of review aims to respond to specific research questions, build on existing studies, select and evaluate contributions, analyse and synthesize data, and report the evidence in such a way that allows the researcher to draw their own conclusions about what is known and unknown [4]. By bringing together the results of different studies on a specific topic, a greater understanding of the topic is also achieved, as well as a more in-depth level of conceptual or theoretical development than by any individual study.

Systematic reviews, in few words, aim at identifying, critically evaluating and integrating the findings of all relevant, high-quality individual studies addressing one or more research questions.

This SRL consists of two phases: first the research of the papers that will then be analysed, identified through a precise search process; then, through a bibliometric analysis, the data in the papers will be analysed with statistical methods to reach conclusions regarding the abovementioned objectives.

3.2 Search process

The search process consists of four phases: 1) Selection of database, 2) Definition of keywords, 3) Articles Selection, 4) Bibliometric analysis.

1) Selection of database: The first step is associated with the source's location. First of all, the database Scopus has been selected and utilized in order to find the majority of articles analysed, since Scopus is considered the largest abstract and citation database of peer-reviewed literature. Subsequently, the research has been extended using the database of Google Scholar and Web

of Science, in order to obtain almost the totality of the articles regarding the two topics.

2) Definition of keywords: Due to the purpose of this study, and following the research questions, the two most important keywords identified are “Lean” and “Digital”. These keywords have allowed to identify a great number of articles with a preliminary focus on these topics and their relationship.
Given the large number of articles identified in each database since these words are largely widespread in the literature, especially the one regarding the last 10 years, other keywords have been selected. Articles concerning the relation of lean thinking and lean production with the Industry 4.0 were retrieved through the keywords: (“Lean” or “Lean thinking” or “Lean Manufacturing” AND “Industry 4.0” or “Smart Manufacturing” or “Simulation” or “Digitalization”)

3) Articles Selection: The total number of papers resulting from the research was high: considering only the Scopus database, all the combinations of keywords have resulted in 2429 papers.
Thus, the alignment of papers with the research topic was checked according to three aspects: (i) title, (ii) keywords and (iii) abstract. Obviously, to the different combinations of keyword correspond a great number of duplications that have been discarded. After this first screening process, on the Scopus database have been selected 136 papers, while considering also Google Scholar and Web Of Science, the total number of documents selected e deeply analysed was 190. These are the papers that, considering what is evident from abstract, title, and keywords, could be relevant to the research questions and could express the relationship or the link between Lean and Digitalization. Is important to highlight that a concrete number of papers was not downloadable in any way, so have been discarded for this reason. Subsequently, a second Screening phase was performed: All 190 papers were fully read to allow excluding the ones that were not aligned with the research topic. In total, 40 papers were disregarded resulting in a final bibliographic portfolio of 150 papers. In the table below is possible to see the

screening process performed to obtain the 150 papers utilised for the analysis.

Database	**Keyword**	**Total papers**	**Papers downloadable selected by abstract and title**	**Papers after reading**
Scopus	Lean+Digital	1184	55	41
	Lean+Industry 4.0	339	41	37
	Lean+Smart manufacturing	191	20	16
	Lean+Digitalization	107	8	5
	Lean+Simulation	608	12	9
Google Scholar	Lean+Digital	200+	31	24
	Lean+Industry 4.0	200+	9	9
	Lean+Digitalization	200+	3	3
	Lean+Smart manufacturing	200+	2	0
	lean+Simulation	200+	2	2
Web Of Science	Lean+Digital	609	1	0
	Lean+Industry 4.0	201	3	3
	Lean+Smart manufacturing	99	1	0
	Lean+Digitalization	56	0	0
	Lean+Simulation	720	2	1
Total			190	150

Table 1: Screening process

4. Bibliometric Analysis

The selected papers are managed using Mendeley, while the analysis and data visualisation are carried out using MS-Excel and VOS-viewer. VOS-viewer is a tool used for the visualization of bibliographic networks based on similarities in a data set. During this phase, the data are consolidated through the analysis and interpretation of bibliometric data.

The analysis was divided into two categories: basic (or bibliometric) and advanced variables. The basic variables analysed were: number of publications per year; countries where studies occurred; type of publication; methodology used in the study, authorship and co-authorship.

With regards to the analysis of the advanced variables, the starting point is the analysis of the Keywords. The other advanced variables are: the conclusions reached in the papers about the relationship between Lean and Digitalization; the Lean practices and the Industry 4.0 Technologies treated in the studies; how the improvement in productivity is reached by the two practices; what are the challenges in the integration.

4.1 Results: Basic variables

Number of publications per year:

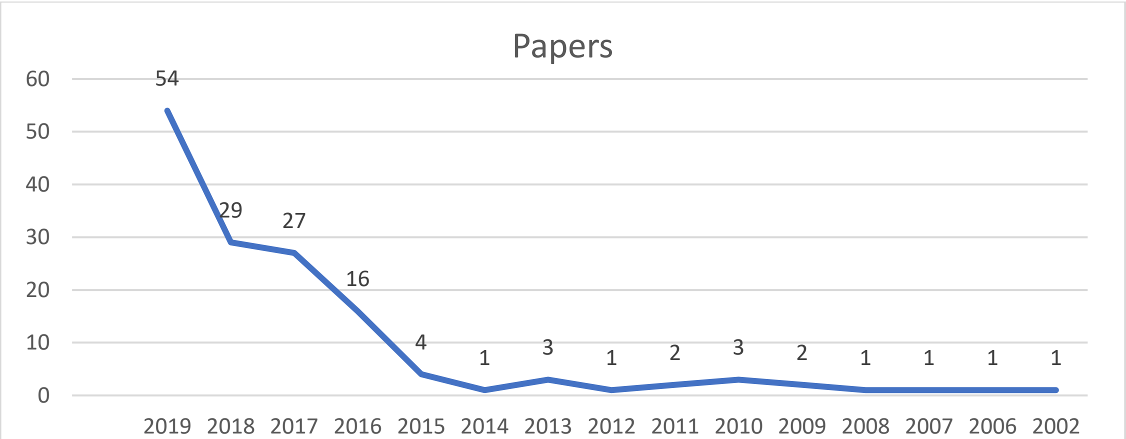

Figure 3: Number of pubblications per year

From this analysis, is notable that 90% of the papers were written between 2015 and 2020. This is strongly influenced by the fact that most of the articles are about industry 4.0, which is a recent topic and is continuously evolving especially in last years. It should be noted, however, that 114 articles out of 150 have been written in the last 4 years, following a strongly increasing trend which underlines that literature and research concerning the relationship between these two topics is strongly expanding and is the subject of increasing attention. This is a first indicator of the fact that a synergic relationship between lean and industry 4.0 could be a key element in the production of the future.

Countries

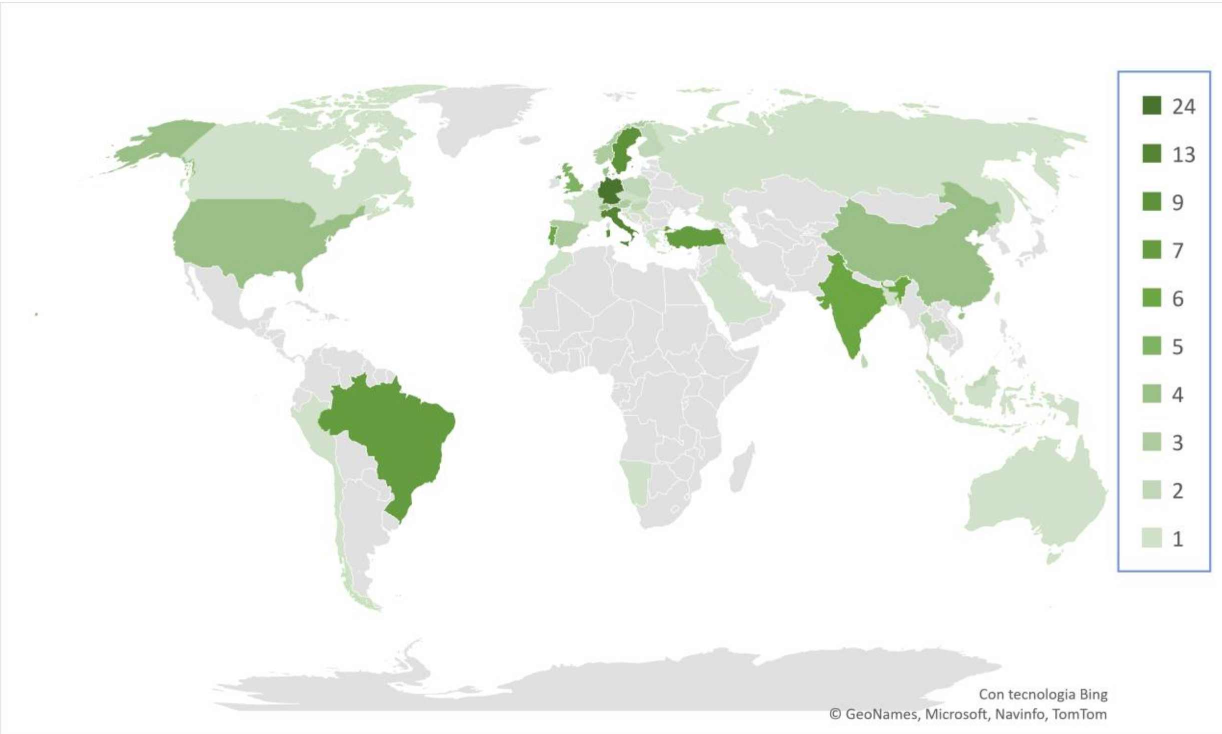

Figure 4: Countries of authors

For what concern the countries where studies occurred, is possible to see that the topic has been widespread researched among the world, since 47 different countries were involved. Germany stood out with 24 publications, corresponding to 15 percent of all the publications. Italy and Sweden presented 13 and 9 papers respectively, followed by Brazil and Turkey with 6 publications. Since Germany is the place where

I4.0 was first acknowledged, it is reasonable to expect that most publications found was developed in this country.

Is notable that 89 papers over 150 have been published in Europe, meaning that the interest about the issue in question is particularly high in our continent; as consequence, Europe in future may be the core of the development of the interaction between the two practices. Finally, it’s interesting that 14 papers are the result of collaboration between authors of different nations.

Type of publication

Among the articles selected, 87 were presented to conferences and 58 published in journals, 5 are extracted from different books, demonstrating the high scientific importance of the treated subject. The high number of Conference papers highlights the desire of researchers to interact with international audience working in the same field and to gain feedbacks. Among conference papers, 64 have been published between 2017 and 2019, stressing the increasing interest around this topic in the last years.

Methodologies in the papers

With regard the research methodologies used in the papers to study the relationship between Lean and Digitalization, considering that each paper can use several methods, in 57 publications has been used a literature review, in 13 the simulation, for 37 times has been used the case study to support the research, 59 papers provided a sort of framework to follow, and finally 23 papers made use of a survey.

Considering the papers using a literature review literature reviews, 40 papers are not supported by empirical studies. As consequence, the largest amount is mainly conceptual (70 percent of the publications); i.e., these studies simply envisioned or conceptually proposed certain relationships between I4.0 and Lean thinking, without any empirical validation. In opposition, only 30 percent of them had an empirical nature and actually verified how these relationships occurred, either through surveys with manufacturers, case studies, or action research in companies implementing both approaches.

Considering the totality of publications analysed, in 58 different papers (39 percent of the publications) has been used a case study or a survey in order to obtain

empirical validation of results achieved, while 41 percent of them remain a conceptual study. These results stress the necessity of deeper empirical studies about this topic.
However, 59 authors have proposed a sort of framework to follow. The proposed frameworks aim to provide a practical approach, at the strategic level, to interlink the method world of lean with the technology-driven vision of Industry 4.0 in order to support digital transformation initiatives.

Autorship and Co-autorship

The authorship network was analysed using VOS-viewer. The resulting co-autorship map was created using the full counting method and considering authors listed in at least two articles among the data set.

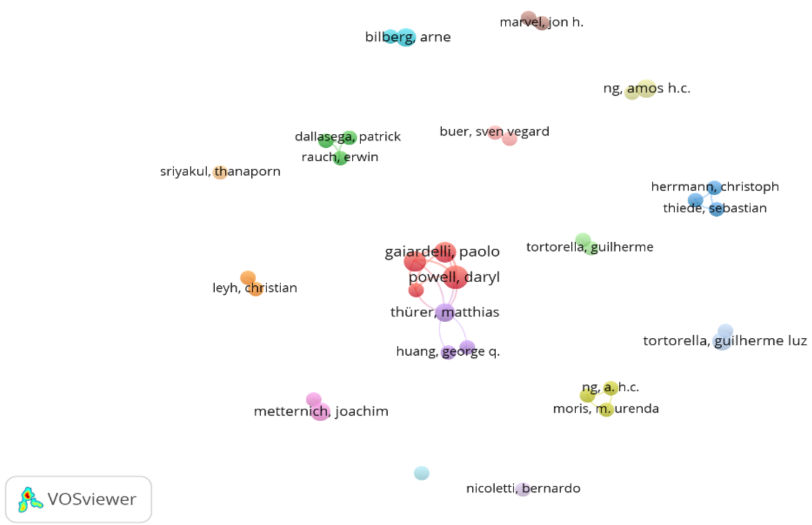

Figure 5: Authors listed in at least two articles

Another map was created using the full counting method, considering authors listed in all papers, and considering only the largest set of connected items, corresponding to 28 authors

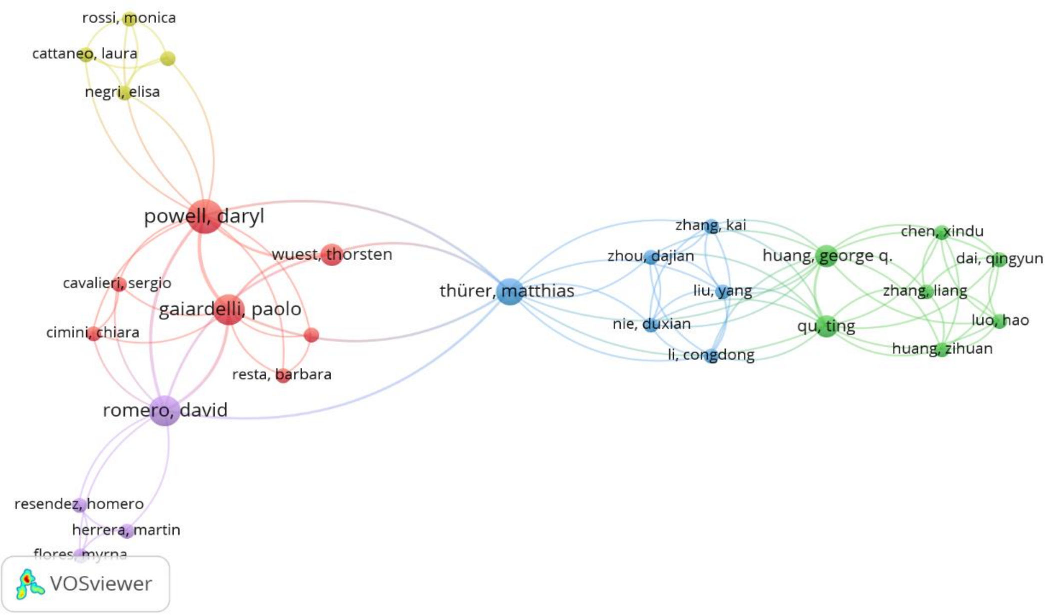

Figure 6: largest set of connected authors

These maps shows the most productive authors (Powell, Gaiardelli, Romero) which contributes with 4 or more papers; what is evident is also a moderate connection level between the authors, especially the most productive ones.

