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"DOES LEAN HELP FOR SURVIVAL? STATISTICAL ANALYSIS OF ITALIAN COMPANIES' ECONOMIC AND FINANCIAL PERFORMANCE DURING THE COVID-19 CRISIS"

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INTRODUCTION

On March 2020, the World Health Organization (WHO) declared the pandemic state due to the widespread outburst of the Covid-19 infection. National governments worldwide had to promulgate special measures to contain the spread of the contagion, and citizens had to abruptly change their lifestyles and habits to adapt to the new situation. Significant effects were also registered for organizations worldwide, which had to reconsider their business models and operational business partially or entirely. Even though sectors were impacted with different intensities, it implied important changes in the world economic landscape.
Even though organizations in the past decades have managed to preserve the continuity of their operations during crises such as natural calamities, minor epidemics, or health emergencies (Bryce et al., 2013), the transnational nature of this event revealed the extent of their organizational unpreparedness and their lack of resilience. Moreover, the interconnection and globalization that characterizes the modern business landscape have contributed to worsen the overall effect of such disruptive event.

In the pandemic, Lean approach can be the solution: its focus on efficiency, speed and flexibility might indeed represent the optimal approach to contrast disruptive and unexpected events. However, according to literature findings, what observed in practice does not always seems to suggest such conclusion. Therefore, this paper aims at enriching the research about the correlation between the two paradigms of lean and resilience.

This research paper is structured as follows. *Chapter 1* starts with a literature review of Lean and the practitioners' insights regarding its role in the Covid-19 pandemic. Lean production is demonstrated to have significant beneficial effects for the performance of firms, with outstanding increases in efficiency through the minimization of waste, which produces cascading positive effects in terms of costs, flexibility, speed, quality, and reliability. However, several authors highlighted instead how the focus on efficiency and on resource minimization which are fundamental in Lean Production might increase the firm vulnerability to disruptive events, and might have negatively impacted the response capacity of organizations during the pandemic. Therefore, the chapter illustrates such dichotomic view witnessed among practitioners, and the possible causes and solutions.

Strictly connected to disruptive events and risk management is the notion of resilience. For this reason, *Chapter 2* provides a deeper investigation on this relatively new concept and on its interrelation with Lean. Moreover, it highlights the limits still present in current literature, and an overview of the quantitative metrics that can provide a proper measurement.

Given the scarcity in current literature concerning empirical results on the relationship between Lean and resiliency, this dissertation aims to advance the matter, by carrying out a statistical analysis that seeks to explore the correlation between these two dimensions in the context of the Covid-19 pandemic. Specifically, the analysis tries to assess whether Lean companies are more resilient to crises and disruptions.

The employed sample is represented by a dataset of 454 Italian manufacturing firms. In order to better understand the composition of the sample and its characteristics, *Chapter 3* provides an extensive and analytical description of the dataset, depicting their general features and the comparison between Lean and non-Lean adopters.

Chapter 4 goes to the heart of the research question, by describing the empirical analysis and by presenting the results. Finally, *Chapter 5* contains a summary of the main findings, also highlighting the limitations of the research, along with its possible future directions and opportunities.

CHAPTER 1: COVID-19 AND LEAN: LITERATURE REVIEW

1.1 Introduction

The Covid-19 pandemic has produced significant impacts at all levels – societal, organizational and personal. The infections have involved more than 213 countries, causing more than 6 million deaths worldwide (WHO, 2022). Many countries put into place a wide range of restrictions and regulations to try and mitigate the impact of the virus, which undeniably transformed the ways we conduct our everyday life and work (Michieli et al., 2021).

Among the many consequences and effects that the Covid-19 pandemic exposed, one of the most prominent was the disruption of worldwide supply chains, defined as "*the combination of an unintended and unanticipated triggering event that occurs at a certain point in the supply chain and the con-sequent scenario that presents a severe threat to the normal course of business operations of the focal firm*" (Bode & Wagner, 2015).

In this particular scenario, the disruption was caused by a sudden and unprecedented surge in demand from patients and consumers for some items, such as medical products, food or house cleaning items. Indeed, one of most evident effect during the first months of the pandemic was related to the shortage of goods, not only for specific medical devices, such as PPE or swab tests, but also for retail, food, and commodities. Indeed, global supply chains experienced difficulties in delivering the needed goods, as their fragility and lack of operational agility became noticeable (Sarkis, 2020). More recently, significant interest has been demonstrated towards the process of development, scale-up and administration of vaccines at the national and international level (Michieli et al., 2021).

Covid-19, as a "black swan" event, has stress-tested many operations, and made evident the fragility and unpreparedness of supply chains worldwide (Browning & de Treville, 2021): being a perfect case of demand shock, it has exposed process gaps or inefficiencies of the current processes in many sectors, healthcare in the first place. At the peaks of the pandemic, the right supply chain strategies and management practices were urgently needed for the optimization of scarce resources, to lighten the impact of shortages, and to quickly expand capacity. Facing scarcities and supply constraints requires a comprehensive strategy aimed at both demand and supply-side roots of the problem (Bohmer et al., 2020).

Since supply chain was called into question, many Operations Management practitioners have started to investigate the causes of such disruptions, in an attempt to provide relevant insights and lessons to be applied immediately in the management of the pandemic, or to prepare for future unsettling events. Predictably, part of research focused on Lean and Six Sigma practices, which gained recognition in the past decades.

This chapter wants to provide an initial presentation of the subject. It first gives a theoretical overview of Lean, describing its basic concepts, principles, and methodologies. Subsequently, it focuses on the topic subject to investigation, providing a literature review on the relationship between Covid-19 and Lean. As it will depicted later on in this chapter, we witness two opposite research streams, one claiming the positive effect for companies applying Lean in the Covid-19 situation, while the other questioning whether such methodology has impaired companies and supply chains worldwide, being one of the causes of their disruption.

1.2 Lean: a theoretical framework

Lean derives from the Toyota Production System (TPS), introduced by its owner, Taiichi Ohno, in the Japanese postwar automotive industry, as an antithesis to the mass production which was the dominating philosophy in the Western world. The term Lean and its principles were theorized for the first time by Womack and Jones, in their books "*The Machine that Changed the World*" (1990) and "*Lean Thinking: Banish Waste and create wealth in your corporation*" (1996). The core logic of such approach is the concept of minimization of waste (*muda* in Japanese), intended as everything that is deprived of value for the final customer. More specifically, Lean theory defines seven types of waste (Womack and Jones, 1996):

- Overproduction: producing more than what is actually required by the final customer. Often produced by inaccurate forecast, it is considered as the mother of all waste;
- Inventory: can be of raw materials, work-in-process, components or final products. It represents an extra cost for the organization, and it represent waste especially when dealing with perishable items;
- Waiting: it represents the time wasted, delayed or lost by an operator or a customer;
- Transportation: it represents time and resources spent to move products within or across the supply chain;

- Motion: it represents all the non-valuable time spent by an operator to perform its daily job tasks;
- Overprocessing: it includes the unnecessary steps in the production process of a product;
- Defects: caused by final products which lack the quality specifications. It is also cause of reputation loss, if the defective product is shipped to the customer.

However, according to other practitioners, waste should not be considered as the main focus of Lean; rather, value maximization should be the guiding principles, which combines efficiency and effectiveness with the intention to use the minimum amount of resources to reach the maximum output (Browning, 2003).

In the book pioneering the Lean methodology, Womack and Jones (1996) defined and generalized the five principles that can applied across firms and industries:

1. **Specify value**: the first thing that a company is called to do is the identification and definition of the value of its products. According to the Lean philosophy, such value must be set from the customer viewpoint (not only in terms of price, but also in terms of quality, features, delivery, flexibility)
2. **Mapping Value**: after having clear what the value is, a firm needs to map the flow of its production process to identify the activities of which it is composed (through a technique called Value Stream Mapping, one of the most vital elements in Lean implementation). Such activities can be of one of three types: value-added (activities that create value for the customer, and therefore must be performed in the best possible way), necessary non-value added (activities that do add any value to the customer, but must be performed due to regulatory or technological constraints, and therefore need to be minimized), and unnecessary non-value added (activities that represent the real *muda*, and therefore must be eliminated)
3. **Flow**: opposite to the traditional “Batch and Queue” approach, the Lean methodology assumes that the production process should work as a continuous flow following the “one-piece-flow” logic, where each item moves along all the stations of the production line without stopping or waiting for the rest of its batch. This approach improves the speed and throughput time, and consequently minimizes work-in-process inventory and its related costs
4. **Pull logic**: in the Lean approach, production is subordinated to actual customers’ need and demand: therefore, each stage of the operations is activated only when “pulled” or triggered by its downstream stage (and therefore, by final demand). As

a consequence, inventory is minimized, as well as the necessity of complex forecasting systems

5. **Perfection:** the final goal of lean is the pursue of perfection, not intended as a static state that will be reached at some point (and that it is impossible to reach), but rather as an ideal condition to which the company strives. To do so, lean companies apply the concept of *Kaizen*, which implies a path of small, incremental but constant improvements performed in every area and by every person within the company. To perform such pathway, a scientific method is applied, called the PDCA (Plan-Do-Check-Act) cycle, which lists the stages that have to be followed.

To delineate the theoretical structure of the Lean approach, with its underlying logics and principles and the tools and techniques to achieve them, we can resort to the illustrative image of the so-called "*TPS House*" [*Figure 1*], which pictures effectively the foundation and the core principles of Lean methodology. Starting from the foundation, which is the stability of operations (which implies processes that are not variable), Lean translates into its two pillars or main principles, which are:

- **Just-In-Time production**: it means having processes "producing the right quantity, at the right time and right time", and therefore being activated only by actual demand. This theory postulates that production should be conducted according to (1) TAKT time (which reflects the pace of the market, meaning the time required by customer to produce a product), (2) single piece flow, and (3) pull production. Such method requires workstations to be arranged in a specific way, in the so-called cell layout, often with machinery and work tools close to each other to minimize motion or transportation wastes
- **Quality (*Jidoka*):** the other pillar of Lean, also called "*Autonomation*", it means "automation with human intelligence" (Womack and Jones, 1996), and consists in the setting of a system composed by machinery and operators, where the productive process stops immediately at the first sign of anomalies, alerting the work team that are required to discover and solve the problem instantly.

Consequently, the tools and techniques through which Lean is implemented within a firm are directly based on such core values, as pictured again in the TPS House [*Figure 1*]. The most important are:

- *5-S*: one of the tools for the achievement of Kaizen, emphasizes the way in which the workplace and its tools and equipment must be maintained in order to reach stability and reliability, and provides to all employees a path to follow. The 5 S-words are Sort, Straighten, Shine, Standardize, and Sustain.

- *Heijunka*: another concept strictly connected to stability and standardization; it is a technique that implies the levelling of the production volume and of the production mix, by distributing uniformly the workload on a given time range, in order to minimize the variations in manufacturing resources, effort and demand.
- *Poka-yoke*: it identifies an error-proofing tool or procedure, that prevents the happening of human mistakes in the productive process, that in turn could generate defects on the final product.

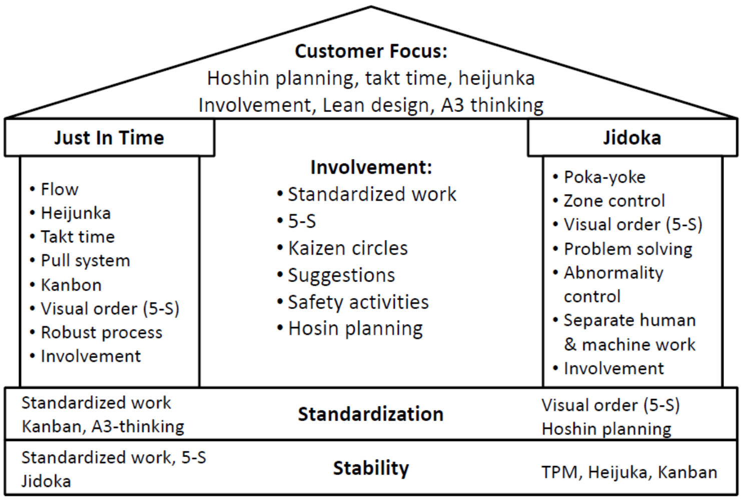


Figure 1 *- The TPS House (source: SixLeanSigma.com)*

In addition to the technical elements described above, one of the main values of Lean is its people-centric attitude, which requires the involvement of everyone within the organization. Therefore, employees in a lean company are not considered passive actors, but rather they are required to actively participate in quality circles and continuous improvement programs. Moreover, they take part in a set of activities, which includes team-based problem-solving, job rotation and enrichment, which are aimed at fostering a greater sense of engagement, personal responsibility and job ownership. The concept of involvement includes also the company's management: indeed, a diffused practice in Lean is the one of *Gemba Walks*, a Japanese term meaning "the real place", which entails that members of the management take regular visits in the production plants and learns how the employees perform their work, and the reasons behind that (Womack, 2011). This activity can prove useful not only to detect wastes and opportunities for improvement, but most importantly to connect with employees, making them more engaged and more prone to provide relevant feedbacks on their jobs (Gesinger, 2016).

One of the most relevant declinations of Lean, which finds significant attention in literature, is the Six Sigma methodology. Six Sigma is a term coined in the 1980s by Motorola; initially born as a tool for quality improvement and error reduction, today has evolved into a framework for business process improvement. It relies on the DMAIC (Define, Measure, Analyze, Improve and Control) problem-solving methodology, which employs a scientific approach based on data and statistical tools, aimed at discovering the root causes of problems within the company, therefore contributing to rational decision-making and to the systematic improvement of organizational routines and processes (Anthony et al., 2018). Another tool for root- cause analysis is FMEA, acronym for Failure Mode and Effects Analysis, which is a useful method to systematically map and detect potential defects and errors in processes and products before they enter the market, and that helps determining and prioritizing the actions and measures to adopt to perform a process improvement.

Lean and Six Sigma approaches shows relevant synergies with each other, and therefore have been integrated in a unique methodology which combines the robustness of Six Sigma and the rapidity of Lean, and it is believed to deliver superior performance in terms of process improvement (Anthony et al., 2018). Indeed, on the one hand Lean is solely focused on flow smoothing, and therefore uncapable to statistically control the process and to remove variations from it; on the other hand, Six Sigma alone cannot eliminate wastes (McDermott et al. 2021). The combined LSS (Lean Six Sigma) strategy combines human and process aspects for continuous improvement (McDermott et al., 2021). Continuous improvement program is determined by the methods of Lean, Six Sigma, LSS, agile and *leagile*, which are all part of operational excellence methodologies (McDermott et al., 2021).

After having provided a necessary theoretical framework of Lean and Six Sigma methodologies, it is clear that such approached present benefits in terms of increased productivity and efficiency, reduced costs and better flexibility. More in general, LSS application has been praised by literature due to the great improvement in the firm’s operational and financial performance. Given the Covid-19 pandemic situation that we have just witnessed, it comes natural to ask whether the implementation of such practices have helped companies to face and recover from the crisis. The remaining part of this chapter will provide a literature review on the effect of the application of Lean methodologies (including also LSS techniques) in the context of the Covid-19 pandemic.

1.3 LSS practices application in Covid-19: the beneficial effect

The first stream of literature focuses on the practitioners' commentaries and papers which explore the positive impact of adopting LSS logics, and how such practices were able to help during Covid-19 and might also aid to mitigate future pandemic-related situations (McDermott et al., 2021).