4.2 Advanced variables

Keywords analysis

The keywords analysis is done considering the keywords included in the articles. First of all, a co-occurrence map of the keywords has been done using VOS-Viewer, in order to get an idea of the most diffused concepts.

In the following map, have been included the keywords which appear at least twice (65 words), since the map with all 317 keywords identified results to be caothic.

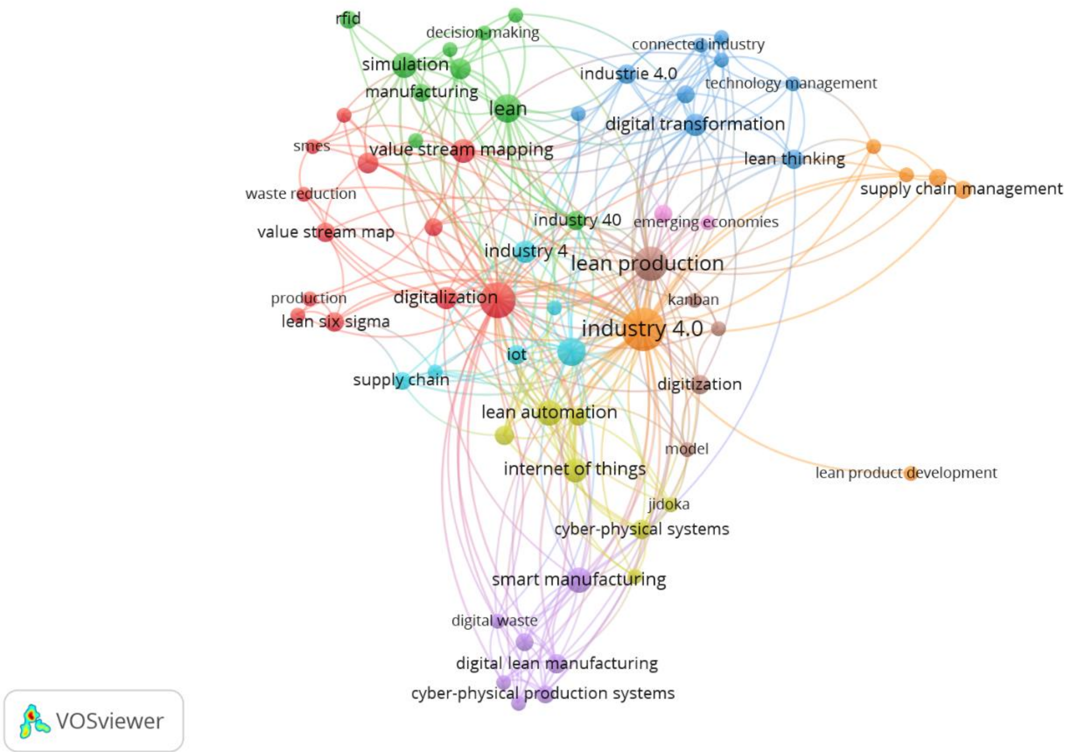

Figure 7: Co-occurrence map of keywords

As is possible to see, there is a great link strength between the keywords. As could be expected, the most diffused keywords are “Industry 4.0” (82 times) and “Lean Manufacturing” (37 times). The keywords linked to the lean concepts are expressed in different ways, as “ lean manufacturing”, “lean production”, “lean management”, “lean”, “lean automation”, “lean thinking”; reaching the total of 131 keywords related to the topic of Lean. The other most diffused words (more than 8 times) are “cyber-physical systems”, “simulation”, “smart manufacturing” “value stream mapping”, “internet of things”. These keywords give an idea of the most important Industry 4.0 technologies (CPS, IoT, Simulation) and of the great importance of Value Stream Mapping among the lean practices. For what concern the Digital topic, the most diffused words are “digital transformation” and “digitalization” (8 times) followed by “digital lean manufacturing”, “digital lean enterprise”, “digital manufacturing”, “digital waste”.

Is notable a lack o keywords regarding production improvement: the keyword "production" is present in two papers, while keywords as "production control", "production scheduling", "quality improvement", "process improvement" appear in only one publication. The keyword "operational performance improvement" is present in 3 papers.
Another lack regards the individual Lean practices: excluding VSM which, as stated above, is present in 13 papers, the most frequent keywords are "lean six sigma" (5 papers) and keywords related to "waste" (7 papers). Keywords as "Kanban", "kaizen", "jidoka" are cited less than 3 times, while the other practices are not present at all between the keywords.

4.3 Papers' contributions

After a first image of the synergies between Lean thinking and Industry 4.0 given by the analysis of the keywords, the papers have been analysed in detail in order to understand which common trends are shown and which relations between the two practices are underlined by the authors. The advanced variable in question therefore deals with the conclusions that the authors have drawn regarding the simultaneous application of lean thinking and digital technologies.
From the analysis, first of all, results three well-defined frameworks: some authors claim that lean and digitalization mutually support each other, improving their performance reciprocally, thus leading to an overall increase in productivity. A second part of papers, on the other hand, states that it is almost exclusively digitalisation, through industry 4.0 technologies, which improves the effectiveness and use of lean practices. Finally, a third part of authors argues that lean practices are the foundation for the implementation of industry 4.0 technologies. These three frameworks will be analysed in detail.

In addition, have been found a good number of papers concerning the mutual cooperation between lean and digital technologies in order to reduce wastes, in their different forms; other papers instead deal with the use of simulation, especially discrete event simulation, simultaneously with the application of lean production; still others deal with how modern technologies improve the value stream map. These trends will also be analysed later.

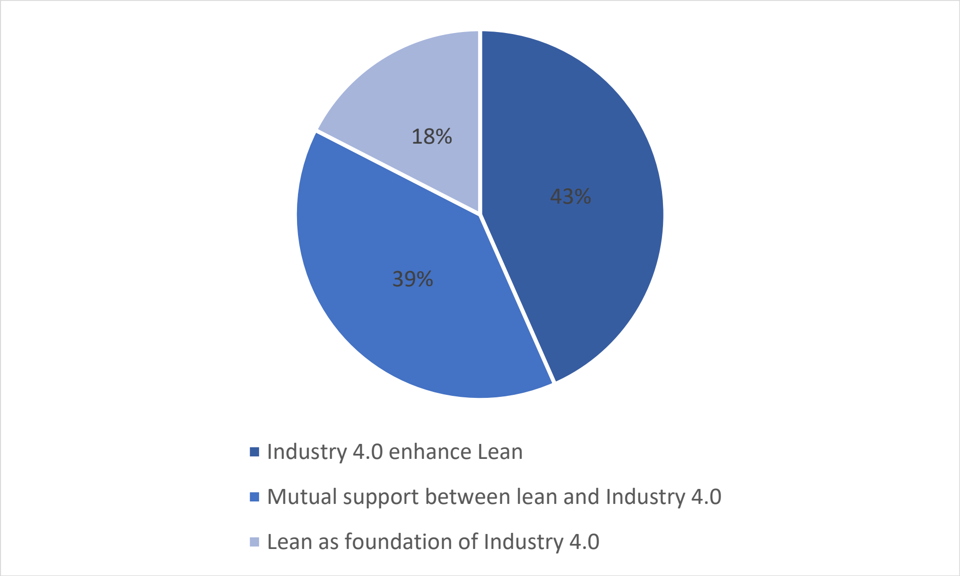

Figure 8: Three main frameworks

4.3.1 Mutual support between Lean and Digitalisation

Over the 150 papers analysed, 74 express a positive and mutually supportive relationship between Lean thinking and Industry 4.0 technologies.

Part of these articles consider more effective the contribution given by technologies to lean thinking , while others consider more incisive the fact that lean is the basis of the implementation of industry 4.0; but in any case these 74 papers consider the positive effects of both practices.

In combining LM and I4.0 the existing literature manifests terms like Lean 4.0, Lean Automation, Smart lean manufacturing, and Lean industry 4.0. As stated, the totality of authors approve the general compatibility of LM and I4.0. Methods of lean management use simplification and standardization in order to make complexity manageable prevalently at the expense of flexibility. Digitalization has the ability to oppose this deficit. Digitalization should be applied when lean principles are carried out and manufacturing processes are geared to each other. The results are robust processes with consequent reduction of processing times, accuracy and elimination of waste, in order to have the basis for an economical implementation for digital technologies. Furthermore, digitalization should be perceived as supporter of lean manufacturing. The symbiosis of lean and digital is expected to have high potential regarding the containment of complexity and raising flexibility as well as efficiency and productivity. [20]

Prinz et al. (2018) stated, as a basic assumption, that Industry 4.0 implementations can reduce the complexity of production systems, thus leading to more manageable processes. But these implementations also require established transparency and standardization of processes and organization. This leads to the second assumption that broad lean management implementations should already be accomplished in manufacturing processes in order to exploit higher effectiveness of Industry 4.0 technologies. While in the past target productivity of production systems could often be achieved with lean management methods, productivity can now be increased much further with the introduction of Industry 4.0 [25], as showed by figure above.

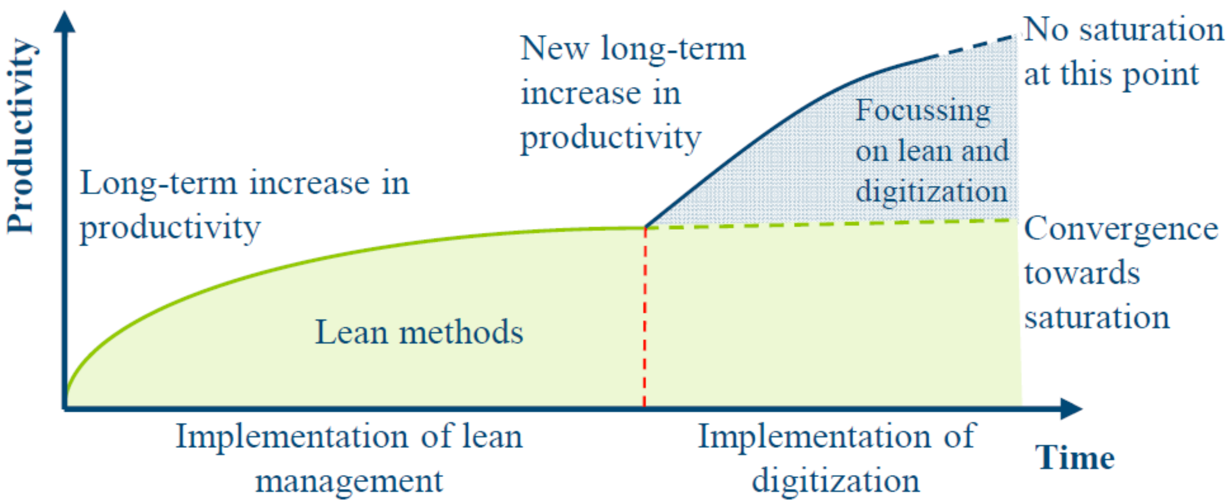

Figure 9: Effect of lean and digitalization on productivity

In few words, digitization can only be implemented successfully if the organization and in particular the processes have been optimized according to lean aspects.

Conversely, it also helps to reduce efficiency losses in a lean optimized production in case of disturbances and to further increase the overall productivity.[25]

Moreover, other authors stated that companies with higher lean and digital maturity tend to perform better, have a better organizational culture, and have a better Continuous Improvement process in place. Their results suggest that although the lean principles of customer orientation and elimination of waste remain the basis of efficient production, the combination of lean thinking and digital technologies enables superior performance compared to a standalone implementation of lean or digital technologies.[5].

Kassem and Portioli (2019) stated that Lean Process (LP) and Industry 4.0 favours similar process characteristics that are rather simple, modularized and easily standardized. Lean Process enables the implementation of I4.0 inside manufacturing companies through the achievement of a waste-free standardized production process that is easier to digitize, because digitizing an inefficient process will keep the process inefficient. In return, I4.0 can support each of the LP bundles and ease the way they are adopted and act on each LP tool by digitizing them or filling the needed gaps in their performances with technological advancements. The integration between I4.0 and LP has a great impact on the operational performance of the company that adopts both paradigms in their processes.[26]

Finally, some authors express the performance implications of an Industry 4.0 and lean manufacturing integration: Sanders, Elangeswaran, and Wulfsberg (2016) argue how Industry 4.0 together with lean manufacturing can improve productivity, reduce waste and consequently reduce costs. Kolberg and Zühlke (2015) describe how modular workstations and flexible manufacturing lines working together with single-minute exchange of die can reduce the set-up time. They also argue for how autonomous Kanban bins that can detect their inventory level and automatically order parts from suppliers can help reduce inventory levels. Ma, Wang, and Zhao (2017) show how CPS-based smart Jidoka is a cost-efficient and effective approach to improve production system flexibility. They also prove other benefits such as increased reliability and reduced cost.[27].

4.3.2 Industry 4.0 enhance Lean

The majority of papers analysed, corresponding to 82 over 150, identified as the main result of the integration between Lean and digitalization an improvement of Lean practices and Lean production system, thanks to the support of technologies provided by industry 4.0. These authors do not deny the positive contribution that lean brings to the implementation of industry 4.0, however they consider the support provided by industry 4.0 much more incisive. Below, citing some of the most influential authors, their reasons will be explained.

Wagner et al. (2017) showed that industry 4.0 applications can stabilize and support lean principles. Their industry 4.0 impact matrix on lean production systems gives a framework to start design and develop industry 4.0 integrated applications. The use case of the cyber physical just in time delivery application show an assessable example for lean process improvement with industry 4.0 technologies based on the presented Impact Matrix.[28]

Lorenz et al. (2019) interviews with company representatives supported the finding that digitalization can enhance lean principles for two main reasons. First, the availability of up-to-date, high quality data increases transparency and facilitates the identification of waste. Second, digitalization allows a higher degree of flexibility regarding to customer requirement (e.g., by enabling product customization or last-minute order changes).[5]

Pereira et al.(2019) assessed that the most common benefits taken to lean from the technologies enabled by the fourth industrial revolution are related to data collection, ease of communication between different productive actors, information processing capabilities, and data display. These technologies, if aligned with lean principles and concepts can, indeed, reduce non-value adding activities in organizations, as well as, improving workers satisfaction. [21]

Considering the contribution of the different Industry 4.0 technology over the lean practices, accurate and timely information sharing is a fundamental condition for the success of JIT and I4.0 offers such condition as real-time information availability and extraction is a major advantage of the new revolution relying on Big Data and CPS. With the help of radio frequency identification RFID, every product in the order note is tagged and IoT uses integrated devices to manage information and track the movements of tagged products along the supply chain, from the source until the destination. This leads to delivering the right product at the right time in the right quantity to the right customer.

With the help of e-Kanban and RFID, the production process is transformed into Pull-based process. E-kanban triggers replenishment automatically, and RFID tracks products in real time.

Using real-time data and cognizant computing that automatically addresses the customer with a tailored marketing based on products usage and feeds the production with customer desires in real, customer involvement is achieved. The real-time production data are also available for employees so that they can themselves participate in the analysis and decision- making process and take on proactive roles instead of the usual passive ones.

Human-Machine interaction makes use of collaboration interfaces such as virtual reality and augmented reality that can improve TPM.[26]

CPS is referred by several authors as a technology that can be effectively used to enhance Lean practices. CPS provides real-time data that can be used to give instant visual feedback regarding performance (KPI) and provide transparency and better communication between production stakeholders. This technology can be helpful in simplifying the use of Andon and e-Kanban systems, as well as, other production pull flow control techniques.

Big Data and Data Analytics are referred by many authors in their major role in improving VSM construction and maintenance, allowing what some authors call dynamic VSM. Other authors refer similar advantages as CPS in real time data collection, allowing effective KPI monitoring. Big Data and Data Analytics are also mentioned in some publications as facilitator to problem-solving, as well as, promoting the empowerment of human workers.

IoT is referred as being effective in improving the supply chain management as a whole, bringing autonomous optimized decisions in terms of flow, facilitating the JIT pillar of lean management. Cloud computing is mentioned in its real time access to information and integration with other computational systems from other companies. Its capacity is associated to the idea of creating automatically standard work instructions in an optimized way. The information sharing possibly available through this technology is the main advantage that can be taken to enhance lean practices.

One of the most obvious uses of VR and AR technologies regards the creation of safe examination of hazardous situations, providing low cost scenarios for training in operation and maintenance, which holds a huge potential to completely change and revolutionize the way humans work and communicate. Autonomous and Collaborative Robotics appear having great potential in creating hybrid workplaces where humans and robots work in a collaborative way. 3D printing is mentioned as being very lean friendly because it perfectly fits one-piece-flow concept with all its benefits to lean thinking.[21]

Finally, Bittencourt et al. (2019) stated that Digitalisation can help the implementation of Lean because:

• Employs technologies that facilitate people's work (e.g., platforms of collaborative work and improved man-machine communication);
• Employs technologies to reduce human effort;
• Connects the real and virtual world;
• Makes production more flexible.[7]

4.3.3 Lean as foundation of Industry 4.0

There are 33 papers over 150 which consider Lean thinking the foundation, or the prerequisite of the implementation of Industry 4.0 technologies.

An important perspective on the interaction between Industry 4.0 and Lean, in fact, is that the Lean can be used as a basis to build an implementation of Industry 4.0, thus becoming a facilitator in this implementation. Lean concepts such as work standardization, organization and transparency are highlighted as support for implementation of solutions linked to Industry 4.0. Buer et al. (2018) show how the simplified, waste-free process achieved through a Lean transformation simplifies additional efforts to automate and digitize the manufacturing process, thus promoting the implementation of I4.0. [7]

Several authors sustain the theory that lean principles simplify the data collection required for digital projects by having streamlined processes, which can reduce the time to integrate digital solutions. Lean thinking moreover ensures a permanent focus on customer value and waste elimination, which facilitates the identification of technologies that support these objectives. One company manager expressed it concisely: “if we do not apply lean principles, we digitalize waste.[5]

Dombrowski et al. (2017) stated that even in future production systems, which are considering Industry 4.0 and modern information and communication technologies, processes need to be defined in an efficient way, before enterprises start to automate these production processes. Thus, Industry 4.0 requires a certain level of process orientation with defined processes, suppliers and customers, tasks and times.[29]
Since Lean production aims at reducing all kinds of non-value-added activities in the process, it makes the shop floor clean and organized. It is easier than to automate and digitize a lean manufacturing process with a well-defined waste-free, clean, organized and visible workflow.[26]

In conclusion, Lean concepts such as standardization, organization and transparency are highlighted in the literature as the pillars for the implementation of solutions related to Industry 4.0, that is, Lean is an important way to consolidate I4.0. Thus, through the review it is possible to systematize how LT is a facilitator of the implementation of I4.0. In this way, it is a facilitator because:

- It trains people as thinkers;
- Simplifies processes and reduces/eliminates wastes so that they are not automated;
- Reduces the possibility of compromising scarce resources;
- Increases the transparency of work processes and organization.[7]

4.4 Other trends identified

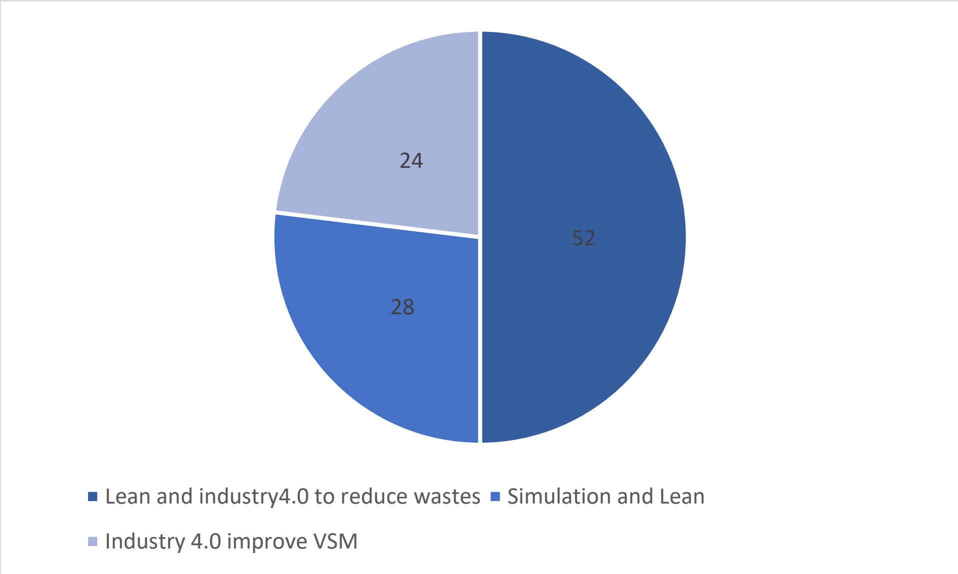

Figure 10:Other trends identified

4.4.1 Lean and industry4.0 to reduce wastes

Among the articles mentioned above and belonging to those 3 categories, it is notable that 52 authors express as one of the main consequences of the integration between lean thinking and digitalization the reduction of Wastes. As mentioned above, there are 8 types of Wastes, and the lean thinking, through its philosophy and its toolbox, aims as first thing to reduce these wastes within the company.
It is therefore obvious that, both as a consequence of the fact that industry 4.0 positively supports lean principles, and as a consequence of the fact that lean is the basis for the implementation of industry 4.0, one of the main objectives and results of the integration between the two is precisely the reduction of production Wastes.
Considering the effect of digitalization on lean, it is clear that different parts of the Industry 4.0 technology have a positive impact on different types of waste in Lean Manufacturing:

- Minimizing and eliminating overproduction: Lean manufacturing seeks to minimize and eliminate overproduction in the factory. Thus, there must be fewer occurrences of producing too much, when there is no direct order for the product or when the products are not needed by the consumers. In an Industry 4.0 manufacturing facility, better order management and information can be communicated to the factory floor and equipment directly. Orders can be immediately directed, decisions could be made more instantaneous and effectively. Industry 4.0 factories are envisioned to be able to have production equipment that collects real time information and act autonomously based on information from the rest of the production facility, supply chain and customer input.

- Minimizing and eliminating waiting time: The CPS provides a better opportunity to have precise control of the activities on and off the manufacturing shop floor. Better or "smarter" decisions can be made on site (on the process or machine level) in order to address the many different types of waste that hinder efficiency. The ability to get immediate feedback from related stakeholders on the vertical and horizontal level could be key in efforts to minimize production waiting time. Better training and use of Augmented Reality /Virtual Reality adaptive technology will be beneficial in improving workers capabilities and minimizing idling in production process together with better data analytics.
- Minimize transportation: Industry 4.0 will enable the better control of the need for transportation including the ability to determine the best route and scheduling on the shop floor for the work in progress (WIP) materials.
- Minimizing and eliminating over-processing: Over-processing occurs when more work is done than required which may also include the use of a more complex process or components than necessary for production.

  Industry 4.0 connectivity will enable the better relay of information and instruction on the shop floor as to enable the accurate diagnostic, visualization and instruction for processing is provided in every step of the production flow.
- Minimizing Inventory: The build-up of inventory either in WIP form, stocks, finished or unfinished state would also be much better in the era of Industry 4.0. The better connectivity between real time information from the customer, supply chain and also individual processing equipment in the factory floor

allows for a better control of production materials. Fast and accurate information flow in Industry 4.0 supports the production of JIT materials enabling just in time production to be achieved in much more different manufacturing environment and industries.

- Preventing defects: Much effort and resources may be wasted due to defects, but Industry 4.0 allows for the prevention and elimination of defects. Better equipment sensors and network integration allow a better monitoring of the production process potentially allowing production process anomalies to be detected well in advance. Smarter maintenance capability would ensure better processing equipment performance and fewer defects during production.

On the other hand, as already said, Lean Thinking facilitates the implementation of I4.0 because it simplifies processes and eliminates waste in a way that it is not repeated, reduces the possibility of compromising scarce resources, and increases the transparency of work processes/organization. As consequence, in preparing the ground for the implementation of 4.0 technologies, inevitably the first objective is the reduction of Wastes, and is therefore a consequence of the integration between the two production principles.[30]

4.4.2 Industry 4.0 improve VSM

A consistent number of articles, 24 over 150, deal with the fact that industry 4.0 technologies have a positive effect on a lean practice in particular, the Value Stream Map.

Hartmann et al.(2018), supported by other authors, presented the method of VSM 4.0 which is an extension of the known VSM. VSM 4.0 focuses on a standard process redesign in a lean manufacturing manner as well as on the handling of all information needed in a value stream (so called information logistics). In the classic VSM, the information view was only used for production control. Information flows to machines, instructions for workers or information for shop floor management were

not analysed or even mapped. The VSM 4.0 method closes this gap and brings a new understanding of information in value streams [31]
While applying Auto-ID enables the instant localization of objects, big data and data analytics facilitate the consolidation of information. Consolidated key performance indicators enable decision making based on facts. The main benefit of VSM 4.0 is the improvement in transparency through a real-time display of value streams. This helps in identifying waste within production processes and leads to a lean value creation. Besides, the effort to carry out VSM is reduced and decisions are based on real-time data.[3]

Davies et al., (2017) presented the Virtual Value Stream Mapping: The concept of Virtual Reality (VR) could be extended to create virtual VSM's. In this VR environment, an understanding of the conventional VSM process will not be needed. Rather than having to understand the interaction of the various VSM symbols, interested stakeholders could be immersed in a virtual value stream where current and future state models could be observed.[32]

4.4.3 Lean and Simulation

The last trend considered regards strictly the previous one, since most of the uses of simulation regard the improvement of the Value Stream Map. In any case, it is remarkable that 28 papers deal with the positive use of simulation, in particular of discrete event simulation, to improve lean processes and to increase total productivity through the integration with lean thinking. However, is important to say that the analysis has been influenced from the fact that during the keywords' search the word “simulation” has been searched expressly alongside with Lean, since is a fundamental technology of the current digital landscape.

Considering the relation with Value Stream Map, as stated by Marvel & Standridge, (2009) VSM is a static representation of the system, since changes in the system over time are not represented.
A simulation model of the same system enhances the VSM model in several ways.

- The model can be analysed using computer-based experiments to assess system performance under a variety of conditions.
- The dimension of time can be included in the model so that dynamic changes in system behaviour can be represented and assessed.
- The behaviour of individual entities such as parts, inventory levels, and material handling devices can be observed and inferences concerning system behaviour made.
- Variability, both structural and random, are commonly included in simulation models and the effects of variability on system performance determined.
- The interaction effects among components can be implicitly or explicitly included in a simulation model.[33]

In general, Lean tools lack the ability to analytically determine the effects of changes made to a single component on other components or overall system performance. This deficiency makes validating lean transformations before implementation almost always difficult if not impossible. Alternatively, simulation models can include how system components interact. These interactions likely affect the ability of the system to meet its performance objectives. Changes made in the operations of one component likely effect the operation of other components as well as the overall performance of the system. Simulation modelling and analysis has been shown to be effective in the same domains, such as manufacturing where lean is most often applied. Thus, simulation is a primary tool for validating lean transformations, the future state, before implementation.[33]

Lean emphasizes “trial and error” and “experiments” or one step at a time process. This limits the opportunity to find possible interactions between components of the system and it does not rely on any methods or models to minimize or eliminate sub-optimization. Using simulation to quantify the benefits that can be expected from implementing system improvements and comparing the actual system with its future performance can assist the organization to take the crucial decisions and avoid failures in the implementation of lean management principles. Additionally, errors when implementing an incorrect future state can be costly and result in unnecessary waste making a lean implementation unsustainable. Simulation on the other hand, can offer a systemic view and provide the analysis of how different changes in one component affect the system. When the system is rather complex to analyse due to the number of existing interactions, the amount of people involved, the variability level, the size of the system or if it is a non-existing system, then simulation is a better tool for identifying where and how to improve the system. It can help to explore, discuss and re-test scenarios that are non-intuitive or non-existing and probably would have been very difficult or impossible to find without simulation. In few words, adding simulation and optimization into the lean toolbox can strengthen, besides others, some of the main drawbacks of lean such as not considering variation, lack of dynamicity and the incapability of lean standard tools of evaluating complex non-existing processes before implementation[34]

4.5 Lean practices and tools and Industry 4.0 technologies

In addition to the keywords' analysis and the in-depth analysis of the conclusions reached by the papers, a further analysis has been made in order to understand which are the most important and significant Lean practices and technologies of the industry 4.0, within the interaction between the two topics. In fact, for each article, it has been indicated which Lean practices and Technologies have been the subject of study; accordingly, has been obtained a list of the most used and analysed practices and technologies in the context of the mutual relationship between the two production methods.

4.5.1 Lean practices and tools

The table shows the Lean practices that are treated by the authors and the frequency with which they appeared.

Lean practices	Occurrences
VSM	35
Kanban	26
Just In Time	24

TPM	15
Jidoka	10
Lean six sigma	10
Kaizen	9
Standardisation	9
Waste elimination	7
Continuous improvement	6
Poka yoke	6
SMED	4
Andon	4
5S	3
Takt time	3
Heijunka	2
Cellular manufacturing	2

Table 2: Occurrences of lean practices and tools

As is possible to see, the already cited Value Stream Mapping is in first place, appearing in 35 different papers.

This result can be justified by the fact that VSM covers all levels of the value stream, being efficient in reducing waste and it is well-known either in manufacturing or in service organizations. Thus, this practice is considered potentially beneficial for the adoption of Industry 4.0 [35] since it provides a structured approach to identify improvement opportunities and to guide organizations toward a leaner operation. As aforementioned, a digitally integrated VSM input with real-time data allows a more in-depth understanding of companies' status quo and assertive design of lean value streams.

Moreover, a good number of articles indicated the positive effect of technologies as Big data, Data analytics, VR and Simulation over this lean practice.

The second practice most used is Kanban: is a fundamental practice in order to apply the pull principle, and with the help of new technologies (CPS, RFID) allow the use of autonomous Kanban bins that can detect their inventory level and automatically order parts from suppliers can help reduce inventory levels.

In 24 papers the Just In Time practice has been considered, first of all because accurate and timely information sharing is a fundamental condition for the success of JIT and I4.0 offers such condition as real-time information availability and extraction is a major advantage of use of Big Data and CPS.

Total Preventive Maintenance appear 15 times. Industry 4.0 is able to provide a large amount of data and information that can be used to improve equipment performance, converging toward the desired objectives of the TPM implementation.[36]. This practice can be improved by various collaboration interfaces as Virtuar Reality and Augmented Reality; moreover CPS are able to collect data about maintenance needs and automatically send signals to maintenance staff. The real-time collected data can be stored and further used for continuous improvement implementation. [21].

The Lean pillar of continuous improvement, expressed by Kaizen practice, is considered 15 times. The appearance of the IoT, Cyber-physical systems and Big Data have created some new possibilities regarding more efficient actuation and continuous improvement of the manufacturing systems. [37]

As expressed by various authors, at the monitoring level, the continuous Improvement principle can take advantage of augmented reality. At the optimisation level, Big data analysis and numerical twin simulation can be integrated into a continuous improvement process aimed at finding an optimal solution. Moreover, is highlighted the use of real-time simulation in the context of continuous improvement to optimise the production system in terms of stocks, movements, overproduction and waiting. [38]

Jidoka, Lean Six sigma, and Standardization are treated in 9-10 different papers. These practices, expressing concepts as work standardization, organization, waste elimination and transparency are highlighted as support for implementation of solutions linked to Industry 4.0. Moreover, CPS-based smart Jidoka is a cost-efficient and effective approach to improve production system flexibility and to reduce process variability and errors.