The table below summarizes the main investigations that claims the beneficial effects of LSS practices in the pandemic:

TABLE 1 *– List of studies highlighting how LSS practices can help firms recover from the Covid-19 pandemic*

Authors	Sample composition	Industry	Results & Conclusions
Hundal et al. (2021)	SMEs in developed and developing countries (N=21)	Healthcare	Identification of LSS techniques that could contribute to organizational and supply resilience. Balancing resources, task prioritization and structured problem-solving approach are the potential LSS benefits that identified in healthcare operations for COVID-19 response
Leite et al. (2020)	-	Healthcare	The effort to flatten the pandemic curve to prepare for an increased demand has resorted to a higher utilization of lean practices, but adaption is necessary to manage inventory and a wider supply chain
McDermott et al., (2021)	Panel of experts (N= 13) Qualitative Research Approach	Healthcare	The research demonstrates: 1)A link between operational excellence methodologies (lean and Six Sigma in particular) in helping treat, prevent, diagnose, and mitigate against pandemics, as well as improving healthcare process efficiency 2)Lessons learnt from Covid-19 can be integrated with operational excellence practices to aid preparedness for these events
Pellini et al. (2021) CASE STUDY	Oncological patients from Verona University Hospital (N=341)	Healthcare	Lean thinking and new technology may be beneficial for reducing SARS-CoV-2 exposure to healthcare workers and patients, maximizing preoperative and postoperative timeframes during the present epidemic, and encouraging the wise use of scarce resources while adhering to oncological principles.
Sheehan et al. (2020)	Experiment at the Children's Health	Healthcare	The utilization of Lean techniques has reduced resource utilization, resulting in costs savings and

CASE STUDY	Ireland pediatric hospital		limited personnel exposure to health risks. This has in turn produced benefits in terms of patient flow and departmental efficiency
Hung et al. (2021) CASE STUDY	Physicians in 46 departments in Northern California (N=317)	Healthcare	Lean redesign produced positive effect in patients' satisfaction and perceived quality
Julião & Gaspar (2021) CASE STUDY	Case study from a Portuguese university (N=762)	Higher Academic Education	Lean thinking can be a driver for the digital transformation of services
Muhammad et al. (2022)	Top-level managers from SMEs located in several industrial zones in Pakistan (N=28)	Mixed (food, packages, steel, foams, chemicals, automotive, textile, checkboard)	Both Lean and Six Sigma positively relate to efficiency, profit and growth
Praharsi et al. (2021)	Case studies (N=25)	Maritime	The implementation of LSS practices can help the industry overcome its inefficiencies and support continuous improvement processes, to maintain the resilience of supply chain in the Covid-19 environment
Sodhi (2020)	Literature review	Manufacturing	Manufacturing industries should implement Lean Six Sigma tools and techniques in order to recover from the after-effects of the Coronavirus
Mishra and Sarkar (2021)	CEO of MSMEs in India & LSS experts (N=127)	Mixed (glass, food, wood, metals, chemicals)	Despite the recognized benefit of LSS practices, its application is prevented by some constraints (high costs, excessive time needed, scarce skills), and some MSMEs cannot implement it due to its complication
Parameswaran & Ranadewa (2021)	Literature review	Construction industry in Sri Lanka	22 benefits derived from the implementation of Lean in the post-Covid scenario

Source: personal elaboration

Predictably, the greater amount of research has focused on the healthcare sector, since the demand shock caused by COVID-19 has severely and suddenly disrupted the whole operations, affecting the resource utilization and exposing the constrained capacity of healthcare system, given that hospitals were already running close to full capacity. Indeed, the sudden increase of patients has created operational bottlenecks, as perceived for example in the Italian healthcare system due to the limited availability of ventilators to treat COVID patients (Leide et al., 2020).

While on the one hand the application of governmental measures regarding social distancing, restrictions and the use of face masks have contributed to the smoothening of demand, it is still necessary for healthcare to find a comprehensive strategy to manage the flows of patients entering the system and coming in contact with its several touchpoints to receive care (Bohmer et al., 2020). LSS practices had already been applied to several healthcare contexts, including both direct and indirect patient care (Hundal et al., 2020), which resulted in lower inventory levels and improvement of performance and process efficiency (Honda et al., 2018).

Capacity in public healthcare is measured by the availability of a wide range of resources, primarily hospital facilities, financial and human resources, and most importantly bed capacity (William et al., 2020), while patient waiting time is considered the core metric according to which evaluate the efficiency of the standard procedures in place (Hundal et al., 2020). The increased demand caused by the pandemic has pushed hospitals to saturate their capacity utilization by controlling simultaneously the variability of supply chain processes and of patients' arrival rate (Leide et al., 2020). Also, the efforts of governments and hospitals directed at flattening the pandemic curve translated into a level loading approach (Leide et al., 2020), in an attempt to smooth demand variability as much as possible and to allow supply chains to absorb possible peaks

Recent research has focused on the investigation of LSS practices, questioning whether they have the potential to mitigate the disruptive effects of COVID-19. According to Hundal et al. (2020), the application of Lean and Six Sigma is particularly effective in a crisis situation where a resource shortage is experienced, to make the processes more efficient and reliable and to create continuous improvement and learning. A wide range of LSS techniques have been inspected, in terms to their potential to help healthcare organizations face the COVID-19 crisis: process flow mapping, VSM (value stream mapping), data analytics, FMEA and poka-yoke proved to be the most used and effective tools to ensure an appropriate response to COVID-19, in terms of resource balancing, task prioritization, and in the implementation of a strategic and structured problem-solving approach [*Figure 2*].

A closely related theme is organizational resilience: since LSS practices involve the identification (and consequent mitigation) of possible risks and critical points through a controlled and systematic problem-solving approach, they often result in process improvements that in turn improve resiliency. More specifically, for companies to apply a proactive approach, process control through continuous improvement projects that can decrease its variation, risk assessment through FMEA, and root cause analysis, are the LSS tools that are able to build such capability, especially in the areas of business operations, patient safety, and ER improvement

(Hundal et al., 2020). Furthermore, one of the most important concepts that promotes supply chain resilience is workforce flexibility, since through cross-training and job rotation of employees, hospitals are able to guarantee diversified skills and to allow an easy substitution of personnel if necessary.

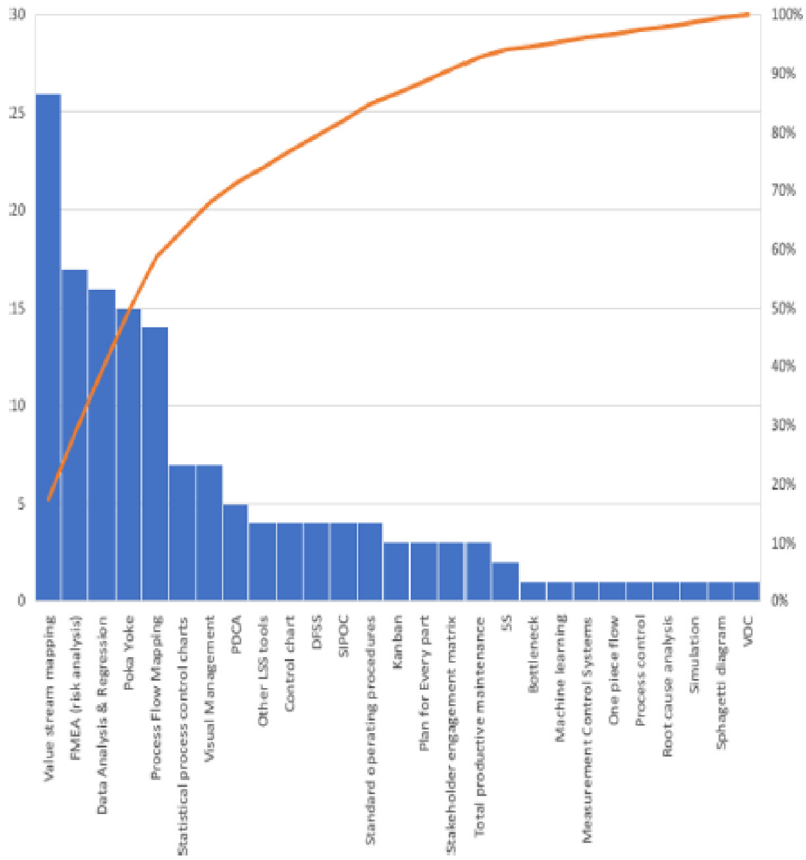


Figure 2 *- LSS tools for Covid-19 response in healthcare operations (Source: Hundal et al., 2020)*

More specifically, value stream mapping is used to map both the current and future desired states of operations, and to spot the gaps that have to be filled, in terms of operational inefficiencies and non-value adding step or resources (Hundal et al., 2020).

Hospitals have been subjected to a great deal of renovation, that included the redesign of their layout according to flow principles, the introduction of 5S and standardized procedures, and the creation of new multi-disciplinary teams (Leite et al. 2020). In particular, the definition and application of punctual specifications has exhibited a great importance, as there was the case for PPEs procurement, where a significant presence of faulty items caused significant wastes, as well as further delays and disruption in the supply chain, with enormous repercussion on the entire healthcare environment.

Moreover, the use of 5S logics combined with visual management systems allowed on the one hand to easily spot out-of-standards conditions, while on the other to aid patients to follow the stricter behavioral rules which had to be introduced to guarantee personal distancing: clear examples are the use of floor signs and directional markers which indicated to patients the path to follow for a smoother flow, or the visual boards and cartels with the indications to follow in public places (McDermott et al., 2021) [*Figure 3*].

Figure 3 *- example of visual tools*

For the 5S methodology, the *Seiso*, the “cleaning” step, started to become fundamental to prevent the contagion, and became one of the main governmental measures to be put in place not only in hospital, but also in every public place. A systematic value stream mapping has contributed to the elimination of the unnecessary wastes and to the minimization of the patients’ exposure to contagion risks, also ensuring smoother flows, through layout re-design and the increased deployment of telematic solutions. Finally, the concept of *poka yoke* has been applied on a large scale, with the introduction of error proofing tools which have become part of our everyday life: for instance, the redesign of door handles, public toilets and sanitizer dispensers that prevent users from directly touch them [Figure 4].

Figure 4 *- examples of error-proofing tool*

Instead, Six Sigma practices have proven to be beneficial most in terms of capacity planning and risk measurement: the most deployed tools are second-source supplying to ensure in-stocks, DMAIC scientific approach that is helpful in ensuring the choice of the most accurate results measures (McDermott et al., 2021), and Failure Mode Effect Analysis (FMEA) to craft contingency plans and the related training, to aid healthcare systems for the prioritization of critical inventories, and for the identification and consequent mitigation of risks (Hundal et al., 2020).

It has also been seen that healthcare systems have applied SMED and quick changeover logics, reorganizing their layouts and configurations to face the increased volume of tests required (McDermott et al., 2021), as well as rearranging their structures in the longer term to adapt to the new situation, with the introduction of virtual medical services and industrial and cross-vertical cooperation among public, private and non-profit organizations (Kaiser, 2020). But this was not only a prerogative of healthcare environments: indeed, we witnessed many examples of companies who reconverted their operations to manufacture medical equipment or other needed goods where the pandemic was at its peak: for instance, luxury clothing organizations started to produce masks, gloves and gowns, while automotive multinationals transformed their production for ventilators and hospital beds (Ivanov and Dolgui, 2021).

According to Leite et al. (2020), in the healthcare section there are some operational challenges arising from the pandemic which require LSS responses. Specifically, low bed capacity might be addressed with a level capacity plan reached through flow redesign and VSM technique, the postponement or utilization of telemedicine for non-urgent medical treatments, and the employment of non-public structures as temporary facilities. Moreover, lean practices have been largely utilized to manage the increased demand in a situation of low capacity, in order to guarantee operations' stability and patients' safety. However, other issues require opposite responses, more similar to traditional predictive approaches. For example, resource shortages related to supply chain disruption (such as the ones related to PPEs, swab tests or other specific medical equipment) have exposed the inadequacies of JIT systems for inventory management: instead, the prevention of such lacks should involve the setting of a proactive plan which involves strategic inventory, closer collaborations with suppliers and cross-vertical cooperation agreements with local organizations.

Similar conclusions were drawn from case studies in the literature that dealt specifically with healthcare issues, such as the treatment of oncological patients (Pellini et al., 2021) or for pediatric patients (Sheehan et al., 2020). Both studies highlight how the use of Lean may help minimize waste, staff, and resources (and consequently costs), as well as keep compliance with health and safety regulations.

Positive results were reached (through Lean redesign of physical spaces and of working teams flows) also in relation to patient satisfaction (which is directly related to decreased waiting times) and access to care, which are imperative metrics to measure the quality of primary care delivery (Hung et al., 2021), and receive particular attention specifically in the healthcare field, since they represent the most sensitive indicators for customer value and operational efficiency.

While most of the available literature on the issue focuses on the healthcare industry, being it one of the most affected sectors and being hospitals the main characters of the pandemic, there are also some literature pieces which have concentrated on other industrial segments. Septically, the service industry has been put under investigation, since the pandemic has suddenly impaired the provision of multiple services, and the possibility to carry them out in person had been severely reduced or even eliminated. Many sectors have been involved apart from healthcare, from education to catering, from transportation to physical activity. For many service companies, this required a change in their business processes and systems, with the aim to deliver the same services through an online mode, where possible (Julião & Gaspar, 2021). In such digital transformation, lean methodologies can represent an enabler that allows organizations to effectively accelerate such change, and to keep their competitiveness without compromising customer satisfaction. Examples of that can be found in the literature, for example in the service redesign of higher education institutions (Julião & Gaspar, 2021), where lean thinking and methodologies such as process mapping, root-cause analysis, and PDCA cycle, have been applied to improve academic services and reduce waste and inefficiencies.

Another literature stream focuses on the manufacturing sector, given the fact that Lean found its first and most extensive application in such industries. For instance, studies have been developed on Indian manufacturing MSMEs, which represent the 90% of the total business structures in the country (Mishra and Sarkar, 2021), showing how Lean and Six Sigma practices represent a helpful toolkit to mitigate the impact of the pandemic and to recover from its after-effects (Sodhi, 2020), not only regarding the standard dimensions (costs, productivity, quality, speed, waste management) but also from the employees point of view, it can be seen as the most effective learning and training instrument that allows to spread and augment skills and abilities (Mishra and Sarkar, 2021). Similar conclusions were reached in studies focused on SMEs in the industrial zones of Pakistan (Muhammad et al., 2022) and Indonesia (Syaputra et al., 2020), which have shown how implementing operational excellence enables organizations to benefit in terms of efficiency, profit and growth (Muhammad et al., 2022).

However, despite the recognized benefits of such production method, the application of LSS methodology is still lagging behind in those countries because it displays several constraints: for instance, the unaffordable initial implementation cost, the time needed for the setup, and the advanced statistical skills, which if absent, they may prevent data from being processed and Six Sigma to be applied (Mishra and Sarkar, 2021). For this reason, simpler tools are preferred, such as Kaizen and PDCA.

Moreover, with the work of Parameswaran & Ranadewa (2021) in Sri Lanka locations, the building business is another area that has been researched. The authors demonstrated a positive effect of Lean implementation in 8 categories (including resource, quality and project management issues), and with Prahasi et al. (2021) who performed an extensive study in the maritime sector regarding the shipbuilding, logistic services and shipping industries in Indonesia, showing how the implementation of LSS practices can help the industry overcome its inefficiencies and support continuous improvement processes, and to maintain the resilience of supply chain in the Covid-19 environment.

Apparently, the Covid-19 pandemic pushed researchers to suggest the application of Lean methodologies as the best practice for recover, useful also for strengthening the company’s position in case of future external disruptions. Nevertheless, it must be noted that the available research on the relationship between Lean and Covid-19 in the manufacturing had focuses mainly on cases from developing economies, and this constitutes a limitation.

1.4 LSS practices application in Covid-19: the detrimental effect

On the other hand, a different stream of literature research underlines how Lean practices have exposed their inability to cope with the supply chain disruptions brought by the emergency worldwide situation, shading a new light on Lean and other process improvement approached, by putting into question its real beneficial value, which has always been praised by literature and operations management key opinion leaders, and found benefits also in financial rewards (Barket et al., 2022).

In *Table 2* below, there is a list of the authors supporting such statement.

***TABLE 2** – List of studies highlighting how LSS practices had a negative impact for companies adopting them in the Covid-19 pandemic*

Authors	Sample composition	Industry	Results & Conclusions
Micheli et al. (2021)	Literature review	-	JIT supply chains are fragile and easily disrupted. Trade-off between efficiency and resilience needs to be reconsidered
Kuiper et al. (2021)	Case studies on Dutch healthcare institutions	Healthcare	Lean application in healthcare results in less capacity and flexibility, which are needed to absorb excess demand in case of an external shock
Allon (2021)	-	-	The over-focus on Lean objectives regarding inventory can make companies unprepared for supply chain disruptions
Ivanov and Dolgui (2021)	Literature review	-	The pandemic has revealed the fragility and unpreparedness of supply chains worldwide, especially due to ripple effects and structural dynamics
Harvard Business Review (2021)	-	-	The increased uncertainty of the current and future situation requires a new strategic approach for efficiency. Agility becomes the new focal point.
Sarkis et al. (2020)	Literature review	-	The fragility of an excessive dependence on just-in-time and lean delivery systems has been made clear by the COVID-19 epidemic. Geolocalization now serves as the tactical reaction.
Bryce et al. (2020)	Literature review	-	Lean production methods are useful to manage strategic and short-term risks, but are vulnerable to extreme operational stress

Source: personal elaboration

The first and most obvious limit of Lean supply chains is the minimization of overproduction and inventory, which can be severely harmful in the event of logistic disruptions, readily causing shortages in supply, production and distribution, product outages and delivery delays. Such theory is not new in literature: in their research conducted in the US manufacturing sector, Eroglu and Hofer (2011) determined that lean methodologies are beneficial to companies' performance only up to a certain degree, and that a degree of buffer stock becomes necessary to ensure smooth operations. The Covid-19 unprecedented crisis aggravated abruptly such side-effect of Lean: faced with such difficulties, many sectors (including automotive and paper) were forced to re-evaluate their pledge to Lean philosophy and redesign their supply chain to allow for recovery (Barker et al., 2022).