Lean practices Tatk time, 5S and Cellular manufacturing and Heijunka have been considered less than the others. Sanders et al., (2016) underlines that takt time calculation is made centrally with the help of forecasted demand and product variants, so rush orders cannot be easily integrated into the production with fixed takt times which is completely contradictory to the Industry 4.0 objective of decentralization and autonomy. Modularity also cannot be enforced as production schedules, product variants and the takt time are fixed.[39] About 5S, has been expressed that Auto-ID and AR can assist in carrying it out more efficiently. RFID ensures the identification and the localization of objects which reduces search time and RFID tags can store instructions for cleaning tools and objects appropriately. Moreover, 5S can help in the cleaning and standardisation practices that have been considered at the basis of Industry 4.0 implementation, for this reason the few appearances in the literature review is contradictory.

4.5.2 Industry 4.0 technologies

The table shows the Industry 4.0 technologies that are treated by the authors and the frequency with which they appeared.

Industry 4.0	Occurrences
IoT	46
CPS	31
Simulation	26
Big data	26
RFID	25
Sensors	20
AR, VR	14
DES	10
Cloud	9
Lean Automation	8
Smart product, Smart machine, Augmented operator	4
Autonomous Robot	3
AVG	1

Table 3: Occurrences of Industry 4.0 technologies

At first place there is Internet of Things, that is present in 46 papers over 150.

IoT is strictly connected to cloud, Big data, AR, RFID, sensors, since it provides the basis for their operation. As already said, this technology support and facilitate all the lean practices, but in particular JIT, Jidoka and Waste reduction. IoT indeed, allows products to communicate with equipment and send a warning when the wrong product is being produced, also allowing the equipment to react to this error warning by stopping the work or by changing products.[38]. IoT, moreover, is referred as being effective in improving the supply chain management as a whole, bringing autonomous optimized decisions in terms of flow. In Addition, the introduction of IoT technologies within production lines has made it possible to speed up maintenance services [40], acting so on Total Productive Maintenance through data sharing with the network and providing information in real time to support decision making by management. The second technology most used is Cyber Physical Systems, that is indeed the second pillar of Industry 4.0. This technology works similar to IoT, since it uses the same architecture enabled by a network. However, CPS promotes greater exchange of data and information destined to the integration and coordination between physical elements and computational systems. Through CPS, products are equipped with self-management capability and the factory can operate according to the smart factory concept; thus, production systems become Cyber Physical Production Systems, enabling a real-time operation in a remote and independent way. [36]. This technology can be helpful in simplifying the use of Andon and e-Kanban systems, as well as, other production pull flow control techniques. Regarding Maintenance, CPS are able to collect data about maintenance needs and automatically send signals to maintenance staff. Smart Jidoka system to reduce process variability and errors is also referred as examples of CPS enhancing Lean solutions.[21]. With 26 papers considering their usage, Simulation and Big Data are important element of the integration between Lean and Digitalization.

Simulation, as previously said, is fundamental in improving VSM and is a primary tool for validating lean transformations, the future state, before implementation. In the papers has been proposed the use of simulation to represent products and find optimal Kanban parameters, such as batch size, minimum inventory and delivery frequency; and the use of simulation to facilitate employee training, allowing employees to train in a simulated environment [38]. In general, The availability of the information provided by the simulation can facilitate and validate the decision to implement lean manufacturing and can also motivate the organization during the actual implementation in order to obtain the desired results [18].

Big data supports all lean processes and in particular TPM, VSM and JIT. Considering Total Productive/Preventive Maintenance, with more advanced analytics and big data environment, machines are equipped to be self-aware and self-maintained. Such machines assess their own health and degradation and utilise data from other machines to avoid potential maintenance issues.[39]

Big Data and Data Analytics are referred by many authors in their major role in improving VSM construction and maintenance, allowing what some authors call dynamic VSM. Big Data and Data Analytics are also mentioned in some publications as facilitator to problem-solving, as well as, promoting the empowerment of human workers[21]. The JIT 4.0 method additionally applies big data and data analytics techniques. The opportunity to analyze detailed real-time process information provides insights into parameters, helps to identify trends, and allows to deduce rules for the production system [3].

RFID and Sensors are other important enablers of the integration between the two paradigms, appearing in 25 and 20 articles. with the help of e-Kanban and RFID, the production process is transformed into Pull-based process. E-kanban triggers replenishment automatically, and RFID tracks products in real time[26].

Sensors are the basis of concepts as Smart machine, Smart product and Augmented operator, and are strictly connected to IoT and Big Data. For the setup reduction purposes (SMED practice), sensors that detect the components of the machines such as the dies, blades etc can speed up the internal setup operations and protect the operators. Speaking about Quality Control and fool-proof mechanisms (Poka Yoke), to prevent the defective parts and products, Pattern Recognition Augmented Reality technologies and sensor applications can be utilized[41].

Considering the Total Productive Maintenance**,** Sensors detect when components need replacing (i.e. oil filters) or oil replenishments are necessary and send signals to maintenance staff[32].
Between the principal I4.0 Technologies, Autonomous robots has been the less studied in the papers (3 times). This may suggest a limited level of synergy between this technology and Lean practices, although has been considered the potential use of autonomous robots to move products between workstations and reduce transportation wastes, and to produce towards the zero defects direction.

4.5.3 Direct application of Lean and Digital integration

This section presents the possible conceptual conjunction of Industry 4.0 technologies and lean methods, which several authors have proposed conceptually or observed directly in the company. These "Lean practices 4.0" are a direct demonstration of the possible positive union of lean and digitalization.

Just-in-time/just-in-sequence 4.0: The lean method JIT/just-in-sequence (JIS) aims to deliver the right product, at the right time, place and quality in the right quantity for the right costs. Several I4.0 tools can contribute to this objective. Automated guided vehicles (AGV), for instance, can transport objects within the material flow automatically, minimizing human mistakes as well as empty trips. Auto-ID technology, such as RFID, can be applied to track material in real-time and to localize objects in the value chain precisely. This results in reduced search time as well as improved process transparency[3]. Data analytics provides new and novel ways in which to plan and execute production and coordinate the upstream supply chain to support the Just-in-Time principle. Enterprise-wide connectivity via a data analytics platform provides instantaneous real-time signalling for production and replenishment[42]. Furthermore, a continuous material flow is supported by reducing machine downtimes through predictive maintenance actions.

Digital Lean CPPSs, or CPPSs-based *Jidoka* & *Heijunka* production systems, refer to autonomous and cooperative human, machine and product 'smart entities' that co-create a networked socio-technical production environment, where all software, hardware and humanware sub-systems can sense, actuate and interoperate. The context-awareness capabilities of Digital Lean CPPSs enabled by means of smart sensors, actuators and adaptive controllers can allow the smart control of the entire production processes in order to avoid *waiting-times* by self-adapting (re-balancing) in real-time for maximum flexibility to manage excessive demand fluctuations *(Mura),* and overburden of machine & operators capacities *(Muri).*[42]

Heijunka 4.0: The objective of heijunka is to level the production program to a constant rate. Some I4.0 tools contribute to improving heijunka. Data analytics, for instance, enhances the forecast quality. New software tools using advanced analytics can be utilized to support the planning process itself. Applying heijunka 4.0 benefits in a reduced effort for levelling the production program. Planning is automated and short-dated adjustments can be integrated smoothly.[3] Through the adoption of smart automation technologies and big data analytics, *Heijunka* becomes much more realizable, allowing for greater optimization capabilities of planning and scheduling tasks, which are now supported by real-time monitoring of tasks execution. [43]

Kanban 4.0: Through simulation methods or a virtual real-time representation of physical objects based on a CAD model (digital twin), new kanban loops can be planned with more foresight and seamlessly integrated into the existing production environment. By applying Auto-ID, a constant monitoring of work in process is possible. Hence, transparency of material movements is increased. This allows a comparison of target and actual values to remove unnecessary stock and as consequence stock levels can be minimized and transparency will increase. Besides, reduced inventory simplifies the detection of bottlenecks in the production processes.

Digital Kanban Systems (DKSs) refer to real-time digital ‘pull’ signalling systems that use a mix of digital technologies (e.g. smart tags, smart bins/boxes, smart dashboards and smart automation) to trigger the Just-In-Time (JIT) movement of materials and electronic information (e-Kanban cards) within a digital lean smart factory in order to eliminate overproduction by being responsive to the current demand instead of forecast. [42]

Value stream mapping 4.0: I4.0 leads to a connected manufacturing environment where data can be transmitted in real-time. While applying Auto-ID enables the instant localization of objects, big data and data analytics facilitate the consolidation of information. Consolidated key performance indicators enable decision making based on facts. The main benefit of VSM 4.0 is the improvement in transparency through a real-time display of value streams. This helps in identifying waste within production processes and leads to a lean value creation. Besides, the effort to carry out VSM is reduced and decisions are based on real-time data.[3]

Total productive maintenance 4.0: Several I4.0 tools support operators in taking on more responsibility. Especially the combination of virtual representation technologies like virtual reality (VR) and augmented reality (AR) as well as head-mounted displays facilitates training as well as maintenance instructions. By displaying virtual elements operators can be guided remotely. Moreover, smart products and CM technology allow for load, wear, and defects to be monitored during machine operation. The early detection, isolation, and identification of faults results in less downtime and prevention of consequential damages.

Visual management 4.0: Auto-ID and AR can assist in carrying out 5S more efficiently. RFID ensures the identification and the localization of objects which reduces search time. Moreover, RFID tags can store instructions for cleaning tools and objects appropriately. Andon is applied for visualizing status and disruptions in production and thus supports the lean principle jidoka. Additionally, andon boards display actual and target values to reveal deviations.

Poka-yoke 4.0: Auto-ID ensures the correct identification and assignment. A digital product memory allows to request required components and helps to identify incorrect deliveries. This prevents adding value to defective parts. By using smart sensors and machine learning, machines can automatically adjust to irregularities to ensure optimal product quality.[3]

Digital Warehouse Operations (DWOs) refer to the automation of warehousing activities with the support of auto-ID technologies, smart boxes, AGVs and real-time inventory optimisation strategies to manage the ideal levels of raw materials, work-in-progress (WIP) and finished product(s) inventories. DWOs automate 'true JIT ordering' on the basis of stock reduction by the use of diverse sensors and smart bins/boxes to manage inventory levels in collaboration with digital Kanban systems and e-billing services. [42]

Smart Human Resources 4.0 (SHR 4.0): is a new concept that is evolving as a part of the overall 4th Industrial Revolution and characterized by innovations in digital technologies such as Internet of-Things, Big Data Analytics, and artificial intelligence (AI) and fast data networks such as 4G and 5G for the effective management of next-generation employees[44].

Now are presented the effects that the previously mentioned concepts of Smart Product, Smart Machine, Augmented operator, have on lean practices and applied in a Lean Management context.

Smart Product: A product can provide through different sensors installed on board machines, operator, planners and workplaces all the information about its scheduling as well as its technical and production features. Achieved data can be re-elaborated through algorithms and analytics to improve process time and quality (TQM), as well as to optimize equipment maintenance services (TPM). Moreover, real time information about product quality and lead times can support the implementation of training activities to improve operator capabilities in production.[45]

In the reference to Kaizen, Smart Products can collect and use for analysis the information about repeating actions from their sensor and semantic technologies properties such as: context-aware, adaptive, self-organized, and proactive and the ability to support the whole lifecycle which allows them for continuous improvement process.[19]

Smart Machine A Smart Machine can contain a smart panel which is based on RFID UHF. Such a solution enables to detect the tagged Kanban cards in real-time. Except RFID, the continuous improvement can be also assured due to production line data collected from machines with technologies such as actuators, sensors and wireless video. These data are analysed and proceeded in the cloud to give better operational intelligence but mainly to avoid mistakes what is the main idea of Poka Yoke. Furthermore, the application of Plug'n'Produce makes it also possible to introduce Single Minute Exchange of Die method into whole production lines[19]. A smart machine equipped with smart interfaces, can receive and send information about its production performances calling for fault-repair to avoid future break-downs (TPM) rather than low level of product quality (TQM). Moreover, smart interfaces installed on each single machine enable intra-communication across the pro-duction system, enhancing production and material handling efficiency and flexibility. [45]

Augmented Operator: The Augmented Operator should reduce the time between failure occurrence and failure notification. In order to achieve it the Andon method can be applied which is one of the principal elements of the Jidoka quality-control method recognized as a part of the Lean approach. It is realized by showing signal lights on an operator smart watch in close to real time. The information concerns both error messages and error locations. Such alerts may be recorded in a database and further studied as part of a continuous-improvement program.[19] In addition, failures can be recognized with CPS equipped with proper sensors and automatically initiate fault-repair actions on other CPS.
Augmented reality (i.e. smart glasses) enables continuous flow and right assembly allowing error prevention, or support employees during pre-ventive maintenance activities (TPM). In addition, smart devices make continuously available on the shop floor real-time KPIs, stimulating employees to empower their performances (HRM)[45].

4.6 Analysis of improvements

During this in-depth analysis of the 150 papers constituting the bibliometric portfolio, the possible productivity improvements, given by the interaction between lean philosophy and modern technologies, were also investigated. It should be noted that all the authors expressed a positive opinion on this interaction, and in 87 papers are considered the possible improvements that lead to enhance company productivity. Some of these authors have used empirical methods to arrive at these conclusions, while others relied on conceptual studies. In the table below a summary of the improvement identified during the literature review.

Improvement	**Number of Papers**
Identification and Reduction of wastes	30
Decision making process improvement	14
WIP, lead time and inventory reduction	11
Enhance efficiency	9
Improve lean principles and lean production	8
Increase flexibility	8
Better working condition and employee engagement	8
Increase transparency	7
Reduction of operating costs	6
Higher operational performance	6
Increase quality (Decrease defects)	5
Improve culture of continuous improvement	4
Efficient organisational performance and planning	4
Reduction of variation and variability	3
Enhance human capabilities (employees skills)	3
Better use of human resources and training	3
Standardisation	3
Information collection and sharing	3
Better human machine cooperation	2
Better communication with customer and supplier	2
Opimisation of resources	2
Create more value for customers	2

Knowledge exchange	1
Speed up improvements and reconfiguration	1
Support organisational learning	1
Decrese number of machine breakdowns and maintenance costs	1
Efficiency in product development	1
Manage complexity	1
Minimize overproduction	1
Moderates the effects of lean supply chain management	1
Real time integration	1

Table 4: Improvement identified in the papers

As expected from the previous analysis, 30 papers express as major contribution of the integration the "identification and reduction of wastes". The reduction of waste is one of the main objectives of lean thinking, therefore digitalization, in its role of supporter of lean practices, get first of all to reduce wastes. The consequence on productivity is obvious, as this process allows company not to automate waste, improving the entire production process, increasing efficiency and reducing costs. In fact, relative to these results, in 9 papers a direct efficiency gains is reported, while in 6 papers a reduction of operating costs is highlighted.