According to Micheli et al. (2021), the pandemic has exposed the fragility of JIT supply chains, which had already been revealed in the past years, when Lean supply chains increasingly experienced disruptions in capacity due to suppliers' disruptions and demand modifications. The continuous and incremental improvement approach, which is a core element in LSS mindset, might in fact slow down the reaction process to demand and capacity disruptions, for which instead speed and flexibility represent an essential requirement (Micheli et al., 2021). While JIT supply chains can prove useful in managing strategic risks in terms of demand oscillations in the day-to-day operations, they have shown their vulnerability to high operational stress (Bryce et al., 2020) and their lack of capability to respond to high volatility levels in the marketplace (Habibi Rat et al., 2021). Indeed, the threats of large unpredictable events (like a pandemic) are not incorporated into Lean Six Sigma projects, which instead are primarily focused on the improvements of stable daily operations (Kuiper et al., 2021).

The healthcare sector was again and unsurprisingly under scrutiny: for instance, Kuiper et al. (2021) have performed a study on the Dutch primary care system, where Lean methodologies have been implemented in the past years with the aim of improving operations (not different than other Western countries). The case highlighted how the focus on efficiency (which have led to the minimization of buffer inventories and the setting up of demand very close to capacity), as well as the dependency of the supply chain network (which make it difficult a fast provision of resources in case of emergency), have aggravated the mismatch between demand and supply when the pandemic erupted, and leading to the fast shortage of medical equipment and hospital beds. National government responded with increase of buffers and the arrangement of a national procurement plan, which are costly strategies but, if further developed, could change the strategic supply chain landscape, impacting other sectors as well. Additionally, leaner operations implemented in the healthcare facilities were considered as one of the causing factors of the bullwhip effect experienced in the Covid-19 crisis, causing the propagation of the demand shock in the entire supply chain. Such consequent has led noy only to aggravate the shortages in the short term, but also to the counter-effect of resource surpluses in the long time.

The downside of Lean has perceived also in other sectors: the automotive industry, which has historically been considered as the pioneer of the Lean approach, had witnessed in recent years many companies, including Toyota, withdrawing from JIT production modes (Allon, 2021) with the aim to create a system "antifragile" supply chains (Micheli et al., 2021), and such trend is expected to exacerbate in the next years. The complications that this sector had to face derived from the fact that many processes were organized Just-In-Time and inventory was available for a period of about 30 days at maximum. Moreover, suppliers and factories have been located in different regions, and subject to different timing of shutdowns and lockdowns (regardless of whether globally or locally organized). As such, even the available inventory or backup capacities were not accessible for longer periods of time (Ivanov and Dolgui, 2021) and the collaboration between supply chain partners was no longer feasible (Bryce et al., 2020). Finally, the worldwide shortage of semiconductor chips had severely impaired the production of the whole industry, with the big players being unable to replenish their inventory (Harvard Business Review, 2021). It is expected that if the automotive industry will radically change its strategic direction and its supply chain configuration, it will also affect other sectors, not only because automotive has usually been the marketplace leader and pace-setter, pioneering and anticipating future trends, but also because its extensive supply chain, which includes adjacent sectors, will adapt to their main client, relocating and changing as required (Allon, 2021).

Some authors assert that the globalization trend that the economy has experienced over the past few decades has helped to establish a complex global production and distribution system, where resources and components are shipped all around the world. This implies a high degree of dependence among all the components of the supply chain, which could further exacerbate the mismatch between supply and demand (Kuiper et al., 2021).

The answer to the threats that lean delivery systems may induce to businesses might imply a return and re-introduction of traditional inventory systems, with buffers and safety stocks. The example of Switzerland, which from 2016 had accumulated inventory of essential food and healthcare products to prevent supply chain outages, and was less affected by the pandemic, with hospitals and supermarkets able to experience the disruptions to a lesser extent, is a significant one supporting that solution (Bryce, 2021). Even Toyota, the father and pioneer of Lean, responded to the crisis by setting up stockpile of resources and supplies of the utmost priority and importance (Harvard Business Review, 2021). Other solutions might include the utilization of flexibility (Kuiper et al., 2021), the creation of intermediate stocks of goods and components to prevent extensive transportation and making local sourcing easier (Sarkis et al., 2020), or the redefinition of the network of supply chain by replacing the global networks by "glocalized" systems, where global and local aspects are intertwined (Sarkis et al., 2020).

However, the common belief among such theories does not translate into a complete condemnation of Lean systems and logics: the authors try to expose how the problem does not rely in Lean system itself, but rather in the way in which Lean philosophy has been mis-used by companies, or over-relied on, and the excessive emphasis that has been put on inventory and waste minimization (Allon, 2021), in the "lack of slack" of the system (Harvard Business Review, 2021). Employing efficiency as the only strategic direction and purpose might create unsafe strategic gaps in case of demand disruptions and makes companies unprepared to deal with such challenges. Instead, they rather highlight the need to re-think the trade-off between efficiency and resilience, to adapt to the high volatility that have witnessed in the Covid-19 crisis, and that we will continue to witness in the future (Allon, 2021); such re-thinking process of supply chains will impact the perception that lean and other process improvement approaches had until the present (Micheli et al., 2021). The primary difficulty of this new age will ultimately revolve around striking a balance between Just-In-Time effectiveness and Just-In-Case strategy (Harvard Business Review, 2021).

On the other hand, other authors have instead underlined the role of agility, and that the pandemic has brought a new era which will be marked by destabilizing events and where uncertainty and demand variations will be always more frequent. To deal with a such novelty, a change of direction is needed, which can be summarized as "flexibility as the new leanness and agility as the new efficiency" (Harvard Business Review, 2021). The already observed tendency is to depart from JIT supply chains, and to create "anti-fragile" networks that are able to respond quickly and efficiently to disruptions in capacity or demand (Micheli et al., 2021).

To conclude, Chapter 1 contained a literature assessment of the research works about Lean and Covid, with the aim to try to understand whether such production method is able to benefit companies in times of crisis. However, the necessity for a resilient supply chain to respond to a pandemic is a subject that frequently accompanies the Lean narrative in literature, and it is also one that is strictly related to Lean and is particularly pertinent in times of disruption. Given the relevance and significance of this component, the following chapter will perform an in-depth examination of the connection between resilience and Lean production.

CHAPTER 2 – LEAN AND RESILIENCE

2.1 An overview of resilience

In the turbulence and volatility which characterize the modern world, supply chains have become used to face risks with an increased incidence and degree (Li et al., 2016; Bhamra et al., 2011). Therefore, supply chain management studies have focused on resilience as the tool to respond to the disruptions that put into threat the normal course of business of the organization. This concept is treated within a variety of scientific disciplines, including ecology and sociology, where it is generally described as the ability of an element to return to a normal state after an external disturbance (Bhamra et al., 2011). In the organizational setting, resilience can be defined as the "*systemic capacity of the supply chain to absorb the negative external disturbances and restore the operational regularity*" (Ivanov, 2021). It is a continuous process (Bryce et al., 2021) requiring a dynamic capability of adaptability (Purvis et al., 2016), because it demands to companies to constantly find new adaptive solutions to the multiple pressures coming from their external and internal environment. Resilience combines two essential skills: the capability to diminish the destructive effect triggered by a particular risk or a crisis, and the ability to return to an acceptable level of performance thereafter (Habibi Rad et al., 2021). Resilience is often linked to enterprise risk management (Ponomarov and Holcomb, 2009), which is the practice dealing with the identification of potential risk sources, along with the testing of possible solutions to mitigate their effect of weakness on supply chains. However, some authors argue that resilience differs from traditional risk management practices, because the latter must entail the quantification of disruptions (Pettit et al., 2013) and therefore it is unable to assess low-probability, high-severity events (Pettit et al., 2010).

According to Meyer (1982), resilience presents three main subsequent phases: *anticipatory*, *responsive* and *readjustment*. The first element is based on the ability of firms to spot and elaborate in advance signals of potential disruptions, along with the possible consequences that may bear on the organization (Bryce et al., 2021). Such forethought will also extend to include the so-called "planned resilience" (Walker et al., 2021), intended as those risk management plans that are created to minimize the impact in the event of a crisis or a disruptive externality.

The responsive phase concerns instead the way in which the organization reacts to the crisis in its immediate happening, neutralizing its negative effects before they occur (Singh et al., 2019), and requires network flexibility (Habibi Rad et al., 2021), redundancy, robustness and collaboration (Singh et al., 2019). Finally, the readjustment phase concerns the firm's recovery in the aftermath of the crisis, in case the disruption has stopped the supply chain (Singh et al., 2019). This classification is partly resumed by Ponomarov and Holcomb (2009), which identity the three elements of *preparedness*, *response* and *recovery*, and by Li et al., (2016), who claimed that in order to build supply chain resilience capabilities, organization must complementarily adopt a *proactive* approach (corresponding to the anticipatory phase) and a *reactive* strategy (corresponding to the responsive and recovery stages). An extension of this framework is provided by Jovanović et al. (2020), which identify five phases of a resilient infrastructure: understanding of risk, anticipation and preparation (both prior to the disruptive event), absorption (at the beginning of the event), response and recovery, and finally adaption/transformation (after the event),

One of the main issue concerning resilience literature is the current lack of a uniform and accepted classification of the defining elements and dimensions that constitute this paradigm (Li et al., 2016; Shen and Sun, 2021): for instance, according to Ivanov and Dolgui (2021), resilience has three components: *robustness* (ability to withstand), *flexibility* (ability to adapt) and *recover* (ability to restore performance and operations after a disruption); instead, authors such Li et al. (2016) claim that its shaping elements are *preparedness* (to undergo future changes), *alertness* (to externalities) and *agility* (in the response to the changes); while the former element is essential for a proactive approach, the last two define the reactive strategy. Also, de Sà et al. (2019) argue that the elements that construct resilience within the organization are visibility, velocity, redundancy, flexibility, and collaboration between supply chain members; such capabilities, however, are required to be developed in different degrees at the different disruption stages which have been detailed before. Nevertheless, the most comprehensive research study on the topic was presented by Pettit et al. (2010) who identified 14 capability factors (defined as those supply chain attributes that help the organization to prevent a disruption or to recover and adapt from it): flexibility in sourcing and order placing, reserve capacity, efficiency, visibility, adaptability, anticipation, recovery, dispersion, collaboration, organization, market position, security, and financial strength.

In order to develop resilient capabilities and systems, the current literature proposes different strategies and practices. On the procurement side, the creation of a flexible supplier base is considered a good mean to face unexpected externalities, through for instance the geographical segregation of contractors or the establishment of backup suppliers (Hosseini, Ivanov and Dolgui, 2019), contract flexibility and incentive agreements, risk pooling, and delayed commitment (Pettit et al., 2010). Similarly, flexibility on the logistic side is reached through multi-sourcing and replacement options for raw materials, multiplicity of distribution channels and rerouting options (Hosseini, Ivanov and Dolgui, 2019), tracking systems to enhance transportation visibility (Ruiz-Benitez et al., 2018), as well as product strategies like alternative uses and modular design (Pettit et al., 2010). On the capacity side, the preservation of buffers and excess inventory in production and storage (Hosseini, Ivanov and Dolgui, 2019; Ruiz-Benitez et al., 2018), as well as backup sources (Hosseini, Ivanov and Dolgui, 2019; Pettit et al., 2010) are practices that aid the organization to meet the new demand arising from unpredicting event. Another important and highly cited strategy concerns the introduction of systems and procedures that improve the collaboration, coordination, and communication between all the actors of the supply chain (Hosseini, 2019 and Pettit et al., 2010; Ruiz-Benitez et al., 2018). Such procedures are aimed at increasing the visibility of operations and of the environment, which can generally be improved by managing the interconnected operations between multiple tiers of suppliers and customers, along with the employment of business intelligence tools (Pettit et al., 2010). Other practices mentioned in the literature include utilization of control information systems (Ruiz-Benitez et al., 2018) and finally, contingency planning, simulation and forecasting to increase anticipation and adaptability (Pettit et al., 2010). However, the different mentioned authors have never applied the listed tactics in a simulation, or neither analyzed their actual effectiveness in the face of disruptions (Cardoso et al., 2015).

However, literature reports a general scarcity of empirical research (Bhamra et al., 2011), especially regarding the relation between resilience capabilities and firms' economic and financial indicators. Pettit et al. (2013) and Li et al. (2016) have conducted studies on the manufacturing industry, which underlined a positive correlation between the two dimensions. In particular, Li et al. (2016) claims that the above-cited element of *preparedness* appears to be the strongest predictor of performance, therefore suggesting that the proactive approach is a more rewarding and effective strategy that a reactive one. Higher degrees of resilience have also been empirically correlated to higher levels of performance in terms of delivery, costs and time to recovery, despite showing a not significant impact on flexibility performance (Lofti and Saghiri, 2018). More in general, resilience has been connected to the sustenance of competitive advantage (Purvis et al., 2016). Given that, it is also important to note that the most relevant downside of resilience is the fact that it creates expensive systems, due to the complexity of the structure, and to the costs connected to maintaining flexibility and to ensure redundancy (Ivanov and Dolgui, 2019). Thus, resilient companies must learn how to solve the trade-off between high cost and risk mitigation (Purvis et al., 2016).

Current research also reports the scarcity of frameworks and assessment tools for resilience: for instance, Pettit et al. (2013) defined the SCRAM™ tool, through which firms can assess their resilience level based on a set of 14 resilience capabilities and 7 vulnerability factors [Figure 5]. The logic behind that is that firms must reach a state of balanced resilience, depending on the degree of which the possessed capabilities are matched with the type of vulnerabilities to which the company is most exposed to (Pettit et al., 2010).

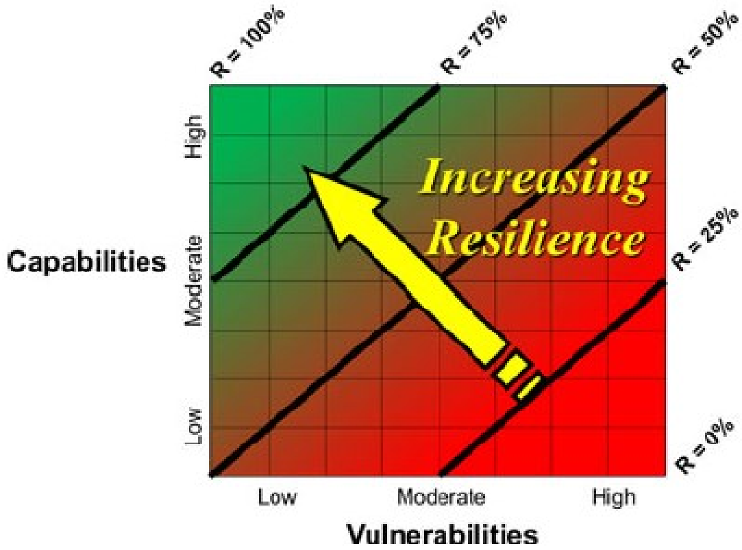


***Figure 5** – Resilience Framework (Source: Pettit et al., 2013)*

Although literature on resilience is still at an early stage, given the novelty of the topic, and even though available works underlines a scarcity of empirical research (Shen and Sun, 2021), operational resilience has often been indicated as the best answer to supply chain disruptions. However, the inadequacy of literature, including the lack of a unique definition of such new concept, has significant implications for further research and may negatively influence future works.

2.2 The relationship between resilience and leanness: opposite or complementors?

Resilience competences and lean practices have often been considered together in supply chain management studies. However, there is a general lack of consensus in literature about the

relation between these two dimensions (Habibi Rad et al., 2021), and whether they have a positive or negative connection (Benitez and Real, 2018).
Apparently, lean and resilience may appear as contrasting forces, requiring a trade-off for the organization (Alemsan et at., 2022), due to their inherent diversity in objective: indeed, Lean is focused on resource efficiency, and aims at eliminating buffers and stock in the processing flow through a logic of "pull" demand: however, such waste minimization practice makes supply chains more exposed to unforeseen disruptions. On the other hand, authors such as de Sà et al. (2019) have argued how redundancy represents one of the most cited factors needed as resilience capabilities, which is achieved mainly through the investment in safety buffers and backup suppliers: such practice is evidently in contrast with Lean principles, therefore alimenting the divergency theory. In fact, as already exposed in Chapter 1, some authors have claimed that lean production methods have made organizations more fragile and less flexible in the presence of disruptive events (Ivanov and Dolgui, 2021). Another trade-off factor is represented by cost: several authors have argued that improvement in resilience is accompanied by the increase in operational costs (Purvis et al., 2016), therefore the efficiency increases connected with Lean are usually associated to a reduction in resilience and vice versa (Ivanov and Dolgui, 2019).