In second place there is the "improvement of decision making process". The Real-time monitoring system enabled by IoT, Sensors and Cyber Physical Systems accelerates the data collection processes, as well as the retrieval of information, leading to optimize the decision-making process [40]. Moreover, Simulation modelling is a powerful tool for management decision making by analysing the effect of various factors of change within the system without making the actual or physical changes, so it contributes to money saving and time saving. The integration of simulation with VSM, in particular, could considerably improve the results obtained in lean projects, helping the decision makers in adding dynamic information to the usually considered static pictures of the processes.[46]

Moreover, IoT is the key technology for data perception and collection from Andon system. It can be incorporated into simulation model for decision making of process improvement. Through the simulation results, the managements are enabled to predict the output based on the given scenarios. Accurate and fast decision is obtained in this case study where the data is collected from actual lean production line.[47]

Another important improvement regards "WIP, lead time and inventory reduction". Even in this case, after various authors the combined effect of Value Stream Mapping and Simulation is a major cause of improvement. A simulation-based real-time solution for production planning, indeed, results in a drastic reduction of the inventory levels on manufacturing environment through the achievement of production on-demand and JIT delivery of components. Moreover, thanks to CPS, the added value of e-kanban system lies in the possibility of knowing the actual inventory of the factory at all stations at any time, as well as the reduction associated with the WIP.[48]

Other authors highlights that for the Work-in Process reduction among the machines, a better M2M Communication, IoT, sensors and data analytics should be used.[41]

The increase of flexibility and of transparency are highlighted respectively by 8 and 7 articles. Regarding flexibility, the case study of Lucherini & Rapaccini (2017) shows that the benefits achieved by the combined use of Simulation with SMED, JIT, and Cell manufacturing have strong implications also on the flexibility of production systems [17]. In their research, Ma et al. (2017) highlights the combination of Lean tools and the principles of Industry 4.0 to develop an intelligent and decentralized Jidoka system based on the CPS, capable of generating an increase in the flexibility of the production system[7].

In general digitalization allows a higher degree of flexibility regarding to customer requirement, by enabling product customization or last-minute order changes.[5]

Considering transparency, various articles highlight that Lean concepts such as work standardization, organization and transparency are fundamental in supporting the implementation and consolidation of the I4.0 [4]. Therefore, transparency is one of the key enablers of Industry 4.0 technologies offered by Lean thinking. In Addition, various authors stress the enhancement of transparency in the production processes, given by the combination of lean and digitalization: Mayr et al., (2018) showed that by appling Kanban 4.0 stock levels can be minimized and transparency will increase; In addition, Auto-ID technology, such as RFID, can be applied to track material in real-time and to localize objects in the value chain precisely. This results in reduced search time as well as improved process transparency. Finally, the main benefit of VSM 4.0 is the improvement in transparency through a real-time display of value streams. This helps in identifying waste within production processes and leads to a lean value creation.

Another important improvement factor regards the human resources. In the papers analysed indeed, the improvement stressed are: “better working condition and employee engagement” (8 papers), “enhanced human capabilities and employees skills” (3), “better use of human resources and training” (3), “enhanced human machine cooperation” (2 papers).

Malik & Bilberg, (2019) stated that the concept of Lean automation by keeping human at the centre of an automation system and utilizing the bests of humans and machines in a combination can offer to achieve high productivity especially in manual works. The results are not only visible in increased productivity but also in increasing safety, improved ergonomic conditions and human wellbeing. [49]

The connectedness of IoT and the distributed nature of these intelligent devices, each with autonomous or semiautonomous behaviour, allow significantly higher production and better use of human resources by eliminating massive information gaps about real-time factory condition; [50] Moreover, from a Learning perspective, and an Autonomation view, modern Jidoka Systems will enable a ‘continuous learning’ of the workforce, since Jidoka Systems aim to develop and enhance human capabilities, rather than their immediately replacement for full automation solutions.[14]

In general, Lean practices tend to be more impactful since Industry 4.0 allows a better understanding of customers’ demands and accelerates information sharing processes. This empowers employees’ engagement which is key in LP as well as throughout the value chain.[51]

Finally, an increase in quality is identified by 5 authors: Omogbai & Salonitis, (2016) showed that using Discrete Event Simulation model to validate improvements in lean practices prior to their actual implementation, the performance of Quality is improved through a 178% reduction in process scrap rate. This is achieved by re-routing work items to eliminate changeovers and improving the performance of TPM through monthly maintenance of machines[52]. Digital Lean CPPSs defined *by* Romero et al., (2018) help to monitor real-time performance in the physical world in order to assess whether production operations are actually being performed at their highest possible productivity level and quality standard, as planned, or if there remain opportunities for improvement *(Kaizen).*[42] Furthermore, machine-learning algorithms, enhanced with inputs from analysis made with Six Sigma methodology, compare individual performances over time, with the performances of the machines in groups, contributing to the optimization of production, improving the quality and availability of the machines.[23]

The concepts of Smart Product and Augmented Operator, expressed by various authors, stress the relationship between sensors, Augmented reality and TQM, with a consequent improvement in error detection and quality.

4.7 Key factors

After identifying the ways in which productivity increases as a result of the integration between lean and industry 4.0, have been analysed the key factors that, according to the authors, are the fundamental elements for this integration to succeed and to achieve this increase in productivity.

Key factor	**Papers**
Human resources commitment and integration	10
Organisational culture	7
Employee skills and training	6
Customer centricity and involvement	5
Real time information flow and sharing	5
Combination of lean and industry 4.0	5
Leadership commitment	3
Real time exchange of data	3
Work Standardisation	3

Simulation	2
Big data analysis	2
Network Collaboration	2
Continuos improvement and robust design	2
Sharing of knowledge	2
Organisational effort	2
Company experience on Lean practices	1
CPS	1
Data collection with six sigma	1
Digital systems to guide employee	1
Geometric lean learning	1
Human centred lean automated systems	1
Industry 4.0	1
LM principles	1
Model of implementation	1

Table 5: Key factors identified

Human Resource commitment and integration is identified by 10 papers to be an important key factor to achieve a good relationship between the two production system. Human factor is one of Lean's key point, so in addition to automation, the human factor must be better integrated into existing models, since employees will remain an essential part of the business processes.[53]

Ōno describes the fact that lean production and automation are not mutually exclusive but the monitoring and use by the employee is elementary and does not work as a replacement. The employee indeed becomes the smart operator of production[54]. V. Bittencourt et al., (2019) affirm that the human factor will always be a key point in any productive process. The main change will be in the nature of work at shop floor level, which will require well-trained employees and the requirement of different skills[7].

Jarrahi et al., (2019) stated that restructuring of organizational forms and culture, adapting of working methods and thus the re-qualifying of employees as well as the understanding of human resource management are recognized crucial factors towards effective Industry 4.0[40].
However, the key factors for achieving high results are commitment and understanding of the staff. In accordance with this, the authors state that staff's resistance to changes is the largest challenge and problem in lean management application. On the other hand, if employees are not educated and untrained it will be quite difficult to deal with usage of complex hi-tech equipment, machines and systems. This represents a challenge for human resources management as well because adequate skills will become much more important. The best way to solve these problems is to involve employees, that will be end-users, in technology design[55].

Employee skills and training indeed is at the third place of key factors, being cited in 6 different articles. The training of the people who work in Industry 4.0 will be fundamental to succeed in the necessary cultural adaptation in this new environment, where man will work in a digital environment, with access to data in quantities and qualities about the industrial process never seen before in history[23].
It is highly likely that work in Industry 4.0 will place significantly higher demands on all employees in terms of complexity, abstraction, and problem solving. In addition, employees will be required to have very high levels of self-direction, communicative skills, and self-organization abilities. In short, employees' subjective skills and potential will face even greater challenges. This offers opportunities for qualitative enrichment, interesting work contexts, increasing individual responsibility, and self-development."[56]
David Romero, Paolo Gaiardelli, Daryl Powell, Thorsten Wuest, (2019) highlight that the quality management practices of the future can benefit from new (smart) digital technologies when combined with greater levels of human creativity, ingenuity and innovation – utilizing their unique capability for collaborative problem-solving.
Basically following the true spirit of *Lean Manufacturing,* firms should not neglect the power of the *'respect-for-people' principle,* even though the promise of automation is extremely attractive[57].

In addition to human factor, “Organisational culture” (7 papers) and “Leadership commitment” (3 papers) are considered notable key factors.
Synnes & Welo, (2016) stated that the key to offer competitive solutions in the marketplace is considering product, people, processes and tools/technology as a total system. In this perspective it is important to invest in knowledge and organizational learning in a strategic perspective.[58]
Rafael Lorenz, Paul Buess, Julian Macuvele, Thomas Friedli, (2019) found out that companies achieving high values for the enabler category “organizational culture” consistently report an open communication culture, which includes appreciating contributions of all employees regardless of their hierarchical position as well as encouraging an open feedback and failure culture. The authors concluded that a favourable organizational culture and some specific continuous improvement practices help the mature implementers of lean and digitalization to achieve superior operational performance[5].
To resume, is highlighted that the changes in the technologies just by themselves will not aid any gain in productivity, an organizational change will be needed to support the use of the new technologies included by Industry 4.0. An investment to adapt the competences of the workers will be needed to embrace the new advances that this industrial revolution will bring. This is in line with the principle respect for people key in lean, where the personnel have to be developed with the aim to maximize individual and team performance. Moreover, this key principle includes the need to understand and build mutual trust among the stakeholders of the organization (customers, personnel, suppliers and shareholders) which will need to be sustained even in the context of Industry 4.0 [59].

“Customer centricity and involvement” is considered a key factor by five authors. Customer centricity is one of the pillars of Lean thinking, according to which the definition of value must always be made from the customer's point of view. Customer involvement becomes even more relevant given the continuous feed-back facilitated by the IoT (social networks, etc.). Clients inputs are collected and have a profound impact in the real-time adjustment of production, tailoring of product design and provide post-sale feed-back. This is shown by the current shift of traditional manufacturers into service providers. Big data allows to overcome limitations of traditional customer analysis tools (such as Quality Function Deployment) providing information on the entire “customer experience” and key visibility on VOCs (Voice of Customer).[60]

Is possible to affirm that in the integration of lean and digitalization will remain the concept stating that the customer is always right: customer influence will keep increasing with the development of Industry 4.0. Subsequently, the focused customer orientation of lean think will stay essential, or even become more important, in the time of digitalization.[8]

“Real time information flow and sharing” is defined a key factor in 5 papers, and “real time exchange of data” in 3 papers. Satoglu et al., (2018) stated that effective information flow should be maintained effective before introducing modern information and communication technologies (ICT). In this context keeping the data in a right and current manner is an important critical success factor in both Industry 4.0 and Lean Production.[41]

Péter Tamás & Illés, (2016) explained that the communication Between devices, information derived from product tracking, and the possibilities in network collaboration will provide more widespread process improvement for manufacturing companies[37].

4.8 Challenges

The last variable considered regards the challenges that authors have defined, regarding the relationship between lean and digitalization. In other words, the factors that contribute to the failed integration between the two subjects were researched: some authors reported these factors as results of empirical case studies, while others theoretically defined them.

Challenges	Number of papers
Human factor integration	3
Lack of standards	2

Employee skills	2
Collaboration	1
High investments costs	1
Lack of open innovation culture	1
Implement lean and simulation in SME	1
Investments in technology for SME	1
Lack of data	1
Lean requires simplicity	1
Need of holistic approach	1
Lack of organisational resources	1
Raise of complexity	1
Resistance to change	1
Top management commitment	1
Lack of flexible organizational culture	1

Table 6: Challenges identified

As is possible to see, there is a prevalence of factors regarding the human resources: 3 papers identify “Human factors integration” while other 2 identify “Employee skills”, while 1 papers highlights “Collaboration” and “Resistance to change”.

The human factor is identified by the authors as a critical point in the company for the implementation of both Lean management and new Digital technologies. In accordance with Mikulić & Štefanić, (2018), the authors state that staff’s resistance to changes is the largest challenge and problem in lean management application. Moreover, they have emphasized that modern technology implementation cause changes in conventional processes. The greatest challenge is human factors that have to adapt and process complex technology and data which is the problem for greying society. The paper proposes removing barriers by integration of human factor within the technology development which is a great solution for dealing with problems regarding technology adoption.[55]

Similarly, Satoglu et al. (2018) stated that erroneous and prejudiced habits and waste-accustomed behaviours of employees about working method is a critical problem to be addressed in the design of manufacturing systems. In this context, the strategy should be to change the process of thought of people after altering their behaviour with the help of a business discipline which does not distress people. Therefore, Lean Management System including work standardization and visual control is suggested to achieve this strategy.[41]

This research proposes the first step which refers to identification of all barriers which prevent the successful adoption of modern technology by a human factor.

Moreover, Mikulić & Štefanić, (2018) presented a literature review that was used as the basis for the creation of possible problems of modern technology adoption by human factors. Problems are identified as follows:

- The lack of standardized instructions for using modern technology
- The lack of previous training
- Insufficient quantity of adequate equipment
- The fear of errors
- The fear of repercussions
- Technical issues of the system and dealing with them
- The fear of changes: The introduction of modern technology is not the only segment that causes fear and resistance to change. Any change that affects the habit change results with fear, and fear causes resistance. The biggest fear is that employees will not succeed in adopting the novelties and will error often.

On the other hand, if employees are not educated and untrained it will be quite difficult to deal with usage of complex hi-tech equipment, machines and systems. This represents a challenge for human resources management as well because adequate skills will become much more important.

Is important to take into consideration that all problems mention above can be solved by making standardized instructions, more specialized training, introducing new politics in the companies that will encourage people instead of scaring them.[55].

This solution is also related to the "Lack of standards" problem defined in 2 articles. As already said, standardized, transparent, and reproducible processes are of fundamental significance for introducing industry 4.0, since Process orientation and standardization can facilitate the integration of physical and digital resources in production avoiding the “digitalization of waste”.

Finally, Lack of open innovation culture and Lack of flexible organizational culture are other specific characteristics that hinders the transformation towards lean and industry 4.0 in a manufacturing SME. Therefore, management needs a long-term holistic transformation plan of above-mentioned dimensions.[61]

5. Discussion

From this bibliometric analysis concerning the relationship between lean thinking and digitalization several important points emerged to be analysed better. First of all it is important to underline that the totality of the 150 papers analysed offers a favourable opinion on the possible integration between the two paradigms, in the sense that no author completely discards the hypothesis of collaboration between the two methods, considering them in antithesis. Some authors highlight possible difficulties to overcome during the integration, while others consider that some lean practices and some technologies will not be part of the combination, but in any case all the authors affirm that through this relationship it is possible to achieve an increase in productivity, or benefits at an organizational and human level.

This consideration, combined with the fact that the subject in question is particularly recent, (given that 90% of the papers analysed were written in the last 5 years, and in 2019 were written a third of the total articles), suggests that in the immediate future the simultaneous application of lean and industry 4.0 could upset the way many companies produce, becoming an important element that every company must consider.

During this analysis, the possible synergies that can be created between the concepts expressed by the two methods, and between the individual technologies of industry 4.0 and the lean practices and tools, have been highlighted several times. Among the most important there are the use of Internet of Things, Cyber-Physical-Systems, Big Data and Simulation in collaboration with Value Stream Mapping, Kanban, Just-in-Time and Continuous improvement.