However, supply chain management literature also includes studies claiming the synergistic nature of these two paradigms. For example, Lofti and Saghiri (2018) empirically inferred that high levels of leanness are not detrimental to the company's recovery time and performance, and therefore lean can be considered a practice for the enhancement of resilience in the supply chain. Birkie's (2016) research proved that resilience and lean practices showed significant complementarities, and firms displaying high lean implementation are usually accompanied by high levels of resiliency. However, the author notes that TPM and JIT practices exhibit instead an inverse contrasting relation with resilience, probably due to the fact that they are strictly related to the manufacturing part of the operations, and therefore can have only a limited role in the anticipation and mitigation of external disturbances.
Ruiz-Benitez et al. (2018a) empirically demonstrated in the aerospace manufacturing sector that lean and resilience paradigms are closely connected, as some lean practices are enabler for resilience capabilities when the organizational objective relates to the improvement of operational and financial performance: indeed, the implementation of lean methodology alone could render the supply chain more vulnerable and exposed to disruptive threats. In particular, the most important lean strategy (that facilitates the adoption of other lean strategies, as well as of resilience capabilities) is the establishment of cooperative, long-term and mutually trusting

relationships with suppliers; on the other hand, the most impactful resilience capability is the creation of a flexible supply base. The author additionally argued that both lean and resilience are concurrent to the improvement of supply chain sustainability (Ruiz-Benitez et al., 2018b). Similar results were confirmed by authors such as Ivanov and Dolgui (2019), who claimed that the precondition to effective lean management is the adoption of a resilience paradigm into the processes of a supply chain, and by Uhrin et al. (2020), who argued that lean production systems should be implemented together with resilience practices to face uncertainty and unexpected events. Also Hills (2013) opined that the lean perspective represents a useful approach to face crises, highlighting in particular the role of human respect and valorization, as well as decentralized decision-making, which fosters employees' continuous training and learning, creating an organizational environment more robust to disruptions.

Other authors claim that the redundancy feature that is distinctive of resilience may coexist with a Lean methodology and its inventory-minimization perspective: indeed, many Lean companies, including auto manufacturers, introduced emergency stocks in critical nodes of their supply chain as a backup in case of crises (Hosseini, Ivanov and Dolgui, 2019). To this end, Cristopher and Rutherford (2004) argument is that supply chain resilience can be achieved through the agile Six Sigma methodology, where spare process capacity is placed in critical stations, in order to reduce the exposure to risk without compromising efficiency; however, the idea is that a total lean approach will expose supply chains to excessive vulnerability, and that therefore an "optimal level of leanness" must be found to allows the organization to incorporate the possible costs of disruptions.

Finally, the redesign of supply chains to incorporate lean and resilience may also have benefits in terms of costs control (Purvis et al., 2016).

The literature is far from unanimous about the interrelation between the two dimensions, and sometimes the results seem paradoxical: for example, Pettit et al. (2010) cite as the resilience capability elements either Capacity and Efficiency: while the former is reached through redundancy and the setting up of excess buffer inventory, the latter implies the typical Lean practices, including waste minimization.

Nevertheless, the review of literature research reveals that often the conclusions depend on the specific lean and resilience practices which are implemented within the organization (Habibi Rad et al., 2021). Thus, the conceptual model designed by Carvalho, Duarte and Machado (2011) is probably the most complete, and pinpoints synergies and divergences depending on the supply chain features which are taken into consideration: indeed, while the synergies between lean and resilience are connected with *integration level*, *replenishment frequency*, and *information frequency*, as well as reduced *production* and t*ransportation lead time*, on the other hand, there are other features, namely *inventory level* and *capacity surplus*, which have opposing effects within the two paradigms, and therefore cause discrepancies.

Table 3 presents an overview of the main characteristics of these two paradigms, to give a synthetic view of their commonalities and discrepancies. Instead, *Table 4* goes more in depth, considering some relevant supply chain attributes and describing how they are declined in the two paradigms, to give a deeper understanding of the similarities and differences.

TABLE 3 *– Synergies and divergencies between lean and resilience*

Elements	Lean	Resilience
Waste elimination	+	
Inventory Minimization	+	
Continuous Improvement	+	
Contingency plans	+	
Just in Time production	+	
TPM (Total Preventive Maintenance)	+	
Visibility	+	+
Collaboration with suppliers	+	+
Readiness		+
Pre-event response		+
Post-event response		+
Recovery		+

Source: Habibi et al., 2021

TABLE 4 *– Declinations of supply chain attributes in Lean and Resilience*

SC Attributes	Lean	Resilience
Purpose	Waste minimization (intended as every activity that is non-value added), to deliver a product with the best quality and at the minimum cost	System ability to return to its original state after a disturbance, in order to ensure demand fulfillment in the case of disruption

Manufacturing focus	Pull production logic, and focus on lower costs through high utilization rates	Focus on flexibility (minimum lot sizes and capacity reservations); scheduling is based on common information
Alliances with suppliers and customers	Establishment of long-term, cooperative and trusting alliances with existing suppliers	Supply chain partners form an alliance network for knowledge-sharing and development of security practices
Network organization	Decentralization of hierarchical structure and responsibility	Decentralization, diversification, localization, segmentation
Approach to suppliers' choice	Choice of low cost and high quality/reliability/flexibility suppliers Single sourcing	Multi-sourcing Flexible sourcing (backup suppliers)
Inventory strategy	Minimization of stock and elimination of WIP buffer inventory	Strategic emergency stockpiles at potentially critical nodes
Lead time focus	Reduction of lead time (as long as it does not increase costs)	Reduction of lead time
Product design strategy	Maximum performance with minimum costs	Postponement to ensure product flexibility
Pricing strategy	Low margins (price is a key customer driver)	High margins due to high resilience costs
Product variety	Low	High (product substituition)
Market	Serving only current market segments, with predictable demand	Have the capabilities to act on and anticipate changes in markets and overcome demand risk

Source: Carvalho, Duarte and Machado (2011); Ivanov and Dolgui (2019)

Despite the lack of general consensus among the nature of the interrelation between lean and resilience, we witness literature research that has focused on the incorporation of these two paradigms within the organization, which to date have generally been developed separately, since apparently, they present different purposes and objectives (Habibi Rad et al., 2021).

One of the most significant contributions is provided by Ivanov and Dolgui (2019), who proposed an innovative supply chain framework, called LCN (Low-Certainty-Need) that is less dependent on external risks, and combines lean and resilience logics in the new dimension of *resilieanness.* Since the ultimate purpose of this framework is the ability to maintain the prearranged performance irrespective of external environmental changes, it requires two essential capabilities: a low need for disruptions prediction (which require costly investments), and a minimum need of coordination and re-planning efforts for the after-event recovery. To achieve so, its characterizing elements are *structural variety and complexity reduction*, *utilization flexibility of process and resources*, and *non-expensive parametric redundancy*. The new LCN supply chain differs from traditional, high-certainty systems, since instead of setting up costly and static methods for absorbing pre-planned disruptions, it creates dynamic and highly adaptable supply chains that can rapidly reconfigure themselves in the event of an external disruption: this allows for gains in efficiency.

Other research inputs on the topic include authors such as Mohammaddust et al. (2014), who modeled an innovative supply chain system that can be employed by organizations to select their optimal supply chain design (in terms of number, location, and capacity of nodes) and the appropriate set of risk mitigation strategies, depending on whether the organizational performance objective is related to lean or resiliency. Similar results are highlighted in Maslaric et al. (2013), who assessed the relation between lean and resiliency from the perspective of risk management, by delineating a matrix which combines lean with uncertainty levels, and that evaluates case by case depending on the type of risk, demand and supply, proposing the optimal strategic response for each risky situation [Figure 6]. In this way, a balance between the paradigms of lean and resilience is assured (Habibi Rad et al., 2021).

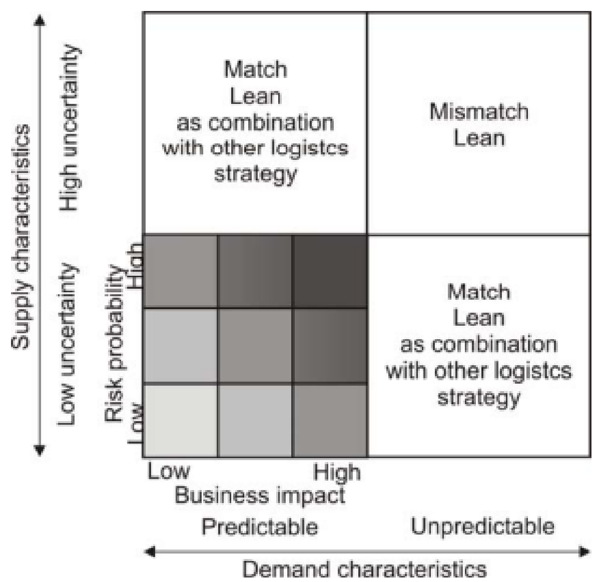


Figure 6 *- the integrated matrix (source: Maslaric et al., 2013)*

The integration has also expanded to include further dimensions: for instance, Carvalho, Duarte and Machado (2011) have conceptualized the LARG framework, which combines together also the green and agile paradigms. The rationale behind that presumes that the commonality among all these paradigms is their final purpose, which is to meet customer demand at the lowest cost (Habibi Rad et al., 2021), but the difference lies in the process and methodology through which such objective is reached. Another example is provided by Purvis et al. (2016), who conceived resilience in a wider environment, as a function of a wider set of paradigms, including leanness [Figure 7]. The authors designed a model, called the RALF tool, which elaborate new organizational strategy and actions to build resiliency by analyzing the four resilience criteria of robustness, agility, leanness, and flexibility.

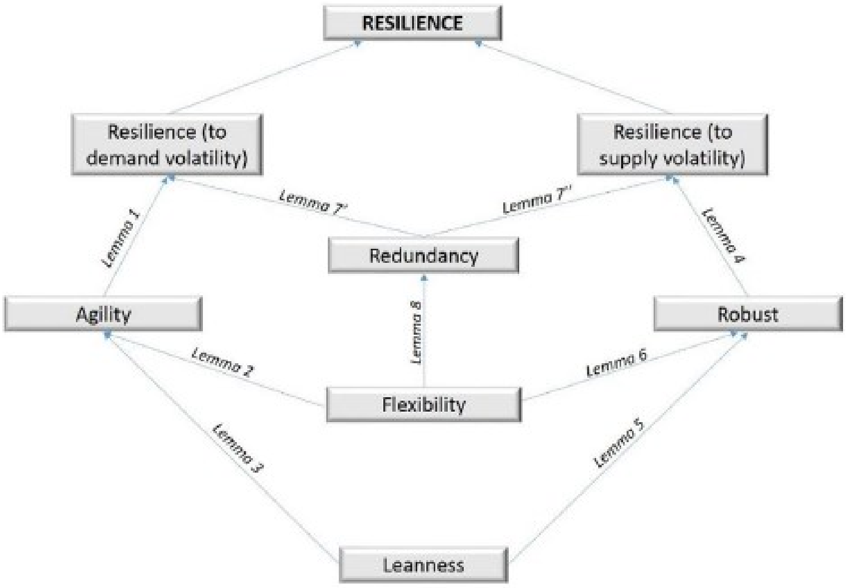


***Figure** 7 – Drivers of resilience (source: Purvis et al., 2016)*

In conclusion, literature frequently pointed out the scarcity of quantitative research regarding the effect of the combination of resilience with leanness, which is also due to the difficulty in selecting appropriate and significant supply chain performance measures (Habibi Rad et al., 2021). Moreover, the opportunity for future and additional research is emphasized, as well as the need to define specific research areas on the topic, in order to foster a better understanding of the underlying dynamics between the two dimensions.

2.3 Resilience and lean production in the Covid-19 crisis

The topic of resilience gained a boost in importance and urgency in the context of the recent pandemic, as an example of low-risk, high-impact disruptive event, that put supply chains under considerable risk (Ivanov and Das, 2020). Covid-19 brough out the need for organizations worldwide to improve resiliency to face the new situation (Trabucco and De Giovanni, 2021), and therefore, several authors focused their study on the reactivity of companies and supply chains to such crisis. Again, research results are contrasting.

For instance, Alemsan et al. (2022) conducted a scoping review centered on the healthcare supply chain, observing how lean practices show a highly relevant relationship with resilience, and in particular are linked to the capabilities of efficiency, visibility and collaboration. More specifically, visual management techniques and work standardization can help improve the clarity and the knowledge of the state of the operations, therefore increasing its visibility, while Value Stream Mapping and inventory management improve the communication between actors in the supply chain, promoting collaboration. Similar conclusions were reached in other sectors, such as construction (Paramewaran and Ranadewa, 2021). Also, Trabucco and De Giovanni (2021) empirically proved that during the Covid-19 crisis lean strategies improved firm's business sustainability (intended as the firm's capacity to mitigate performance losses in the event of a disruption, within the economic, social, environmental and operational fields), which in turn was positively correlated to resilience; however, their analysis did not prove true for all factors, as for instance the preservation of costs, delivery time, customer service and inventory availability were not displayed connections to resiliency.

On the other hand, Ivanov and Dolgui (2021), investigated whether Lean supply chains, whose core logics are JIT and single-sourcing, actually show less resilience, and therefore reveal their inadequacy in a pandemic setting, where instead traditional measures (such as high-cycle and safety inventories, backup suppliers, or capacity buffers) might prove to be more useful. According to such authors, lean supply chain values and methodologies might have been one of the primary factors of *ripple effects* during the pandemic (described as the triggering impacts of disruptions along the supply chain, and the cascading and propagating effect of failures on the whole network), alongside with global sourcing and global production: however, they note that this does not necessarily implies that JIT inventories are less resilient than traditional, high-level inventory systems, because a significant variable to take into account is represented by the accessibility of such supply chains, as their location has to be reachable for both in-bound and out-bound logistics.

Ivanov and Das (2020) highlight how the pandemic has brought unique implications for supply chains, and how it is intrinsically different from other low-probability, high-impact disruptions, due to the fact that, unlike similar events like natural disasters or terrorist attacks, it is not confined in a limited time window or geographical area. Consequently, the impact on the different nodes of the supply chain is dilated in time and variable, as the different facilities and storages can be forced to undergo a stop either simultaneously or one after the other. Given the unicity of this event, the traditional resilience strategies adopted to manage the connected business risk have limited effect: for instance, the institution of subcontracting facilities and the accumulation of emergency inventory, both typical attributes of resilience, can help to mitigate the effect of the disruption only for a limited initial time, but the prolonged and increasing closure of facilities and suppliers due to lockdown will inevitably cause stoppages and performance losses, making these measures useless in the long-term. According to the authors, resilience strategies should focus on real-time adjustments, for example by the continuous opening and closing of the facilities at the different supply chains nodes.

Other research works instead has highlighted how Covid-19 has made evident the inadequacy of the whole theoretical framework that permeates the concept of resilience. Thus, research on such concept has been developed through the last decades in an effort to react in a systemic way to external disasters and disruptions: its insufficiency depends on the fact that its focus relies on the setting up of assets and reactive plans that intervene only when a disruption actually occurs, instead of treating resilience assets as active and value-creating components of operations decisions (Ivanov, 2021). The introduction of new theoretical frameworks, for instance the AURA (Active Usage of Resilience Assets) approach, which claims that the introduction of redundancies, contingent recovery plans and visibility systems as active resilience assets, will allow to reach a real state of lean resilience. By fundamentally shifting the way resilience is considered, organizations could reach real lean supply chains.

The unexpected and sudden crisis of Covid-19 has accelerated some trends and research topics that practitioner had highlighted in the light of the environment we are facing. In the following years, resilience will be considered the most important capability of supply chains, and many practitioners agree that we will witness a shift in paradigm, from design-for-efficiency to design-for-resiliency (Ivanov and Dolgui, 2021). However, this does not necessarily imply that Lean methodology will disappear or lose its importance. Even though it appears to be no unique judgement and solution to the interrelation between lean and resilience, many authors have questioned how the focus on supply chain resilience and flexibility, which has become imperative after the Covid-19 crisis, will influence the perception of lean practices (Micheli, 2021). The common view is that the two dimensions have synergistic potential, and further research is needed to analyze their interdependencies and to develop new frameworks and tools that incorporate them to achieve operational excellence.

2.4 Resilience indicators: a literature review

One of the main flaws of resilience literature concerns the identification of metrics and indicators that are able to quantitatively and significantly measure resilience within organizations and supply chains, as well as more broadly in the whole network. Moreover, they often coincide with risk management indicators (Shen and Sun, 2021).

The range of proposed indexes is varied. For instance, Barroso et al. (2015) started from the concept of the "Resilience Triangle", which depicts the reaction of the firm in the face of a disruption on the dimensions of time and performance [*Figure 8*], portraying either the disruption severity (the depth of the triangle) and the recovery time (the triangle's length). The impact of the disruption corresponds to the area of the triangle, which therefore must be minimized to reach the optimal level of resilience.