In the papers have been described many direct applications of the combination of the two paradigms: Digital Lean CPPSs, or CPPSs-based Jidoka & Heijunka production systems, refer to autonomous and cooperative human, machine and product ‘smart entities’ that co-create a networked socio-technical production environment[42]. Smart Jidoka system to reduce process variability and errors is also referred as examples of CPS enhancing Lean solutions. Just-in-time/just-in-sequence 4.0, in which Auto-ID technology, such as RFID, can be applied to track

material in real-time and to localize objects in the value chain precisely. The JIT/JIS 4.0 method additionally applies big data and data analytics techniques.[21]
Kanban 4.0. and Digital Kanban Systems (DKSs) refer to real-time digital 'pull' signalling systems that use a mix of digital technologies (e.g. smart tags, smart bins/boxes, smart dashboards and smart automation). Through simulation methods or a virtual real-time representation of physical objects based on a CAD model (digital twin), new kanban loops can be planned with more foresight and seamlessly integrated into the existing production environment. By applying Auto-ID, a constant monitoring of work in process is possible.
In Value Stream Mapping 4.0 While applying Auto-ID enables the instant localization of objects, big data and data analytics facilitate the consolidation of information. Virtual Reality (VR) could be extended to create virtual VSM's.
Total productive maintenance 4.0 refers to the combination of virtual representation technologies like virtual reality (VR) and augmented reality (AR) as well as head-mounted displays that facilitate training as well as maintenance instructions. Sensors detect when components need replacing (i.e. oil filters) or oil replenishments are necessary and send signals to maintenance staff.[3]

With regard to the overall integration of the concepts, three main trends were highlighted:

- 74 papers express the mutual support between Lean and Digitalisation
- 82 authors argue that Industry 4.0 enhance Lean
- 33 authors state that Lean is the foundation of Industry 4.0

The majority of papers highlights the support given by industry 4.0 to Lean principles: I4.0 technologies, indeed, facilitate people's work and reduce human effort (thanks to platforms of collaborative work and improved man-machine communication), connect the real and virtual world allowing accurate and timely information sharing, make production more flexible. Moreover, the availability of up-to-date, high quality data increases transparency and facilitates the identification of waste. Finally, digitalization allows a higher degree of flexibility regarding to customer requirement (e.g., by enabling product customization or last-minute order changes).[5]

33 authors instead, state that Lean thinking and principles are the foundation of Industry 4,0 implementation: Lean concepts such as work standardization, organization and transparency are highlighted as support for implementation of solutions linked to Industry 4.0. Lean thinking moreover ensures a permanent focus on customer value and waste elimination, which facilitates the identification of technologies that support these objectives.

Finally, Lean trains people as thinkers and simplifies processes and reduces/eliminates wastes so that they are not automated.

The 74 papers which sustain the mutual support between Lean and Digitalisation consider the above-mentioned benefits of both practices in a mutually supportive relationship. The symbiosis of lean and digital is expected to have high potential regarding the containment of complexity and raising flexibility as well as efficiency and productivity.

In few words, they express that the combination of lean thinking and digital technologies enables superior performance compared to a standalone implementation of lean or digital technologies.

From the numbers regarding these trends it turns out that it is above all the digital world to support a company in which Lean has been implemented, through technologies favourable to improve the lean practices in their daily use; but in any case Lean seems to be fundamental not to digitize the wastes, as well as to integrate the right organizational culture and get the employees' commitment.

Other trends identified in numerous publications regard: the reduction of wastes as consequence of the integration of the two paradigms, the positive correlation between the use simulation and the lean thinking, the positive influence of new technologies on Value Stream Mapping. Regarding the first point, 52 authors show that, both as a consequence of the fact that industry 4.0 positively supports lean principles, and as a consequence of the fact that lean is the basis for the implementation of industry 4.0, one of the main objectives and results of the integration between the two is precisely the reduction of production Wastes. Considering the effect of digitalization on lean, it is clear that different parts of the Industry 4.0 technologies have a positive impact on different types of waste in Lean Manufacturing, acting on all eight types of wastes. On the second point, 28 articles treat the use of simulation alongside with lean practices and lean thinking. Is showed that adding simulation into the Lean toolbox can strengthen, besides others, some of the main drawbacks of lean such as not considering variation, lack of dynamicity and the incapability of Lean standard tools of evaluating complex non-existing processes before implementation. Finally, 24 papers express the positive correlation between digitalization and Value Stream Mapping, highlighting that the main benefit of "VSM 4.0" is the improvement in transparency through a real-time display of value streams. This helps in identifying waste within production processes and leads to a lean value creation. Besides, the effort to carry out VSM is reduced and decisions are based on real-time data.

For what concern the increase in production and the benefits given by the contemporary application of lean thinking and new technologies, the identification and reduction of wastes is one of the fields that improves most, and that has been cited more times by authors (30 times). Thanks to the reduction of wastes there are direct improvements as increasing of efficiency and reduction of costs.
Following, the decision-making process (14 papers) according to various authors undergoes major improvements, especially thanks to the integration of simulation with VSM and lean tools in general. Moreover, the Real-time monitoring system enabled by IoT, Sensors and Cyber Physical Systems accelerates the data collection processes, leading to optimize the decision-making process [40].
Another important improvement regards "WIP, lead time and inventory reduction" (11 papers); different authors highlight as positive on this direction the combined effect of Simulation and Value Stream Mapping, Simulation and IoT and JIT, CPS and Kanban system.
Finally, are considerable the improvement regarding the human resources, corresponding to better working condition and employee engagement, enhancement of employee skills and training. Above all, is the connectedness of IoT and the distributed nature of the intelligent devices associated, each with autonomous or semiautonomous behaviour, that allow significantly higher productivity and better use of human resources by eliminating massive information gaps about real-time factory condition.

The human factor, besides being one of the reasons of the increase of the business productivity, is also the main key factor regarding the success in implementing lean and industry 4.0. Human resources commitment and integration, indeed, followed by employee skills and training, are stressed by several authors as the most important factors to consider in order to obtain an effective integration of new technologies in a lean environment. From these results is evident that employees will remain an essential part of the business processes, since lean production and automation are not mutually exclusive, but the monitoring and use by the employee is elementary and does not work as a replacement. The employee indeed becomes the smart operator of production inside this new working environment. It is highly likely that work in Industry 4.0 will place significantly higher demands on all employees in terms of complexity, abstraction, and problem solving. In addition, employees will be required to have very high levels of self-direction, communicative skills, and self-organization abilities.

For this reasons, human resources integration in this new context can be the most critical challenge that companies have to deal with. Employees resistance to changes is one of the largest challenges in both lean management and industry 4.0 application. As consequence, from the authors is suggested to companies to make standardized instructions, more specialized training, introducing new politics in the companies that will encourage people instead of scaring them.

6. Case study

6.1 Lean and digital in food sector

During the systematic literature review, a special section regarding the food and beverage sector was created, since the case study examined concerns a company working in this field. However, no papers were found directly concerning the simultaneous application and integration of lean and digitalization within the food sector. In any case, the papers in the literature dealing with the use of lean thinking and lean tools in industries within this sector have been analysed; In addition, papers dealing with the use of digital technologies to support food sector companies were analysed.

It is generally perceived that lean manufacturing principles cannot be easily applicable in industries where the production operation is carried out in large batches such as in food and drink industry [62]. Moreover, the beverage industry tends to have high product volume and a continuous process flow, it is hard to rearrange their equipment into a cellular configuration and to use pull systems. However, the continuous flow creates a high need for total productive maintenance to ensure high equipment reliability.[63] Although these considerations, all articles analysed presented a positive effect of lean implementation on companies and SMEs.

Lean Practices	Papers
Kaizen	11
VSM	10
5S	8
Standardisation	6
TPM	5
JIT	4
SMED	3
Waste elimination	2

Employee engagement	2
Customer involvement	2
Takt time	1
Flow	1

Table 7: Occurrences of Lean practices

Industry 4.0 technologies	Papers
IoT	5
Cloud	5
CPS	4
Additive manufacturing	3
Big data	3
AR, VR	3
Simulation	3
Sensors, RFID	1

Table 8: Occurrences of I4.0 technologies

From the 38 papers analysed it turns out that the lean practices more used from the companies of this field are continuous improvement/Kaizen, Value Stream Mapping and 5S; while concepts like waste elimination, flow and customer involvement appear in very few articles. The concept of Kanban is not mentioned in any article.
With regards to the technologies of industry 4.0, IoT, Cloud computing and CPS are the most cited, as was expected, while the use of RFID and sensors is treated in only one article.
Also for these papers have been investigated both the possible improvement to corporate productivity due to the use of these techniques, and the key factors that according to the authors have allowed the integration in the company of lean concepts or new technologies, resulting then in higher productivity.

Regarding the improvements obtained, the authors report the reduction of wastes and of costs in first place, followed with a little gap by quality improvement, increase of production efficiency, increase in flexibility. Here too, as in the general analysis presented above, the reduction of Wastes is the main reason for the increase in company productivity. Considering the key factors, top management commitment and support is cited 9 times, and results as the most important factor for the integration in the company of lean thinking, but is also cited as important factor for the integration of new technologies. The presence of a change agent is another considerable factor in order to successfully introduce lean concepts in the company. Even in this case the human factor is regarded an important enabler of lean thinking and technologies, since human resources skills, training of managers and employees, and employee participation and engagement are cited several times by the authors. Finally, organisational culture and communication are other factors cited multiple times. Considering the barriers specific to the nature of food processing industry, The results illustrate that the major barriers to the implementation of lean manufacturing practices are the sequential cleaning time, long set-up time between product types, and high perishability of the products. [64]

Key factors	Papers
Top management commitment and support	9
Change agent	5
Human resources skills	4
Organisational culture	4
Training of managers and employees	3
Communication	2
Employee participation and engagement	2
Nature of the process	1
Cooperation with customers and suppliers	1
Quality control and process monitoring	1
Technological context	1
Knowledge	1
PLM	1

Table 7: Key factors identified

Improvements	Papers
Reduction of waste	7
Reduction of costs	6
Quality improvement	3
Increase production efficiency	3
Higher Flexibility	2
Employees engagement	1
Improve NPD performances	1
Continuous improvement culture	1
Enhanced food safety and transparency	1
Improvement in resource efficiency	1
Customer satisfaction	1
Increase OEE	1
Information sharing	1
Reduced customer complaints	1
Standardisation	1
Improve overall business performance	1
Reduce the impact on environment	1

Table 10: Improvements identified

From these results it can be said that in the literature lean thinking is effective even in the food sector, in which companies can get substantial benefit even with limited investment. Moreover, is important for the food companies to stay competitive and robust by being flexible, responding in a faster manner, producing efficiently and delivering the required quality. Such requirements are feasible with the technological advancement in Industry 4.0 [65].

Finally, is highlighted that Top Management support is very important for manufacturer looking to create a competitive environment whilst also providing the qualified resources required for implementing Industry 4.0. In addition, The Lean management implementation success mainly depends on top management commitment, on engaging all the workers through training and by changing their habits by means of improvement tools [66].

6.2 Business context and methods applied

Cantine Quattro Valli is a winery company in Piacenza managed by the Ferrari and Perini families since 1952. It is the fulcrum of a production spread all over the world, the guarantor of a quality strongly pursued and symbol of the tirelessness of an always united family. The company is a real service centre that is headed by a series of companies distributed throughout the territory of Piacenza. The production philosophy of Cantine Quattro Valli is to offer its customers an articulated choice of wines from Italy's highest vocation areas; the rigorous principle and true cornerstone of the policy is to guarantee consumers that each and every wine offers an absolute expression of its territorial origins.

The project in which this study is involved, thanks to a collaboration between Politecnico di Milano and Cantine Quattro Valli, is called "Digital Label Management". The project aims to develop an innovative digital system to improve the management of the life cycle of labels, a component of great importance for the oenological product. The project will increase transparency and availability of information and the involvement of different stakeholders in the design, production and storage of labels for wine products. The goal is to reduce waste of time, waste and rework in both design and production.

The addressed issues are:

- The current label management process is little formalized and not optimized. There are many repetitions in the process and in the information that circulate, the lead time of certain activities suffer strong variation. It is important to understand the causes of these recirculation and long lead times because the company suffers great losses. Repeating the same activity several times, in fact, involves a waste of resources that could be re-allocated in activities that generate value for the company. In addition, a high variability in the lead time of some activities may fail to meet the deadlines required by the customer for the delivery of the product.
- Currently, a label code is used that comes from the unique supplier only when creating the order of that label. Many phases of the label's life cycle

management remain out of code. In addition, the current code is not speaking (it is not informative). This causes a strong dependence on the supplier, who is the only to provide a product code and the company must therefore depend on its timing; moreover, the code not giving information about the product often causes strong confusion and disorganization among the different actors.

- There is no single digital label catalogue comprehensive of information about: past projects, remaining physical labels in stock and information on orders that are going to arrive. This is a source of poor coordination between marketing, graphics and production, and the lack of a history of past projects makes it impossible to use a design perspective for re-design to improve future projects.

- Optimal integration of the high-productivity labelling machine into the bottling line. Failure to evaluate obsolete label codes or with problems of low rotation or high scrap, in order to be able to make the appropriate decisions about.

- Design methodology for redesign to avoid obsolescence and high waste rate in labels, as many products in stock could be reused for future projects. In addition, at the moment the label design process is not formalized by exploiting the information that comes from the field. In fact, communication with the customer is in some cases poor and his requests are often unclear, causing time losses due to further communication and changes.

My collaboration with the professors of the Polytechnic and with the employees of the company concerns: the mapping of the process through a digital method, with the objective of finding inefficiencies and re-circulations using a lean perspective; the search for criticality and possible improvements, which consider greater digitization as a possible solution; the digitalization of the warehouse, and the integration of warehouse management into managerial software, thanks to the close collaboration with the warehouse manager.

6.3 Process Mapping

The labels life cycle management process was mapped together with company members, using a digital workspace for visual collaboration called Mural, alongside with Microsoft Teams. The objectives of the mapping are:

- Clarifying the life cycle management flows of labels
- Clarify who are the actors in the process
- List the information needed in input to the various actors
- Listing what they give in output
- Which are the software used by process actors

The issue addressed is the fact that the current label management process is little formalized and not optimized since there are many repetitions in the process and in the information that circulate, in addition the lead time of certain activities suffers strong variation.
Thanks to Mural it was possible to create a framework in which every actor involved in the process has inserted its activities in temporal order, alongside with the timing of the actions and the instruments/software used during the activity. The final result was to obtain the process mapped with the activities in sequence of all the actors, starting from the request of the customer and ending with the label in the product that reaches the customer. (Annex 1)

The process resulting from the mapping is now described:
The first action is the customer's request, received by e-mail from the commercial office. Following, by email or meeting, takes place the new project brief from commercial and in parallel the new project is activated. In the brief phase, the project card file on excel is compiled by the marketing, in which all the technical data of the project are noted, thanks also to direct questions to customers during the brief; this card is sent by email to the technical management, to the workshop, to the purchasing office and to the graphic designer, then a meeting takes place between the parties. A first feasibility check of the project is made by the production team through a meeting, in order to highlight possible obstacles to the start of the process. At this stage everyone makes their own checks and then share them. In parallel,

partial checks are carried out on the indications on the labels under construction. Immediately after is given the ok from the management to start the project (less than 10% of times a project does not receive the ok, a compromise is found to continue).
At this point, the study of the customer's requests by the marketing and the graphics department takes place, through online searches, in which any examples sent by the customer are evaluated, followed by a check with the production office. Then marketing and graphic office proceed to the design of the new label through Illustrator, are therefore drawn different projects to be sent to the customer. Here is made a feasibility check of the label and the different projects together with production and printer through meetings and emails, followed by a preliminary check of the legal statements. At this point it can often happens that there are recirculation: the printer could tell that a project is not feasible because of the colour or other elements, as well as the production, who propose alternatives to return to the design of the label or to the drafting of projects, where changes to the initial idea occur. Subsequently the proposals are sent to the customer through the commercial, there is a first comparison with the customer about the graphics, and then the company receive the ok from the customer through commercial (about 50% of the times the customer does not give the ok, with regard to fonts and dimensions above all, so the process go back to ideation at design office). It is then made a final control of the legal statements, through meeting with external consultant.
Now we move to the formal part, with the arrival of the confirmation on draft with any changes and the compilation of the project confirmation form by marketing and graphic. Subsequently, the customer approves the project confirmation form and the executive draft is requested at typography, by the foreign sales office and graphic office. Once the draft is ready the approval of the customer is required by email (If the customer requires some modification, especially paint and colours, the process returns to the request for the printer's draft, about 20-30% of the time); moreover, the customer does not always require the mock-up, sometimes the process goes directly to the approval. After the approval of the draft the process proceeds with the order of the label via email to the suppliers. Therefore, the order confirmation of Scriba comes by email or phone, which includes the code of the new label, and then there is the coding of the labels in ASSO (the management software) and the coding

in Excel. Following, employees proceed loading orders on management and in parallel is created a bill of materials that is called final product card in which are inserted the article codes, labels and collars, in the management software; to these codes are linked the physical inventory of the goods and the costs. In parallel in support of the programming, the weekly Reports of the needs vs labels availability are compiled in order to have a situation of the needs with respect to the stock of labels. (In case of reordering instead, the first phase is the compilation order and sending to the supplier, followed by the confirmation of order by Scriba, then by the reception orders from commercial and by request verification stocks for putting in production. Finally the orders are loaded on managerial software.