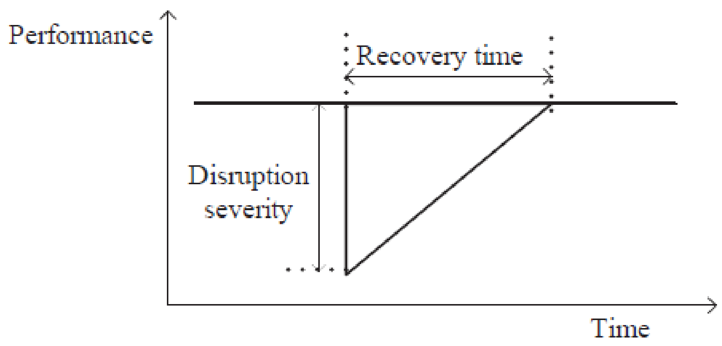


Figure 8 *– The Resilience Triangle (Source: Barroso et al.,2015)*

According to the authors, proposed performance metrics (the y-axis) are lead time ratio, total cost or fulfilment rate.

In particular, the resilience ratio is defined by the authors as in the equation below:

$$R_i = 1 - \frac{\int_{t_0}^{t_1} (P_i - P_{it}) \partial t}{P_i (t_1 - t_0)} \cong 1 - \frac{\sum_{t=t_0}^{t_1} (P_i - P_{it})}{P_i (t_1 - t_0)} = 1 - \frac{\sum_{t=t_0}^{t_1} \left(1 - {P_{it}}/{P_i}\right)}{P_i (t_1 - t_0)}$$

where the performance of the firm is calculated over a time period that goes from the pre-risk situation to the recovery moment.

A similar framework was partially retaken and expanded by Jovanović et al. (2020), who designed a resilience matrix based on the five stages of crisis reaction, and five dimensions involving the resilience process [*Figure 9*].

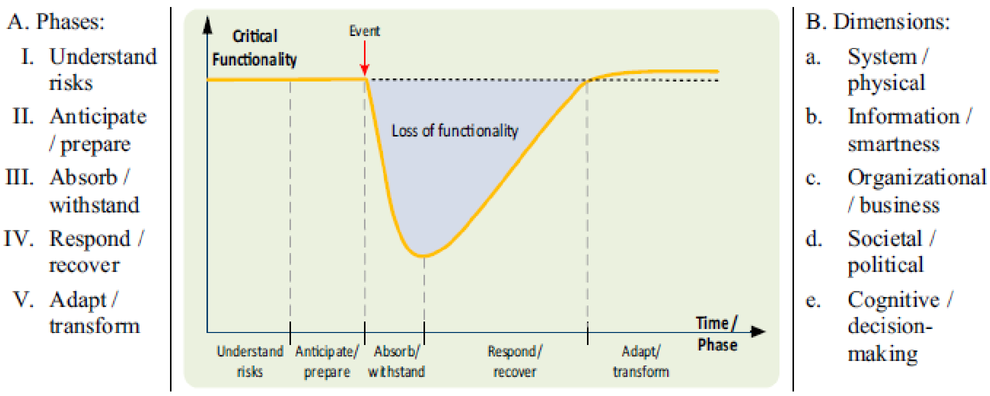


***Figure 9** – The Resilience Matrix (source: Jovanović et al., 2020)*

They therefore identified two methods for resilience assessment through indicators: the direct method aims at calculating the area of the functionality curve through the identification of appropriate macro-indicators (such as Robustness, Absorption Time, Functionality Loss, Recovery Rate), while the indirect assessment deconstructs the framework in a bottom-up approach, measuring indicators for each issue (intended as every factor that can constitute a resilience element) in each of the phases. This framework differs in that the selection of the examined indicators is different every time, since it relies on the specific disruption that the company must deal with.

Instead, Torabi et al. (2015) proposed a calculation of resilience loss based on the three types of capacity individuated by Hosseini, Ivanov and Dolgui (2019), absorptive, adaptive and restorative, corresponding respectively to the resilience strategies of inventory pre-positioning, backup suppliers and restoration of disrupted suppliers. The loss in capacity and the time to recover associated to each of these practices are used to calculate the area represented in *Figure 10*, which depicts the disruption effect occurring in the organization in terms of capacity; again, this area must be minimized to reach a resilient condition.

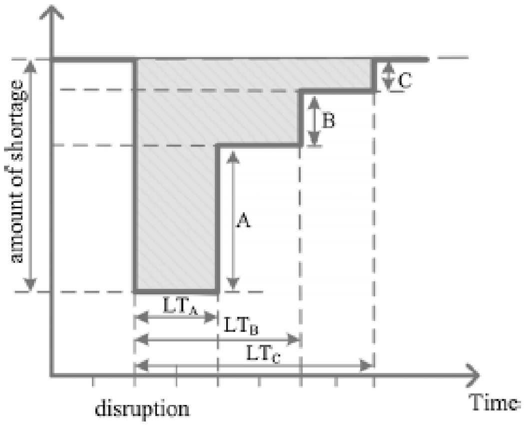


***Figure 10** – Recovery process after a crisis (source: Torabi et al., 2015)*

The resulting equation for the resilience metric is detailed below, where RL stands for the resilience loss, $\mathbb{Q}$ represents the needed number of items, while T denotes the length of the recovery process.

$$R = 1 - \frac{RL}{\mathbb{Q} \times T}$$

An alternative calculation of index considers instead the service level (Ojha et al., 2018), calculated again over the time period between the pre-disruption and recovery moments.

$$R = 1 - \frac{\Sigma\left(\frac{Sw}{S_0}\right)}{w_H - w_0}$$

Other simpler proposed indexes are the TTR (Time To Recover), defined as the time required to a supply chain node to restore to its normal condition and full functionality, and the TTS (Time To Survive), defined as the time under which a supply chain node's performance is not impacted after a disruption (Simchi-Levi et al., 2015). Some authors embrace also classical measures, such as expected net present value or expected customer service level (Cardoso et al., 2015).

Further works (Karl et al., 2018) performed a deep review on the different metrics utilized in resilience literature, and identified the most commonly used non-financial operational indicators to be *capacity utilization*, *stock level*, *delivery* and *order lead time*, *quality of final products*, as well as customer-related KPIs such as *customer satisfaction* and *damage return* *rate*. Moreover, the authors connected such indicators with the different constituent elements of resilience. The results are summarized in Table 5 below.

***TABLE 5** – Common KPIs in relation to resilience factors*

	Stock Level	Order Lead Time	Delivery Lead Time	Capacity Utilization	Quality of goods	Supplier Delivery Efficiency	Customer Satisfaction
Security			x			x	x
Knowledge management		x	x	x	x	x	x
Information sharing	x		x				x
Robustness	x						
Redundancy	x	x					x
Collaboration					x	x	x
Risk Management	x	x	x			x	
Agility	x	x	x	x		x	
Flexibility		x	x	x			

Source: Karl et al. (2018)

Similar results are theorized by other practitioners: for instance, Rajesh (2016) enumerated a set of non-financial metrics, which are aggregated according to five indicators, that overall can measure the level of resilience of a firm. The metrics are associated to flexibility (which is measured by stock-out rates, or inventory accuracy rate), responsiveness (on-time delivery ratio, product put-away time ratio, supplier contract approval time), quality (forecasting quality, percentage of tested products, shipping accuracy), productivity (percentage of back order, suppliers' fill rate, storage space utilization), and finally accessibility (network intensity, proportion of retailer or supplier with direct access to the manufacturer). The indicators were then utilized in a grey prediction model to generate future forecasted value.

In conclusion, resilience is still a new and partly unexplored area of research (Cardoso et al., 2015), and the lack of a unified definition makes the identification of a unique appropriate index more complex. In particular, there appears to be a scarcity of empirical research regarding the relation between financial KPIs and non-financial resilience indicators (Karl et al., 2018), as in most cases, indexes are related to supply chain-specific measures associated to time and capacity.

CHAPTER 3: DESCRIPTION OF DATASET

3.1 Introduction

As seen in the previous chapter, literature on the relation between LSS practices and Covid-19 has mainly focused on qualitative elements, but it is often not supported by data. Therefore, this study aims to explore the impact of Lean on the pandemic performance of companies, in a more quantitative fashion. More specifically, the main research question that will be investigated is whether companies that apply Lean performed better than others after the impact of the pandemic.

To perform such analysis, the main source of data retrieval is a survey developed by the Department of Economics and Management, in 2018. The survey was submitted to manufacturing firms concentrated on the Italian territory, between 2018 and 2019, with the purpose of inquiring on the features of the productive systems and processes of the companies, with a specific focus on Lean practices. The questionnaire was divided into two sections: the first collected information on the registry of the surveyed companies, collecting general information such as name, number of employees, main site location, whether it was a family company, percentage of profit registered abroad, sector, and many others. Instead, the second went into a detailed investigation on Lean techniques, exploring whether they are implemented and, if so, their extent of diffusion and application.

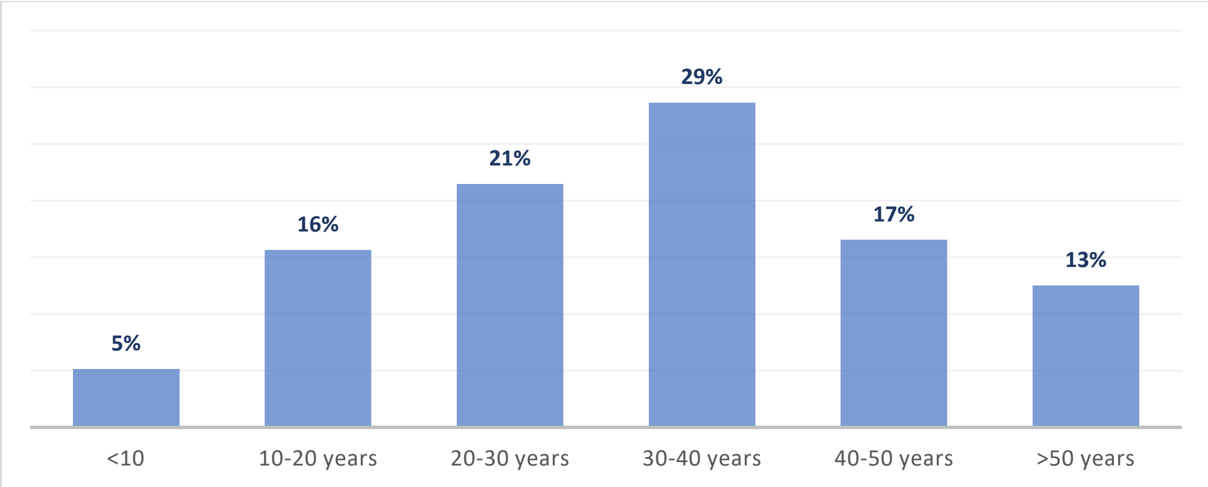
The data have been collected into an Excel database, containing also a wide range of economic and financial indexes of the companies of the sample, such as EBITDA, ROE, Debt on Equity ratio, ROA and production average inventory. The existing data, which covered the period 2008-2018, were integrated with the performance of the years 2019 and 2020, retrieved through the Orbis database, which gives access to detailed financial information on more than 400 million of companies worldwide, both listed and not listed.

In the following section, a detailed description of the sample will be performed.

3.2 Sample identification – Section 1: Demographics and features of the firms

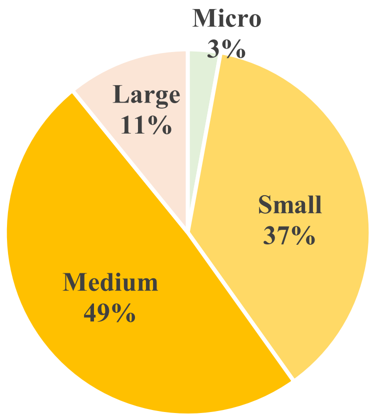
The utilized sample consists of 454 firms, categorized according to different demographic information. The first and most basic dimension to be examined is the age of the organizations, determined as the difference between the current ear 2022 and the year of foundation indicated in the survey. *Graph 1* pictures the proportion of companies according to their years of life: as depicted the majority of firms belongs to the range 20-40 years.

***Graph 1** – Age of sampled companies (N=447)*



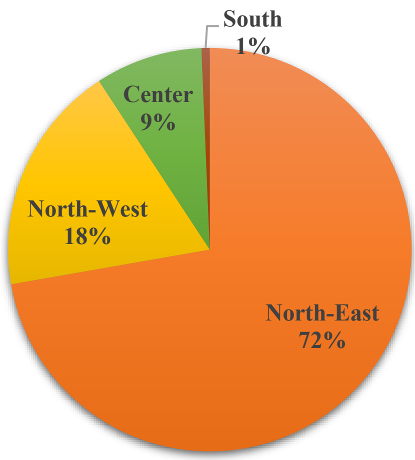
The next feature concerns the companies' size, determined by their number of employees: according to Recommendations 2003/361/Ce of the European Commission, companies are classified as micro if they have less than 10 employees and an annual turnover not superior to 2 million euros; small enterprises have up to 50 employees and an annual turnover not superior to 10 million euros, while medium enterprises have less than 250 employees and an annual turnover not superior to 50 million euros. In the considered sample, out of the 451 respondents, 13 of them are micro enterprises, 168 are small enterprises, 221 are medium, while the remaining 49 are considered big enterprises. In *Graph 2* it is possible to observe the distribution, with almost half of the sample (49%) being classified as medium enterprises. Such result is in line with the country trend, with medium enterprises constituting the heart of the Italian economical fabric (source: AIDAF Yearbook 2015).

Graph 2 *- Size of sampled companies (N=451)*

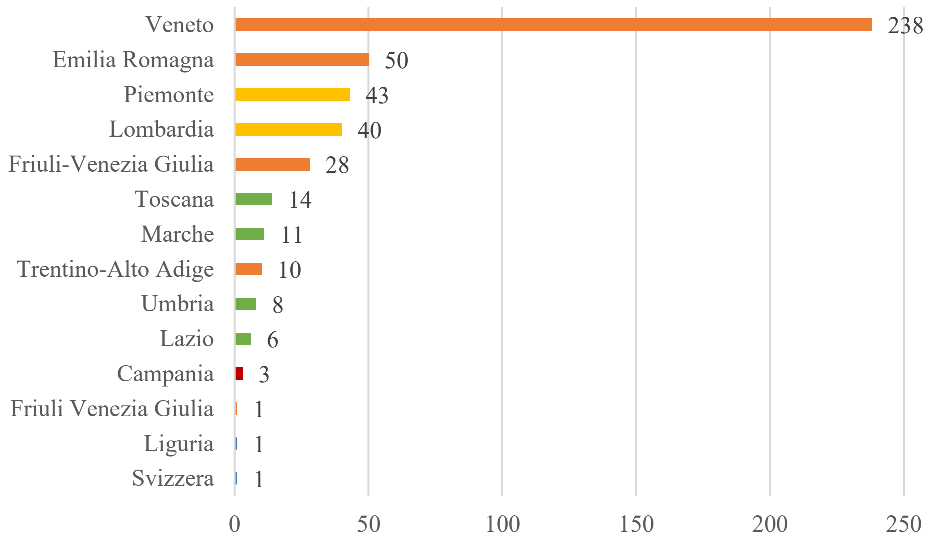


A further dimension that has been considered is related to the geographical location of the main operational headquarter. Most of the companies are situated in the Northern region of Italy (80%, 362 firms), and more specifically in the North-East [*Graph 3*], with Veneto being the most represented region (238 firms), followed by Piemonte (43 firms) and Lombardia (40 firms) [*Graph 4*]. The Central part embodies the 19% of the sample (89 companies), with Emilia Romagna as the leading region (56%). The remaining 1% (3 firms) of the sample is composed by Southern Italy, with Campania as the only represented region.

Graph 3 *- Distribution of geographical location of main operational headquarter (N=454)*



Graph 4 – Regional distribution of the main operational headquarter (N=454)



Another feature considered is the sector in which the firms of the sample operate, classified according to the Italian ATECO 2007, an alphanumeric code which identifies and classifies the economic activity on a national scale, for purposes of homogeneity in statistical analysis. For the investigation related to the survey, the first 2-digits of the code are considered, which represent the *Division*, and is the highest level of detail. All the companies in the sample belong to *Section C - Manufacturing Activities*, which includes the range of two-digits codes from 10 to 33. As shown in *Graph 5*, the highest proportion of companies belongs to the *Manufacture of machinery and n.c.a. (Non Codificato Altrove) equipment* sector (ATECO code 28), followed by *Manufacture of metal products* (ATECO code 25).

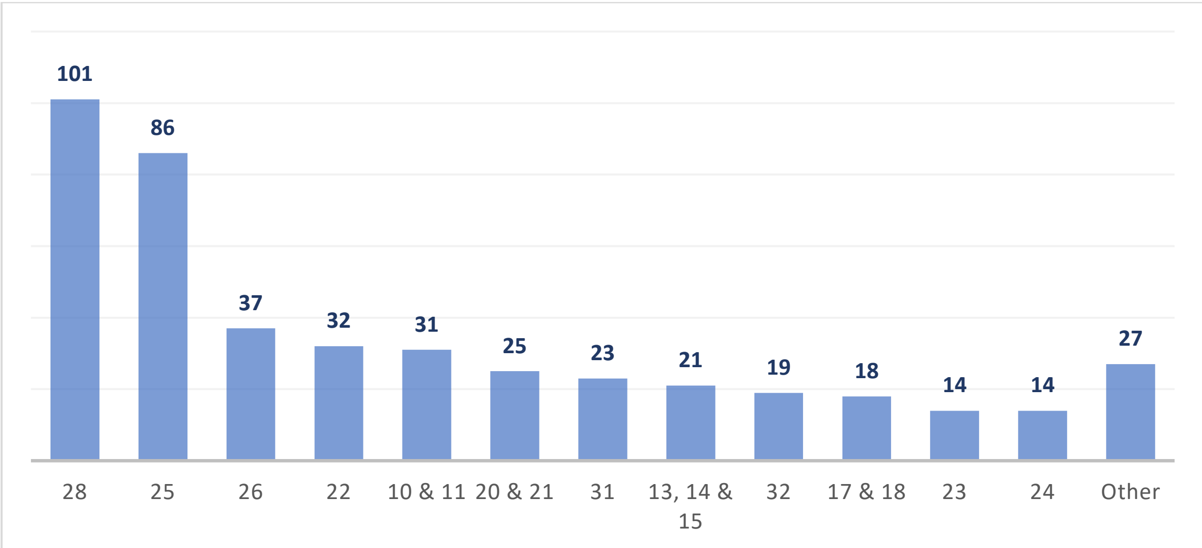
In Table 6 below it is listed the ATECO 2-digits code with the corresponding sector, in order to provide a legend useful for Graph 4.

***TABLE 6** – ATECO 2-digits code taxonomy*

ATECO 2-digits code	**Sector**	**ATECO 2-digits code**	**Sector**
10	Food Industry	22	Rubber and plastic products manufacturing
11	Beverage Industry	23	Other non-metallic mineral products manufacturing
12	-	24	Metallurgy
13	Textile Industry	25	Metallic products manufacturing

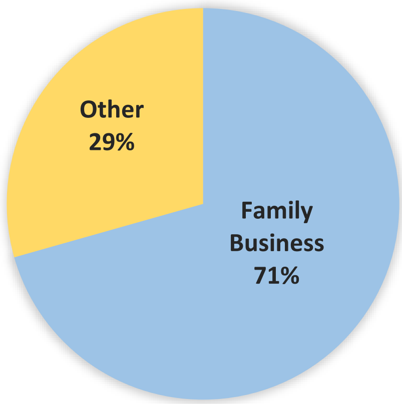
14	Apparel and leather goods manufacturing	26	Computer and electronic equipment manufacturing
15	Leather products manufacturing	27	Electric appliances and non-electric domestic appliances manufacturing
16	Wood Industry	28	Machinery and N.C.A. equipment
17	Paper manufacturing	29	Motor vehicles, trailers and semi-trailers manufacturing
18	Printing and reproduction of recorded media	30	Other vehicles
19	Coke and petroleum refining products manufacturing	31	Furniture manufacturing
20	Chemical products manufacturing	32	Other manufacturing industries
21	Pharmaceutical products manufacturing	33	Repair, maintenance and installation of machinery and equipment

***Graph 5** – Market sector of the firms in the sample (N=448)*



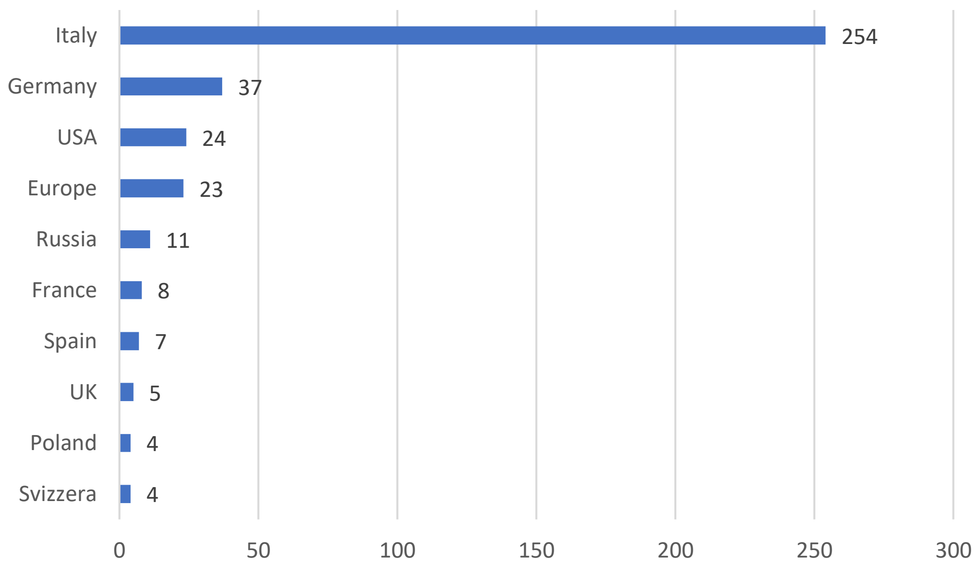
The investigation continues by taking into consideration the corporate structure of the firms: from *Graph 6* below, it is clear that the majority of the sample is composed by family business (71%, 317 companies), intended as those economic activities in which, as disciplined by the Italian Civil Code, either the spouse, relatives within the third grade of kinship, or similar, appear as collaborators of the founder. Such elevated proportion is in line with the Italian trend, where family-run businesses represent the core of the Italian entrepreneurial fabric, representing the 75,2% of productive units with at least 3 employees, and 63,7% of those with at least 10 employees (according to the last Istat Business Census, 2018).

Graph 6 *- Percentage of family business in the sample (N=449)*

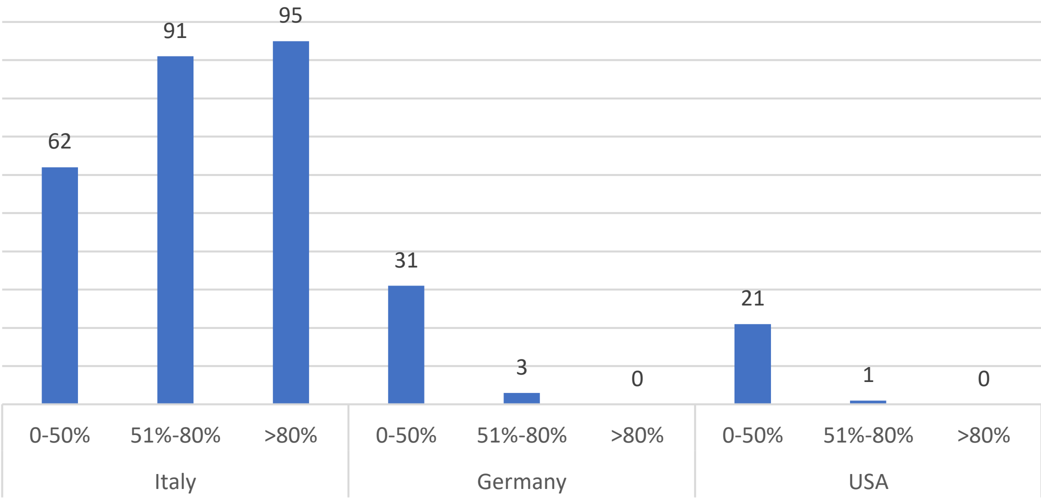


The main market indicated in the survey is Italy [*Graph 7*]. This is in line with the preponderance of family businesses seen above in *Graph 6*; indeed, according to the AIDAF Yearbook 2015, Italian family companies are concentrated in the domestic market, therefore they show a scarce inclination to the internationalization. And by further investigating, 65% of the family businesses have indicated Italy as their main markets, while for the companies with other governance structures, Italy still represents the majority, but with a slightly minor proportion, 52%.

Graph 7 *– Main market of the surveyed companies (N=416)*

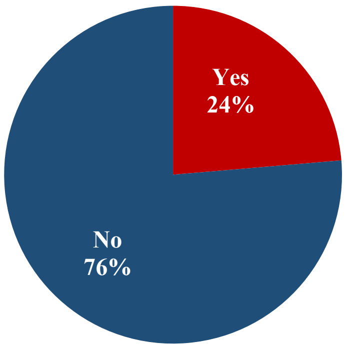


Graph 8 *– Percentage of sales on main market for the top 3 indicated countries (N=402)*

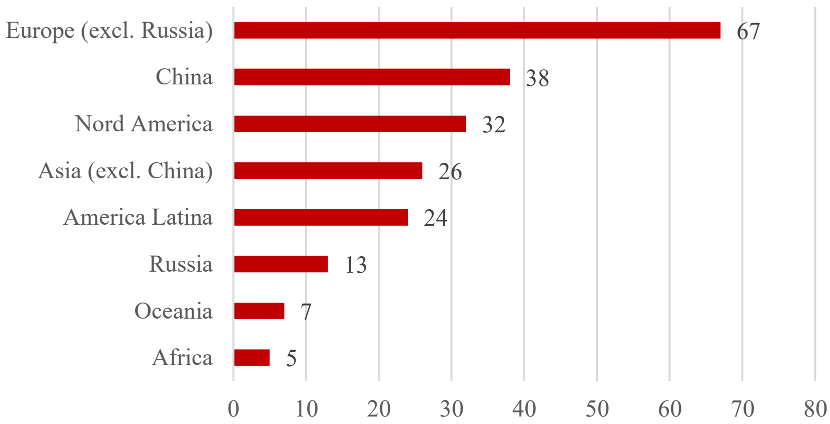


Directly related to what outlined above, and as well connected to the size of the companies in the sample (which sees a preponderance of medium and small firms), is the presence of plants outside Italy. Only the minority of the sample firms (24%, 105 firms) affirmed to have an additional plant abroad [*Graph 9*], which are concentrated mainly in Europe (Russia excluded) and China [*Graph 10*].

Graph 9 *– Presence of plant abroad (N=444)*

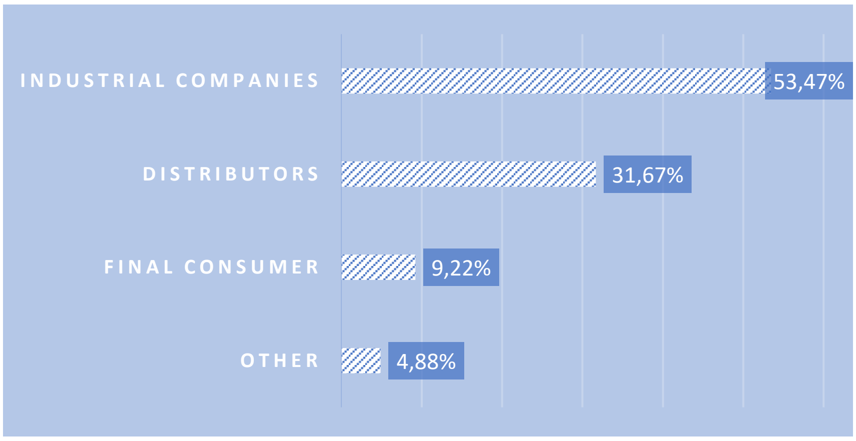


Graph 10 *– Location of plants abroad (N=212)*



A further classification is performed with respect to the type of customer. Indeed, a company usually sells to 3 main categories of users in variable proportions: final consumers, distributors, and industrial companies. Considering a first estimate of the turnover for each of the outlined categories, the highest percentage corresponds to industrial companies, with an average of 53.47%, followed by an average of 31.67% for distributors, and 9,22% for final consumers [*Graph 11*].

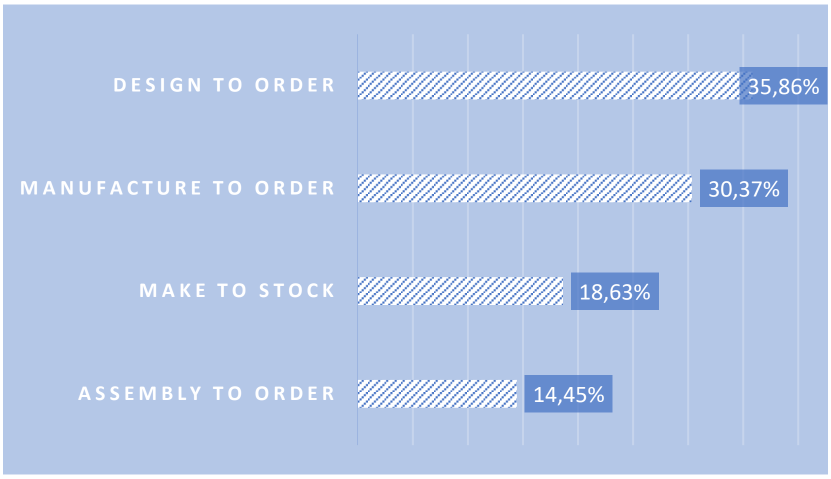
Graph 11 *– Average percentage of profits for client's category (N=404)*



The survey continues by investigating the operations strategies, in terms of manufacturing approaches. Specifically, the four main methods are design to order (in which the product is designed according to the client's specifications and where the production process, including the raw materials' purchase, is not activated until an actual demand comes), manufacture to order (in which design and purchase of raw materials is performed in advance, while the manufacturing process is activated only in response to a specific order from the downstream client), assembly to order (where design and purchase of raw materials, as well as the production of components are executed beforehand, and the reception of the actual order triggers only the final assembly of the finished product), and make to stock (where design, procurement, production of components and assembly are all realized beforehand, and the client can only choose among a pre-defined range of finished products).

As displayed in *Graph 12*, which shows the sample's average percentage of turnover for each of the four approaches, the highest is associated to design to order (36%), followed by manufacture to order (30%).

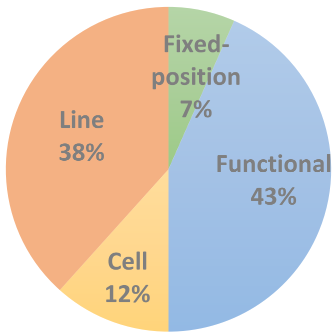
Graph 12 *– Average percentage of total sales for operations category (N=423)*



Moreover, another investigated feature is the productive layout, for which four main types were considered: fixed position layout (where the product remains fixed in the same position, while operators, tools and machinery move around it to perform the necessary manufacturing activities), functional layout (where operators, machines and tools are grouped according to the activity they are assigned to, while the product travels among the different departments to be processed), cell layout (where productive resources are organized in units which are able to perform all the necessary activities to produce a specific product or a family of products), and line layout (where resources are organized in a productive line, along which the product goes through in a predetermined path, to receive the necessary processing).

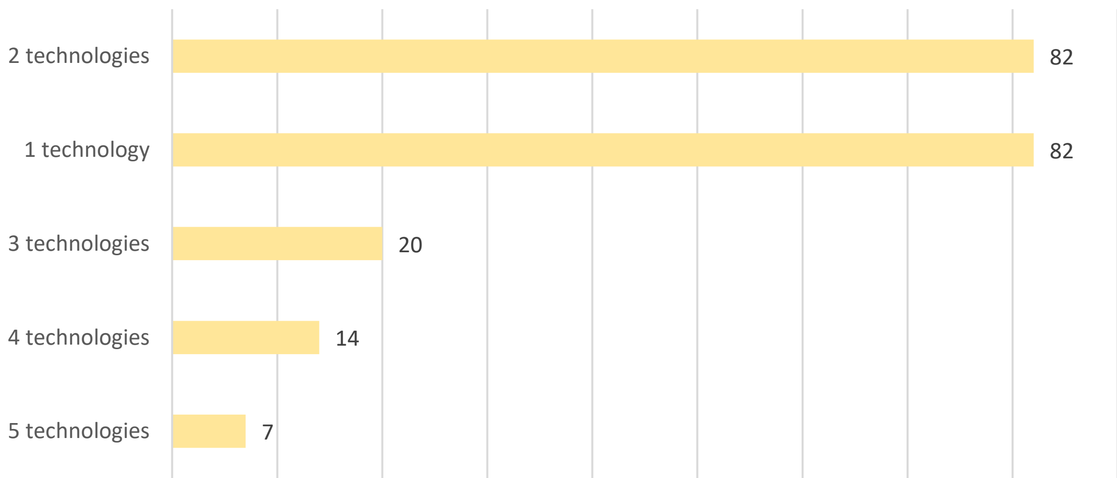
Graph 13 displays the distribution of the layouts in the sample: the two most used are functional (43%) and line (38%).