Is then awaited the arrival of the goods, which depends heavily on the type of label and the urgency, and is monitored the arrival goods to understand when it’s actually possible to start the production.

After the goods have arrived, the graph proceeds with a qualitative control of the goods and in parallel a quantitative control of the goods is made on excel, with attached photo of the label and relative link in table. After the check, is done the physical storage on the shelf of the goods with forklift, followed by computer storage on excel. Then there is the picking of the stock necessary for the production, in parallel with the verifications regarding the use of the correct labels for the reference during picking and verification of the code of the labels in the product card during picking, related to the article code. In parallel, periodic stock checks are carried out in order to check whether the goods on the shelf correspond to the one marked on excel.

Before picking, in some cases it is necessary to print texts, lots and/or year on labels, since the labels do not always show the year.

Just before production, another check of the label code of the product sheet is made during bottling and a check of the use of the correct labels for the reference during bottling, because it may happen that modified labels are not updated in the project card; this problem is related to reorders, not to the new product.

Weighing is carried out for inventory management purposes before the start of production of a new product and once full production is started. Then the post-production inventory is added to the shelf and then the post-production inventory is added to the computer, and finally the percentage of waste is calculated by computer. A quality report is made daily between production and production, in which data are collected to improve production in the future. At the same time, supplier fault management takes place based on production problems, which involves graphic office and production. Monthly inventory extraction is done, as the managerial software does not take into account the waste. Finally, the label on the product reaches the customer.

6.4 Criticality and improvement

Following the mapping of the process, we conducted several online interviews (using Microsoft Teams) with all actors involved in the process, in groups of two or three people working along the same point of the process. The purpose of these interviews was to understand the criticalities of this process, investigating the reasons why some activities undergo large variation in timing (from hours to weeks) and by directly asking the actors which factors they consider critical during their work.

The result is a series of problems that occur along the various stages of the process and concern the activities of different actors. These issues were divided into internal to the company, external to the company and general problems.

Internal:

- Difficulty in searching products: due to the lack of a internal label code
- Lack of coordination: due to information not clear from the commercial
- Lack of communication between members
- Lack of an archive of historical labels
- Mismatch of information transmitted between marketing and commercial office

External:

- Poor communication with customer about graphics, executive draft
- Trial and Error referred to executive draft and to the style on which to set the work
- Not completeness of requests of the customer

- Supplier dependence
- Difficulty in interpreting customer requests: difficulty in language and content

Generals:

- Lack of overall vision: actors don't know the status of a Project (ongoing, approved, etc.), and don't know whether Departments are over-loaded
- Planning and prioritisation difficulties: orders are very often urgent
- Lack of logic Design for Redesign
- Total information dependence on the supplier: risk of communicating incorrect information to the customer since actors rely totally on the supplier without checking the information.
- Lack of KPI for business performance control: no indicators are calculated to analyse company performance.

Always thanks to the proposals and the help of the employees, various solutions have been conceived and proposed. It was decided together with employees to start implementing the first four.

1) Creation of a template format for collecting input from the customer, made by commercial, marketing and graphic together, so as to obtain targeted information from the customer during the first comparison and solve the problems of: not completeness on the part of the customer, mismatch of information transmitted, difficulty in interpreting customer requests. During the meetings via Teams it emerged in fact the need to create a template useful to group all the information regarding the client's order. This format would allow to share the information also to the actors who do not communicate with the client but who are directly involved in the process in the following phases. In fact, often the downstream activities must be interrupted due to the lack of necessary information not disclosed by the commercial. The format, which could be done with excel, word, or google form, has as template a table containing the necessary information chosen by all actors (nationality, label form, label colour, ecc.) with the related options from which the customer must choose. This solution requires no expense and can be designed in short time.

2) Creation of a visual catalogue which show to customer examples of labels, in order to facilitate communication with the customer and definition of specifications comprehensive of prince range, made by marketing office together with the commercial manager. This solution should facilitate the poor communication with customer about graphics and executive draft, and avoid the fact that the customer, once seen the draft, is very often not satisfied of colours and format chosen in previously. This visual catalogue could be a sort of specification which propose to the customer possible solutions with relative price range, accompanied by images to clarify the colours and formats from the visual point of view, so that the customer has a clear idea of what he prefers and in order to propose at a lower price labels in overflow in stock. This solution requires no expense and can be designed in short time.

3) Creation of an historical digital archive for labels classified by country, customer and other factors, including finished product photo/image, using PLM software or shared folders. The graphic and marketing department deal with this solution which should avoid the problems of lack of an archive of historical labels, difficulty in searching products, total information dependence on the supplier. This solution allows the company to be independent from the supplier, who is currently the only holder of a purchasing and sales history, which is a big risk if the supplier is changed in the future. In this way it is also possible to consult previous projects in a design for re-design perspective to build on them in future projects, in order to pursue continuous improvement. the investment required is low, it can be monetary if company decides to use PLM software, or it is only in terms of time of the graphic office that must deal with the issue.

4) Update of the coding system on the company’s management software, with creation of mnemonic code for each product, and integration of the warehouse management that now is managed on excel. Actually, the product code used in the company is the one assigned by the supplier. With this solution is possible to act on the issues of information dependence on the supplier, difficulty in searching products due to the lack of an internal label code. In fact, since the production uses

the supplier code, there are great difficulties in other departments such as marketing and graphic department in finding products, so a mnemonic code would facilitate searches and obtain a more orderly and standardized process. The digitization of the warehouse will be discussed in the next paragraph.

5) Creation of a collaborative IT support where all the information are aligned and everyone can enter and see the status of the activities and of the projects. This solution involves all the actors, in order to solve the general problems of lack of overall vision (actors don't know the status of a Project) and planning and prioritisation difficulties.
Two alternatives have been proposed to the company: a simple solution, based on a system of shared network folders or free project management software, which require a correct and constant updating by employees. A more complete solution concerns the use of a paid PLM software that allows the management of projects and activities at company level. This solution, however, would increase coordination between departments and improve teamwork within the company on individual projects.

6) Adding of various descriptive fields on management software in the product card. This solution is related to 4), because it is useful for the integration of warehouse management in managerial software.

Using Pollev it was possible to ask online the actors involved to indicate which solutions can have the greatest impact on their work and which ones they wish to implement first. It was therefore decided to start with the first four described here, choosing among the actors a person responsible for each project.

6.5 Warehouse Digitalisation

Another business difficulty present until recently was the physical and digital management of the warehouse. Before the arrival of the current warehouse manager in fact, the labels were located and managed in a confusing way, without a logic of locations on the shelves. In addition, there was a high number of stocks for most labels and there was no method to know how many labels were left on the reels after they were used for production. As a result, the exact number of labels in stock was not known.

When the new manager arrived, in addition to giving a physical order to the label reels and shelves, he created a digital database on excel, since the company does not have a specific warehouse management software.

QUATTRO VALLI

Codice etichetta	Descrizione etichetta	Codice prodotto	Anno su etichetta	Descrizione prodotto	Esistenza 98%	Quantità pesata	Data conteggio	Peso etichetta (g)	Peso anima (g)	Altezza anima (mm)	Peso /altezza anima (g/mm)	Note	Quantità etichette sealed	Peso Bobina 1 (g)	Peso Bobina 2 (g)	Peso Bobina 3 (g)
813848E	FRONTE	ED131MFRFC1		0,75 MOLTO FORTE VINO ROSSO D ITALIA	**17.086**	190	30/04/2020	3,7746	76,7			Rilevata a fine prod	16.900	795		
813848R	RETRO	ED131MFRFC1	2018	0,75 MOLTO FORTE VINO ROSSO D ITALIA	**432**	441	30/04/2020	2,4288	76,7			Rilevata a fine produzione		1147		
813718E	FRONTE	EG844ALDICVBE		0,75 GUTTURNIO SUPERIORE DOC COLTO VI	**2.927**	2.987	20/11/2019	1,235	41,817	79,5				3730,8		
813718R	RETRO	EG844ALDICVBE	2017	0,75 GUTTURNIO SUPERIORE DOC COLTO VI	**2.522**	2.574	20/11/2019	1,175	40,53	78	0,520			955,8	2149,5	
813718P	PENDAGLIO	EG844ALDICVBE		0,75 GUTTURNIO SUPERIORE DOC COLTO VI	**18.885**	2.944	20/11/2019	2,23	300	senza anima		Peso cartone stimat	16.000	6864,5		
813442E	FRONTE	2855		0,75 ORTRUGO dei C.P.DOC Friz. Il Poggiarel	**39.666**	5.072	20/02/2020	0,9852	32	61	0,525	Rilevata a fine prod	34.695	3330	1731	
813727RA	RETRO ANONIMA	2855	Anonima	0,75 ORTRUGO dei C.P.DOC Friz. Il Poggiarel	**8.758**	4.345	17/01/2020	0,5418	27,87	53	0,526	Rilevata a fine prod	4.500	1172	1238	
813442R18	RETRO 18	2855	2018	0,75 ORTRUGO dei C.P.DOC Friz. Il Poggiarel	**3.647**	3.722	17/01/2020	0,548	28,4	54	0,526	Rilevata a fine produzione		2068		
813442R19	RETRO 19	2855	2019	0,75 ORTRUGO dei C.P.DOC Friz. Il Poggiarel	**53.892**	3.971	20/02/2020	0,556	27,87	53	0,526	Rilevata a fine prod	50.000	2236		
813444E	FRONTE	2857		0,75 GUTTURNIO DOC friz Il Poggiarello spag	**67.535**	2.246	20/02/2020	0,9762	32	61	0,525	Rilevata a fine prod	65.333	2225		
813728RA	RETRO ANONIMA	2857	Anonima	0,75 GUTTURNIO DOC friz Il Poggiarello spag	**9.298**		21/11/2019	0,5546	24,19	46	0,526	Rilevata a fine prod	9.298			
813444R18	RETRO 18	2857	2018	0,75 GUTTURNIO DOC friz Il Poggiarello spag	**11.820**	5.939	21/11/2019	0,548	28,4	54	0,526	Rilevata a fine prod	6.000	2232	866	241,5
813444R19	RETRO 19	2857	2019	0,75 GUTTURNIO DOC friz Il Poggiarello spag	**60.000**		20/02/2020	0,556	27,87	53	0,526	Rilevata a fine prod	60.000			
813441C	COLLARINO	2857		0,75 GUTTURNIO DOC friz Il Poggiarello spag	**71.700**		16/04/2020	0,4546	17,884	34	0,526		71.700			
700276E	FRONTE	8300		0,75 GUTTURNIO DOC Frizz. P. e PERINI	**45.901**	1.939	30/04/2020	2,3596	62,594	119	0,526	Rilevata a fine prod	44.000	4639		

Figure 11: Excel database for warehouse management

The database associates each label code to the article code, moreover it associates the description of the product and the label type (front, back, collar). These data have been extrapolated from the management software of the company “ASSO”.

The most important data in the database are those related to weight management: In order to obtain the existence in stock and to know the exact quantity of labels remaining on the reels already used in production, the warehouse manager has created a weight-based method. Since the supplier is unique, the reels of the same product have a uniform core weight per cm, since are always made with the same raw material. As a result, the reels’ cores are of different heights but have the same weight/height ratio (g/mm). In this way, depending on the height, it is always possible to know the weight of the core, in order to separate it from the weight of the reel and, as consequence, to know how many labels there are. On Excel this method has been made using few columns in which inserting reels height, reels weight and weight of labels, it is immediately indicated the existence of labels for each product. The existence considers 100% of sealed labels plus 98% of the amount weighed,

to give a safety margin due to the fact that the weighing is not perfect, because the weight can change according to temperature and season.
Since working on excel is dangerous, because data can be modified or lost easily, and since one of our solution is the integration of the warehouse management on the management software, through a video call with the warehouse manager and the “ASSO” technician it was decided to integrate the management system used on excel in the management software, including weighing procedures.
It was decided to use minimum valuable product logic, starting with moving all the work of excel on the management software, while in future the company will think about how to add lots and how to manage more suppliers.
Currently in the system is not indicated the chronological of the loads and discharges of the material. In the management software there would be the possibility to make documents for each product to indicate the movements of entry and exit of the reels from warehouse, going to also integrate the location.
Parallel to this, it has been thought for the future to use a location management with barcode, putting a barcode on each label and reel and on each location, with the aim not to make mistakes regarding the labels in production, and to allow each operator to see if he pick-up the right product.

KPI

Regarding the indicators, the manager of the warehouse on Excel has introduced the percentage difference with respect to the produced quantity, to understand how much abundant to stay when it orders labels in order to minimize the stock (now it has a prudential of 3-5%). This indicator will be integrated into the software to be able to carry out this statistic.

Esistenza iniziale	Esistenza finale	Consumi	Produzione	Scarto percentuale
155174	**108350**	46825	44460	5,05%
124823	**78536**	46287	44460	3,95%
159281	**112000**	47281	44460	5,97%

Figure 12: Percentage difference with respect to produced quantity on excel

They lack instead indexes of rotation: these are essential in order to better manage the warehouse, also considering that the objective of the warehouse manager is to reduce as much as possible the stocks, aiming to adopt the just-in-time method.
To avoid over-stocks or discontinuity, flow management is therefore primary. In addition to the risks in terms of storage capacity, poor flow management can lead to an exponential increase in storage costs.
The first of the two essential indicators for the good management of supplying is the index of rotation of the stocks (or "turnover rate"). In essence, it is the speed at which the stock renews entirely over a given period, calculated using the following formula:
Total demand (over a period X) / Average stock = Turnover rate
Obviously, to achieve this calculation, company must first know the "average stock" which is determined as follows: (Initial stock + Final stock) / 2 = Average stock

As long as company can ensure that its needs are covered for a given period with a well-organized supply, it can manage just in time without fear of any stock discontinuities. With this in mind, is useful to calculate the coverage index, or "coverage rate", using this formula: Average stock / Average demand = Coverage rate

Defining this ratio allows manager to improve the management of supplies and to have the right amount of product at the right time, so he can best cover the demand from sales. Whereas the management software allows to know all loads and unloading of goods, it is easy to integrate these two indicators in the system

Future project: warehouse digitalisation

The warehouse manager has opened to the warehouse automatization and digitalisation as a future opportunity.
One of the great strengths offered by warehouse automation is undoubtedly the possibility of improving productivity, respond to the difficulty of recruiting staff to cope with peak activity and reduce the burden of tasks by eliminating some low value-added activities. Mechanization can also be useful to solve problems related

to the costs and limitations of the available surface thanks to the high density of storage allowed by some solutions

There are numerous mechanization solutions to optimize storage operations. These are automated systems that move along lanes to store and collect products in storage locations. The main technologies used are: pallet Stacker, miniload, multishuttle, carousel, AGV.

In addition, wearable technology gives employees and warehouse managers access to a lot of information in real time, regardless of their location, environment and physical constraints. Wearable devices are small computers that can be attached to the wrist, placed on the head or on any other part of the body. Devices such as smart glasses, augmented reality and voice devices are becoming increasingly popular. One of the future projects will therefore be to use new technologies to digitize the warehouse and the practices related to it, under the direction and needs of the warehouse manager. One of the first technologies considered is the implementation in the future of a digital scale connected to the network, which can reduce the margin of error of weighing.