***Graph 13** – Layout type (N=438)*



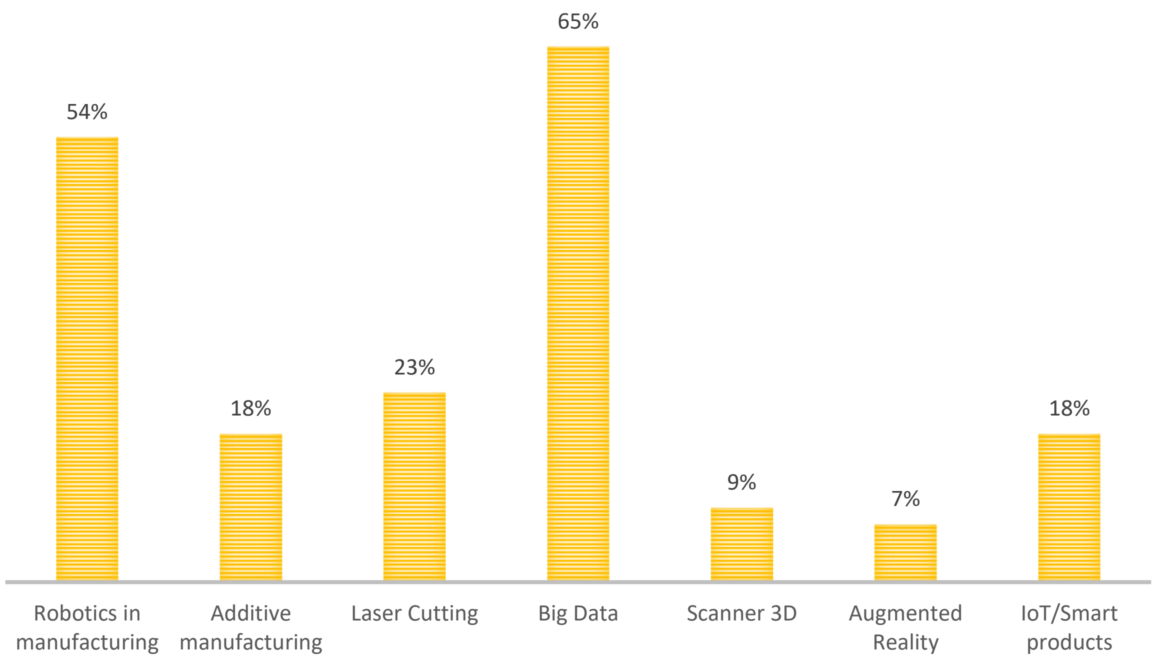
The last dimension investigated in the first section of the survey relates to the adoption of Industry 4.0 technologies. Indeed, digitalization and automation are becoming the core strategies to face the challenges poses by the rapid evolution of the industrial world, and this implies a digital transformation of companies, including forms of smart manufacturing. The seven technologies considered in the survey are representative of the whole spectrum of such dimension, including not only the manufacturing processes, but also big data analytics that are able to take advantage of the big dose of information coming from productive plants and systems, and to make interconnections possible to obtain a complete picturing of the whole manufacturing process (Nexus, 2019). The majority of the sample (67%, 201 out 299) employs at least one of such technologies, in line with the Italian trend, according to which one out of two companies has adopted 4.0 technologies (Osservatorio 4.0, 2021). In *Graph 14* there is a further representation of the companies and the quantity of technologies adopted: most of them employs only one or two technologies, while none is adopting more than five.

***Graph 14** – Amount of Industry 4.0 technologies employed (N=205)*



Graph 15 instead shows in detail what are the types of technologies which are most in use within the considered sample, with respectively Big Data (65%) and Robotics in manufacturing (54%) as the top employed technologies, a trend that entirely reflects Italy's industrial fabric (Osservatorio 4.0, 2021).

***Graph 15** – Employed Industry 4.0 technologies (N=299)*

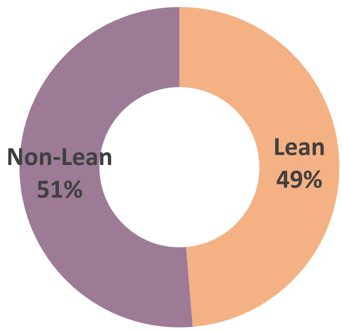


3.3 Sample identification – Section 2: Lean methodology

After a first general overview of the sample, the survey focuses on its main purpose in the second section, aiming at the investigation of the Lean practices and solutions adopted by the companies.

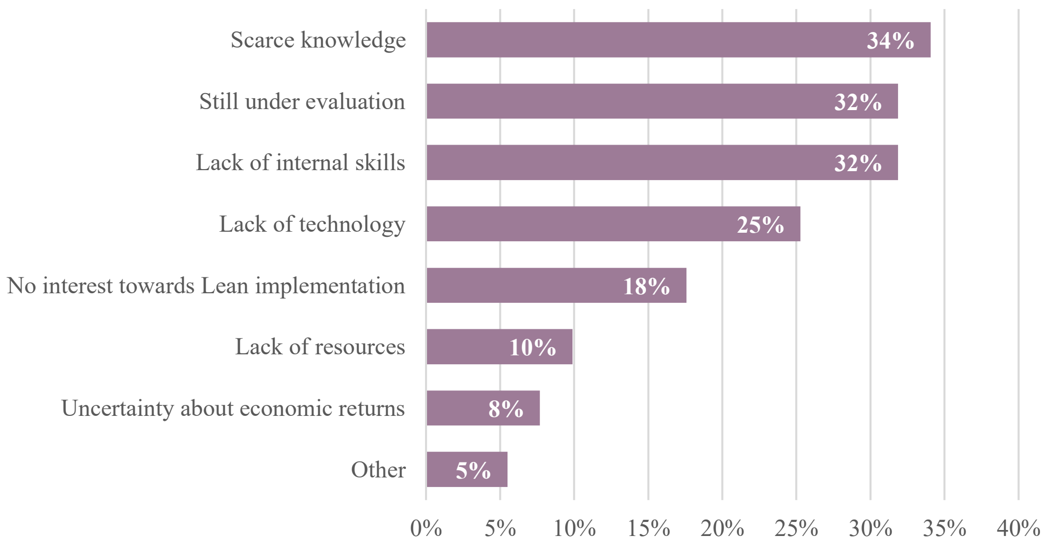
The sample is almost equally divided between Lean and non-Lean adopters. Of the 454 companies of the sample, 221 (49%) declared to employ at least one Lean technique [*Graph 16*].

Graph 16 *– Distribution of Lean adopters and non-adopters (N=454)*



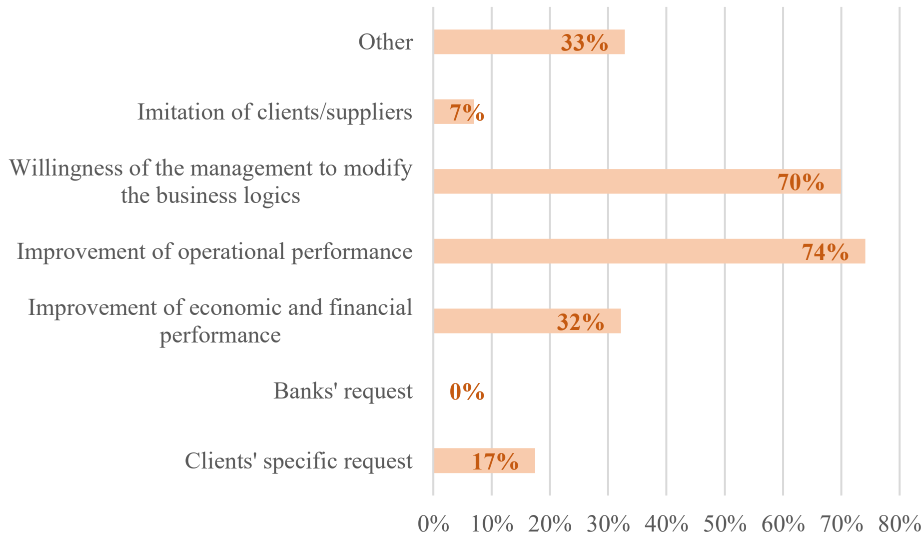
A deeper investigation is carried out first on the non-Lean subgroup, by exploring the motivations behind the choice of not implementing such methodology. Out of the 233 non-adopters, only 91 (39%) gave an explanation: as shown in *Graph 17*, the most common reason is the insufficient knowledge about Lean (31 responses, 34%), strictly followed by the fact that Lean methodology is still under evaluation (29 responses, 32%). Such results are explained by the fact that Lean is more than a simple manufacturing approach, and it is rather configured as a whole change process that includes every process and actor within the company (Lean Enterprise Institute, 2019), therefore it might mean that organizations are still cautious and prefer to understand better what such transformation implies. Moreover, the answers outlined how there are some internal elements which are hindering companies from implementing Lean methodology, such as the lack of internal skills (29 responses, 32%) and of proper technology (23 responses, 25%).

Graph 17 *– Reasons behind the non-adoption of Lean practices (N=91)*



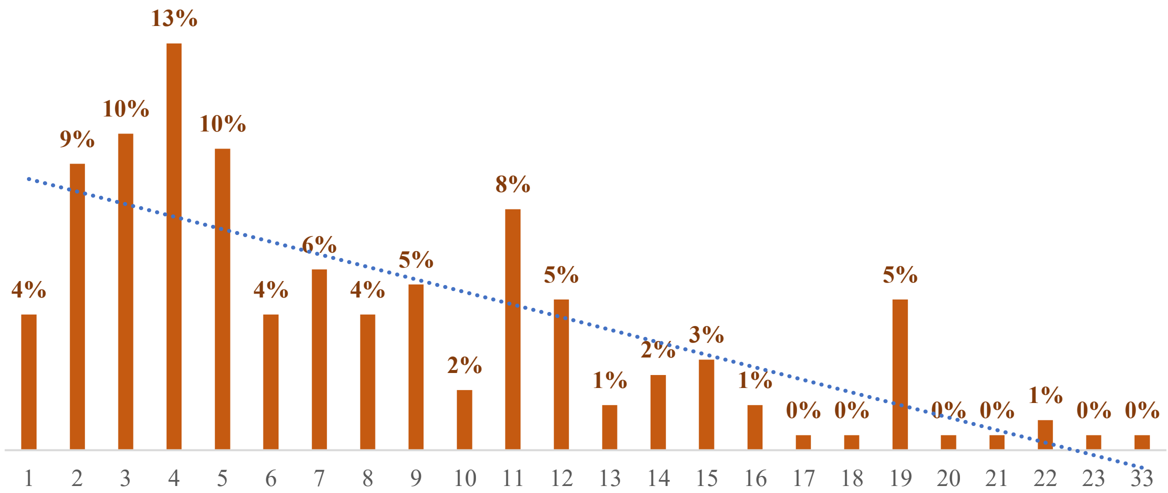
Similarly, Lean adopters were asked to motivate the reason behind the implementation of such practices: out of 143 responses (65% of total Lean adopters of the sample), the two main motivations behind the adoption of Lean were the need to improve the company's operational performance (106 responses, 74%), and the willingness of the management to change the business logics (100 responses, 70%). With a minor degree of choice, the change was driven by the need of improvement of the economic and financial performance of the firm (46 responses, 32%), probably because the positive correlation between Lean and financial performance is still not acknowledged and demonstrated [*Graph 18*].

Graph 18 *– Reasons behind the adoption of Lean practices (N=143)*



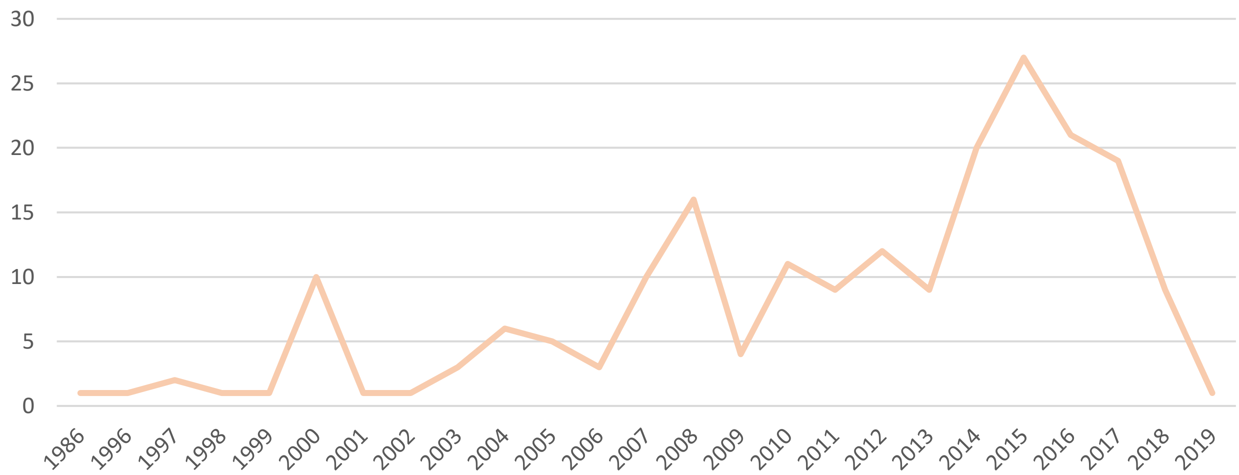
The survey progresses by further investigating the Lean sample. In particular, two dimensions are constructed from the answers of the questionnaire. The first dimension considered is **leanness maturity**, defined as the time interval (expressed in years) in which the company have started to apply Lean techniques (calculated by subtracting to the current year -2022- the starting year of Lean implementation declared by each company): *Graph 19* shows how most of the 203 respondents have been implementing Lean for less than 10 years (61 companies, 69%).

Graph 19 *– Distribution of leanness maturity (N=203)*



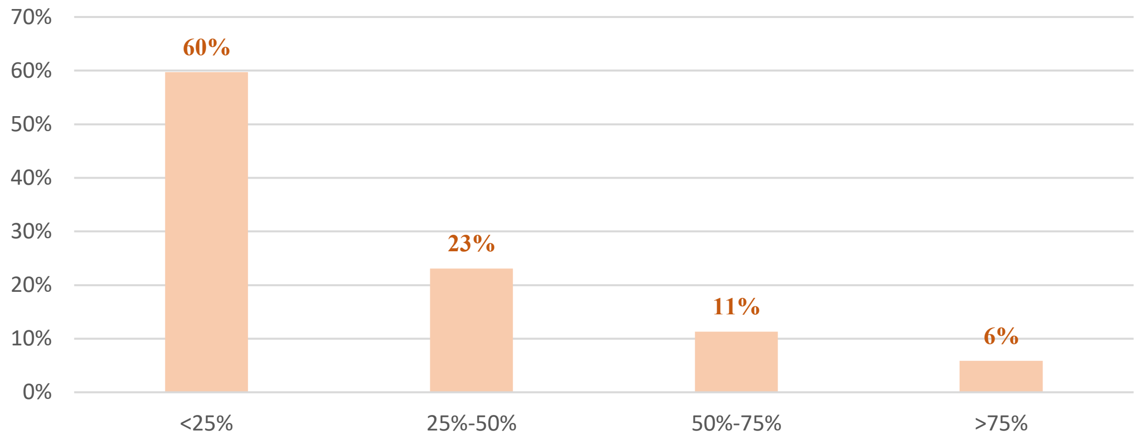
Graph 20 shows instead the trend of the adoption of Lean practices during the years (until 2019, which is the last year available in which the survey was filled by the sample), from which it is clearly visible the increasing trend, with a peak in the time interval 2013-2015, and a subsequent decreasing trend.

Graph 20 *– Trend of Lean adoption (N=203)*



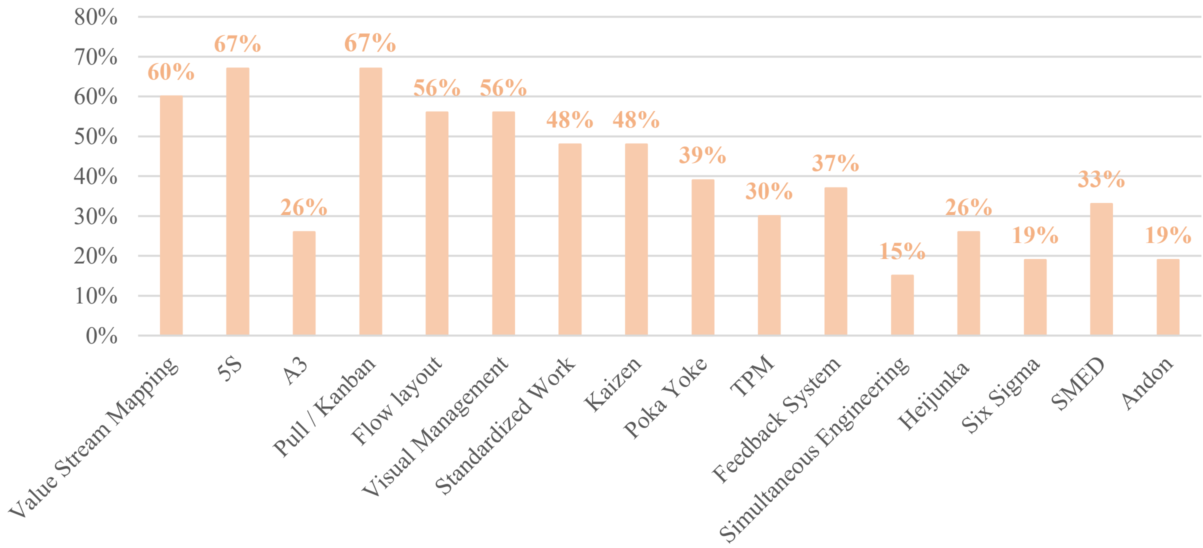
An additional dimension considered is the one of **leanness intensity**, which describes the proportion of Lean techniques employed by a firm. For each of the listed tools, the company had to indicate one or more areas of application (production, warehouse, logistics, quality control, sales, purchasing, technical office, administration and control, IT). *Graph 21* depicts the distribution of the sample in terms of the above-described dimension, showing how most of the organizations are concentrated in the low-intensity area, with 103 companies (47% of the sample) employing 11 or less tools (the median).