7. Conclusion

From this study emerges a rather complete and profound vision of the integration and relationship between Lean thinking and Digitalization. The Systematic Literature Review was the method used to understand some aspects of the integration between lean thinking and digitalization that are not entirely clear and evident in today's literature. Following a process of article research and screening, 150 papers were selected and deeply analysed. The SLR highlighted first of all the fact that these two elements have been interacting for a few years, since the 4.0 industry is in continuous expansion and is of recent origin, and because initially these two concepts were seen in antithesis by many experts, given their different nature. Since 2016, however, in research, the relationship between Lean and Digitalization (represented mainly by Industry 4.0 and its technologies) has increased almost exponentially and is following a strongly positive trend. This is already a first indicator of the fact that these two paradigms could be increasingly linked in the company of the future. Of the 150 papers analysed, a good part (39%) is supported by empirical studies, such as surveys, case studies and simulations.

From the analysis conducted emerge the technologies most cited by the authors, which have been most often approached to Lean methods, together with those less cited, which are probably not suitable for integration at the moment. Conversely, the lean practices most cited emerge, which have greater, or at least more verified synergies with the digital world, together with the less cited, which could be in antithesis with the new digital concepts.

In addition, it emerges as the main focus of this study what are the real interactions between Lean thnking and digitalization, from the point of view of the support that the two systems give each other. It emerges that it is mainly new technologies that support lean management and individual lean tools, as described in 82 publications. The most common benefits are related to data collection, increase of transparency and flexibility, ease of communication between different productive actors, information processing capabilities and sharing, and data display. These technologies, if aligned with lean principles and concepts can, indeed, reduce non-value adding activities in organizations, improve the decision-making process, as well as, improving workers satisfaction. First, the availability of up-to-date, high quality data increases transparency and facilitates the identification of waste. Second, digitalization allows a higher degree of flexibility regarding to customer requirement (e.g., by enabling product customization or last-minute order changes). Moreover, accurate and timely information sharing is a fundamental condition for the success of JIT and I4.0 offers such condition as real-time information availability and extraction is a major advantage of the new revolution relying on Big Data and CPS. This leads to delivering the right product at the right time in the right quantity to the right customer.

The second trend identified, supported by 33 authors, concerns the fact that lean thinking is considered a prerequisite, or foundation, for the implementation of digitization and industry 4.0 in the company. Lean concepts such as work standardization, organization and transparency are highlighted as support for implementation of solutions linked to Industry 4.0. A simplified, waste-free process achieved through a Lean transformation, indeed, simplifies additional efforts to automate and digitize the manufacturing process, thus promoting the implementation of I4.0.

Lean principles simplify the data collection required for digital projects by having streamlined processes, which can reduce the time to integrate digital solutions. Lean thinking moreover ensures a permanent focus on customer value and waste elimination, which facilitates the identification of technologies that support these objectives. To summarize, if a company does not apply the lean principles first, it digitize waste. In practice, Lean thinking is a facilitator because it trains people as thinkers, simplifies processes and reduces/eliminates wastes so that they are not automated, reduces the possibility of compromising scarce resources, increases the transparency of work processes and organization.[8]

Finally, the third main trend identified argues that the relationship between lean and digitalization is to all intents and purposes a mutual support, in which the two production principles support and improve each other in a synergistic way; this assumption is expressed in 74 papers.

In general, Methods of lean management use simplification and standardization in order to make complexity manageable prevalently at the expense of flexibility. Digitalization has the ability to oppose this deficit. Digitalization should be applied when lean principles are carried out and manufacturing processes are geared to each other. The results are robust processes with consequent reduction of processing times, accuracy and elimination of waste, in order to have the basis for an economical implementation for digital technologies. [21]

Moreover, some authors stated that companies with higher lean and digital maturity tend to perform better, have a better organizational culture, and have a better Continuous Improvement process in place. These results suggest that although the lean principles of customer orientation and elimination of waste remain the basis of efficient production, the combination of lean thinking and digital technologies enables superior performance compared to a standalone implementation of lean or digital technologies.

From these trends it is clear how Lean and new technologies can interact and be used simultaneously within a company. All authors pointed out that there are improvements in business productivity and these improvements are primarily due to the support given by industry 4.0 to lean practices already in use, increasing the main results of lean management, such as waste reduction. However, it is also essential the contribution that lean has as a prerequisite for the successful implementation of new technologies within a company, whether it is an SME or a large company. Already from this analysis we can therefore conclude that the two elements under investigation can support each other, increasing the results that would be achieved with a standalone implementation of the two. Moreover, the main enablers of this integration have been identified, also at the level of integration between individual technologies and lean practices and tools.

At this point it was investigated how the concept of productivity changes within this relationship, and how productivity is increased within the company.

The identification and reduction of wastes is identified by 30 papers as major contribution of the integration. Since the reduction and elimination of waste is one of the principles of lean thinking, it is normal that industry 4.0, supporting lean and associated results, should help in the elimination of waste. It was then presented how digitalization affects all the different types of wastes and how the individual technologies act on lean tools to achieve this goal. The consequence on productivity is obvious, as this process allows company not to automate waste, improving the entire production process, increasing efficiency and reducing costs.

The improvement of decision-making process is highlighted by 14 articles, since the Real-time monitoring system enabled by IoT, Sensors and Cyber Physical Systems accelerates the data collection processes, as well as the retrieval of information, leading to optimize the decision-making process. Moreover, Simulation is a powerful tool for management decision making by analysing the effect of various factors of change within the system without making the actual or physical changes; the integration of simulation with VSM, in particular, could considerably improve the results obtained in lean projects, helping the decision makers in adding dynamic information to the usually considered static pictures of the processes.

The combined effect of Value Stream Mapping and Simulation brings improvement even regarding the WIP, lead time and inventory reduction, that is another important improvement identified by 11 authors. A drastic reduction of the inventory levels on manufacturing environment through the achievement of production on-demand and JIT delivery of components is the results of the Application of IoT, sensors, Cyber Physical Systems on JIT practices as Kanban.

The increase of flexibility and of transparency are highlighted by various authors: in general digitalization allows a higher degree of flexibility regarding to customer requirement, by enabling product customization or last-minute order changes.

Finally a very important improvement factor regards the human resources, since in the papers analysed lot of improvement stressed regard better working condition and employee engagement, enhanced human capabilities and employees skills, better use of human resources and training, enhanced human machine cooperation. Actually, smart feedback devices, worker support systems and improved man-machine interface facilitates better empowerment and involvement of employees in the organisation. Moreover, from a Learning perspective, and an autonomation view, modern Jidoka Systems will enable a ‘continuous learning’ of the workforce.

Finally, the key factors contributing to the positive integration between Lean thinking and digitalization, and the related challenges that could prevent the achievement of a synergic relationship between the two, were researched during this analysis.

Human Resource commitment and integration is identified by most papers to be fundamental. Human factor is one of Lean’s key point, so in addition to automation, the human resources must be better integrated into existing models, since employees will remain an essential part of the business processes. The employee

indeed becomes the smart operator of production, able to use the connectivity offered by the network created by IoT and CPS to improve its performance of flexibility, efficiency and knowledge, but keeping as a guide the lean principles of team-work organization, multi-skill, high responsibility for work within their areas .
Different authors state that staff's resistance to changes is the largest challenge and problem in lean management application. On the other hand, if employees are not educated and untrained it will be quite difficult to deal with usage of complex hi-tech equipment, machines and systems. This represents a challenge for human resources management as well because adequate skills will become much more important.
The training of the people who work in Industry 4.0 will be fundamental to succeed in the necessary cultural adaptation in this new environment, where man will work in a digital environment. Basically, following the true spirit of Lean Manufacturing, firms should not neglect the power of the 'respect-for-people' principle, even though the promise of automation is extremely attractive.
In addition to human factor, Organisational culture and Leadership commitment are considered notable key factors, because the changes in the technologies just by themselves will not aid any gain in productivity, an organizational change will be needed to support the use of the new technologies included by Industry 4.0. An investment to adapt the competences of the workers will be needed to embrace the new advances that this industrial revolution will bring. This is in line with the principle respect for people, where the personnel must be developed with the aim to maximize individual and team performance.
Customer centricity and involvement is also considered a key factor by various authors. Is possible to affirm that in the integration of lean and digitalization will remain the concept stating that the customer is always right: customer influence will keep increasing with the development of Industry 4.0. Subsequently, the focused customer orientation of lean think will stay essential, or even become more important, in the time of digitalization.
In addition to human factor, that is identified by the authors as a critical point in the company for the implementation of both Lean management and new Digital technologies, the lack of open innovation culture and lack of flexible organizational culture are other specific characteristics that hinders this transformation. Therefore,

management needs a long-term holistic transformation plan of above-mentioned dimensions.

To deepen the results of these analyses and to give an empirical value to this study, it has been involved in a project with the winery company Cantine Quattro Valli. The project's aim is to develop an innovative digital system and to make use of digital technologies in order to improve the management of the life cycle of labels, a component of great importance for the oenological product. Thanks to Mural, a collaborative online platform, and thanks to the use of online calls using Teams, it has been mapped the process of labels' lifecycle, with the collaboration of all actors. From this it was possible to understand what are the critical issues, the causes of recirculation and large variation of time in performing activities. Following, always thanks to the proposals and the help of the employees, various solutions have been conceived and chosen. This is an example of a process mapping and identification of wastes with a lean vision, enabled by use of digitalization. Between the solution ideated and chosen, that will be implemented during the following months, there are: the creation of a template format for collecting input from the customer; the creation of a visual catalogue which show to customer examples of labels; creation of an historical digital archive for labels classified by country; update of the coding system on the company's management software, with creation of mnemonic code for each product and the integration of the warehouse management that now is managed on excel; the creation of a collaborative IT support where all the information are aligned and everyone can enter and see the status of the activities and of the projects.
These solutions, made possible by the use of basic digital technologies, have been designed following lean thinking principles, with the aim to reduce waste, improve communication with customer and supplier, reduce non value added activities and lead times, increase internal communication and teamwork. In addition, the fact that these solutions solve problems proposed by employees and have been partly proposed and chosen by employees themselves, perfectly follows the lean principle of respect for people. Always in this direction, these solutions ensure that the work of each person is aligned to provide value to the customer. Moreover, lean thinking promotes the creation, use and reuse of knowledge for learning purposes, as well as some of these solutions that follow the vision of design for redesign.

Several digital technologies contribute to the use of these improvements, such as collaborative IT support, the use of management software for the digital warehouse, the collaborative platform used to mapping the process, the digital historical archive. These technologies offer the possibility to increase transparency, flexibility, information exchange both within the company and externally to customers and suppliers, connect the real and virtual world, facilitate employees work.
Regarding the digital warehouse, it was decided to integrate the management system used on excel in the management software, including the weighing procedures that are fundamentals in the system used by the actual warehouse manager in order to know the stock existence. This software will improve and facilitate both digital and physical management, as barcodes will also be assigned on products and locations. In addition, it will be possible to introduce KPIs in the software for efficient inventory management. All this puts the bases for a future automation of the warehouse, in which will be possible to automate 'true JIT ordering' on the basis of stock reduction, by the use of different sensors and smart bins/boxes to manage inventory levels in collaboration with digital Kanban systems.
In general, it was possible to see from this case study how the principles of lean thinking can be applied with the help of digital technologies. In this project the two elements support each other to increase business productivity, acting on reducing waste (both related to time and inventory), improving internal and external communication and employee working conditions, and increasing the ability to fulfil client requirements.

It should be noted that during this work there were some limitations: during the Systematic Literature Review's searching process, some articles and publications related to the topics covered were impossible to download, as Politecnico di Milano does not have access to some online databases. Regarding the case study, there were the following limitations: the project between Politecnico and the company is not finished yet, so the actual improvements will be seen only in a few months; the brevity of the project does not allow to consider more decisive interventions, while the limited availability of economic resources (being an SME) does not allow to consider the use of more expensive software and technologies in the immediate future; moreover, the particular historical period in which this project was started has strongly limited the interactions with the company, so that every activity and reunion was carried out online.

Finally, the work done so far in the case study, lays the foundations to continue the project in a direction of greater digitization, continuing to follow the principles of lean. The goal is to use innovative methods to better communicate with customers at various stages of the process, as the company produces highly customized products. Moreover, once the process will be optimized and free from wastes, is possible to think to further increase the information sharing and the internal communication, through digital software, smart devices, smart communication systems.
This study lays the groundwork for further studies on this fundamental subject, as the collaboration between Lean and Digital world will undoubtedly be tried and used in most companies in the near future, and could bring great productivity gains by acting on a myriad of business factors, as demonstrated by this work. Future studies could focus on optimal employee management in this area of integration, as it appears to be a key element for successful implementation. In addition, future studies could be based on business cases and empirical methods to demonstrate and evaluate the benefits of a firm implementing these two elements, as much of the literature on the subject is theoretical.

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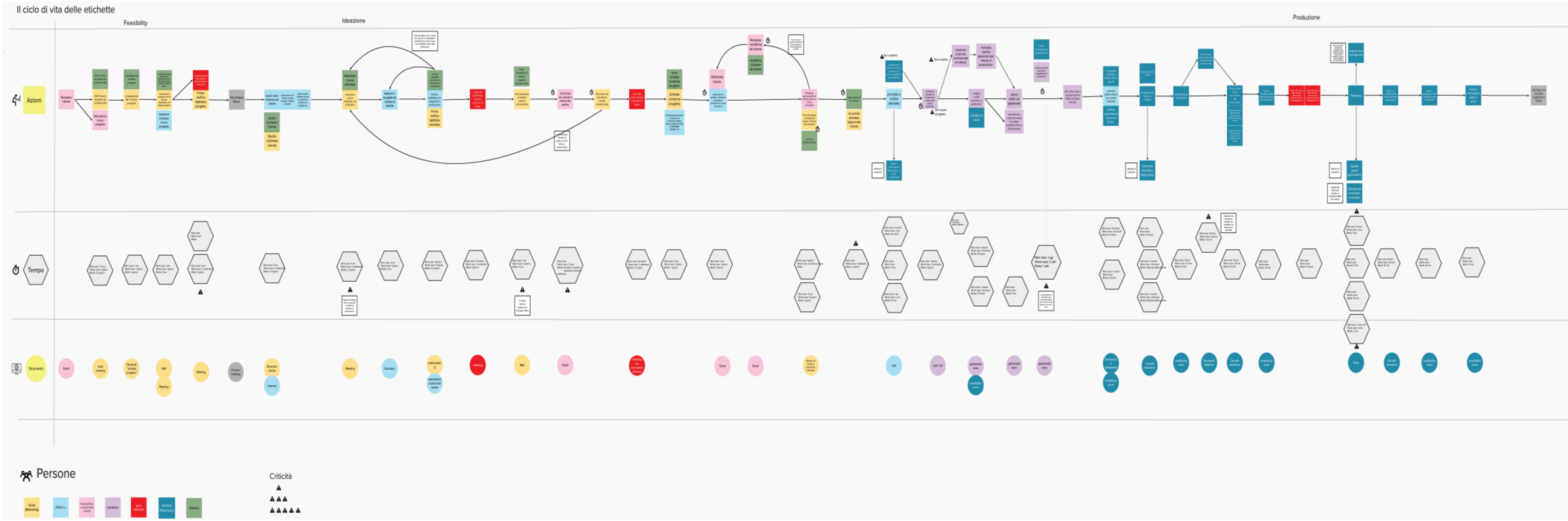
Annex 1


Il ciclo di vita delle etichette
Feasibility
Ideazione
Produzione
Azioni
Tempo
Strumento
Persone
Criticità