Graph 21 *- Leanness Intensity (N=221)*

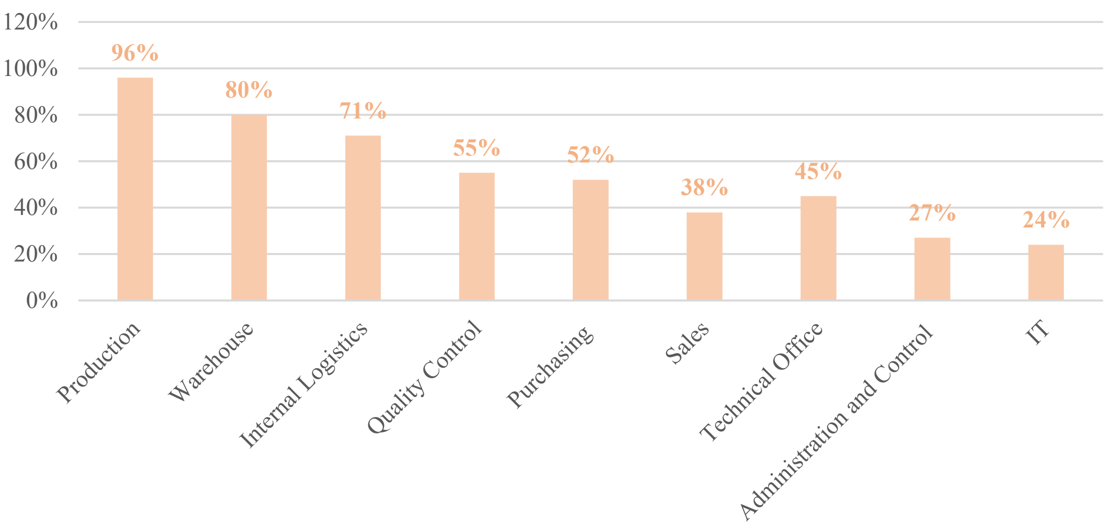


The analysis of the Lean techniques develops with the examination of the distribution by type of tools and by the functional area in which they are applied. From *Graph 22* it is visible how 5S and Pull approach are the most employed. Predictably, 96% of firms applies Lean tools in production (since Lean is born primarily as a manufacturing approach), followed by warehouse (as one of the main objectives of such methodology is inventory minimization) and internal logistics [*Graph 23*].

Graph 22 *– Distribution of Lean techniques by type of tool (N=221)*

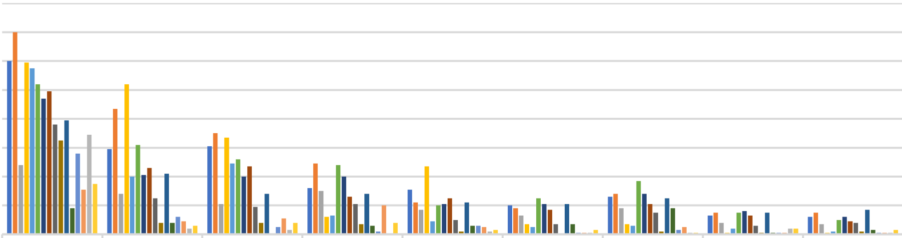


Graph 23 *– Distribution of Lean techniques by functional area (N=221)*



Finally, *Graph 24* gives a more detailed view, by showing the combination of the two above-pictured elements. It is clear how the answers were concentrated in the upper-left area of the graph.

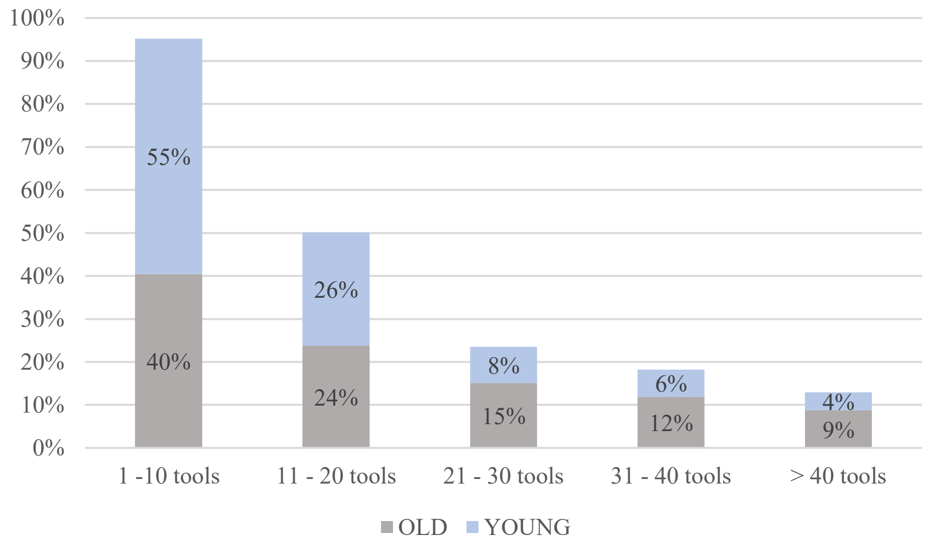
Graph 24 *– Combination of Lean Techniques and functional area (N=221)*



	PRODUCTION	WAREHOUSE	INTERNAL LOGISTIC	QUALITY CONTROL	PURCHASING	SALES	TECHNICAL OFFICE	ADMINISTRATION	IT
Value Stream Mapping	120	59	61	32	31	20	26	13	12
5S	140	87	70	49	22	18	28	15	15
A3	48	28	21	30	17	13	18	8	7
Pull / Kanban	119	104	67	12	47	7	7	1	1
Flow layout	115	40	49	13	9	5	6	4	2
Visual Management	104	62	52	48	20	25	37	15	10
Standardized Work	94	41	40	40	21	21	28	16	12
Kaizen	99	46	47	26	25	17	21	13	9
Poka Yoke	76	25	19	21	10	7	15	6	8
TPM	65	8	8	7	2	0	2	1	2
Feedback System	79	42	28	28	22	21	25	15	17
Simultaneous Engineering	18	8	0	6	6	7	18	1	3
Heijunka	56	12	5	2	6	1	3	1	1
Six Sigma	31	9	11	20	5	1	5	1	1
SMED	69	4	3	0	2	1	1	4	1
Andon	35	6	8	8	3	3	1	4	3

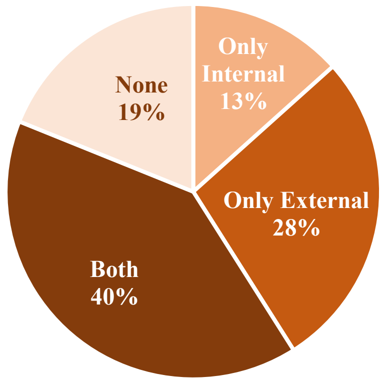
When combining the two dimensions of Leanness Intensity and Maturity, we can consider the weighted average of the leanness maturity (8 years) and use it as the turning point between "old" and "young" firms (which are respectively the ones with a high and low leanness maturity) and relate it to the number of Lean tools applied. *Graph 25* depicts such situation, predictably showing how young Lean organization implement a minor amount of practices and tolls.

Graph 25 *– Leanness maturity and intensity (N=221)*



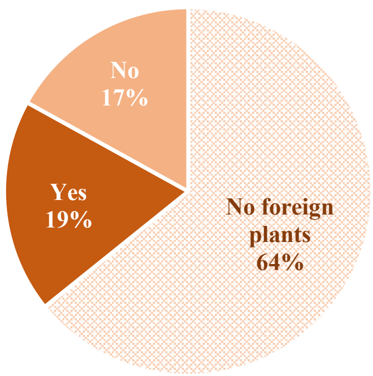
Going into more detail about the specificities of the Lean implementation, from the survey it is possible to understand that in the majority of the cases, the enactment of Lean techniques is made through to a compresence of dedicated internal actors and external consultants (87 firms, 40% of the cases), while the second most-employed solution is the hiring of just external consultant (28% of the sample), as shown in *Graph 26*. This last solution proves to be useful, because on the one hand it can help to provide the firm with high-knowledge and high-expertise people that can help in the initial and delicate stage of initial implementation, while at the same time it can help to train internal actors, that will not only retain the necessary knowledge, but that can also be configured as the "Lean Champions" within the company, responsible of maintaining the change.

Graph 26 – Actors involved in Lean transformation (N=217)



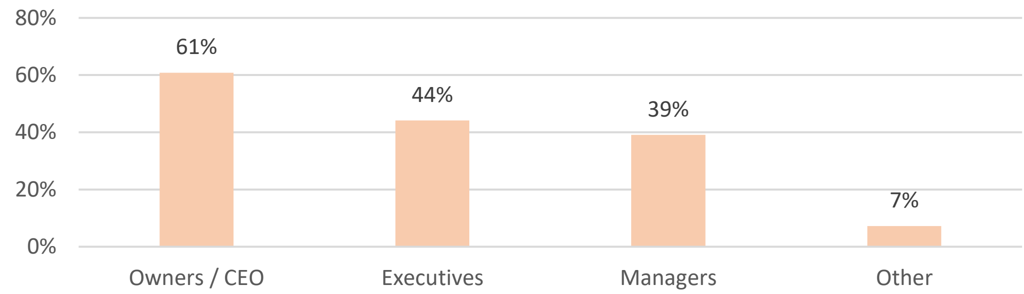
For a small part of respondents, Lean techniques are applied also to foreign plants, when present [*Graph 27*]. This result is in line with theoretical studies, postulating that parent companies often find difficulties in implementing lean in foreign subsidiaries or facilities (Boscari et al., 2016), and some scholars attribute the difference in subsidiary contexts as one of the main causes of failure in Lean programs (Maritan and Brush, 2003). Given the low leanness maturity of firms formerly outlined in *Graph 18*, it is expected that firms decide to expand the application of Lean also to its foreign facilities only after having consolidated and master it on its parent site.

Graph 27 *– Application of Lean techniques also on foreign plants (N=218)*

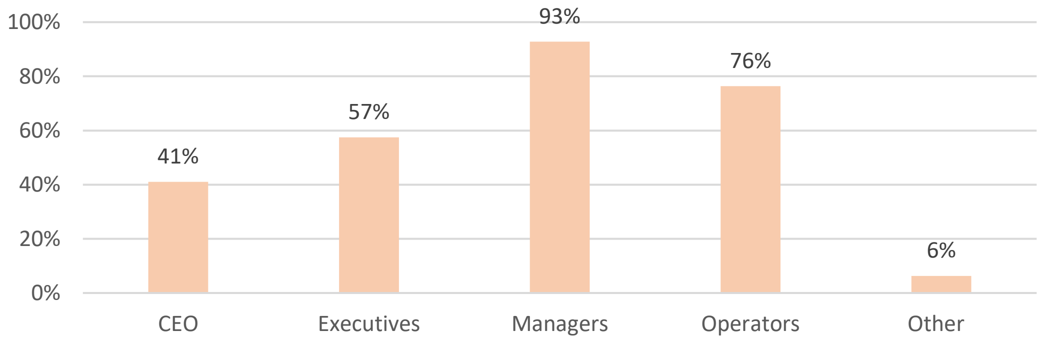


The survey continues with the investigation of the involvement and engagement of the higher hierarchical layers in the implementations process: indeed, for the Lean transformation to be carried out properly, it is essential to consider it not as a project, because rather as a "long term and endless strategy for the company" (Durin, 2018). From *Graph 28* and *Graph 29*, it is possible to distinguish how the greatest involvement comes from the highest hierarchical positions, with 61% of the sample indicating their owners and CEO as active actors: such result is reasonable, given that the Lean transformation process constitutes a radical change in organizations, and therefore the active participation of the highest hierarchical figures in necessary to lead the change. Instead, the role of supporters in the Lean activities is a prerogative of managers (93% of the surveyed firms), since they represent the decision-making bodies which are the closest to workers and day-to-day activities, dedicated to the control and the supervision of the correct and effective application of Lean techniques.

Graph 28*– Actors actively involved in Lean transformation (N=207)*

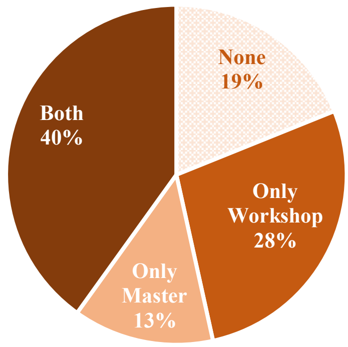


Graph 29 *- Main supporters of Lean activities (N=138)*



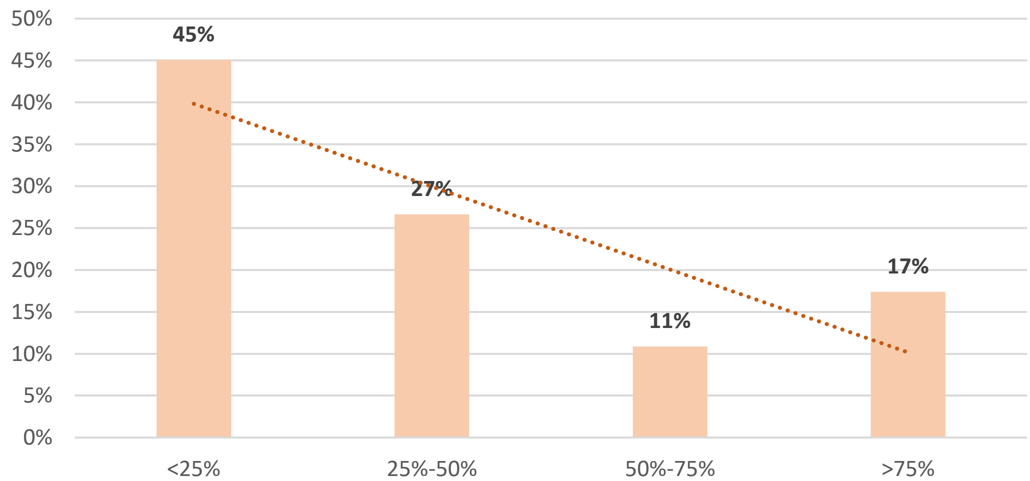
Another fundamental aspect of the Lean transition is the training throughout the organization; according to Dinis-Carvalho (2020), "the need to involve all employees and managers in continuous improvement processes with lean vision requires ways of training that effectively change the routines and culture in a company". Specifically, in the survey this aspect was investigated by asking firms whether they invested in Masters (courses for executives, managers, and employees) or Workshops (courses directed at workers, with a more practical footprint). Out of the 193 respondents, the 40% of the Lean sample combines both type of training [*Graph 30*], in order to ensure an appropriate preparation and an aligned mindset throughout the whole company.

Graph 30 *– Type of training (N=193)*



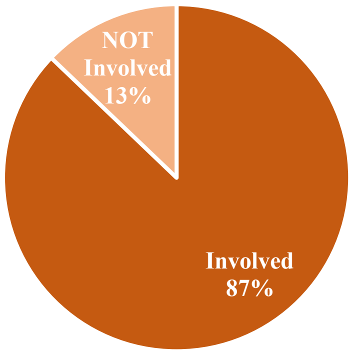
Nevertheless, one of the core principles of the Lean methodology is the attention and consideration towards the employees at every layer of the organization, the recognition of their value, and their involvement in every aspect of their work. This is an aspect that is often neglected by organizations, and it is called the "invisible" part of Lean (Dinis-Carvalho, 2020), being the most difficult concept to transfer and to coach to organizational leaders. In line with what just outlined, a relevant insight emerging from *Graph 31* is indeed the difficulty for the sample in engaging their employees in the Lean projects carried out by the company: we witness a decreasing tendency in the ability to engage high proportion of employees, and with only 6% of the sample declaring to have involved the entirety of its employees.

Graph 31 *– Percentage of workforce involved in Lean activities (N=184)*



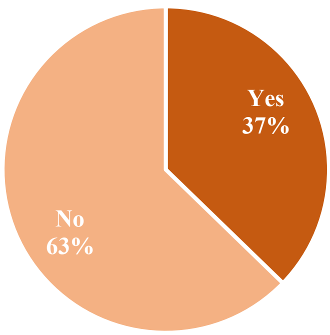
However, we can see that Lean firms are making the effort, since the greatest majority of them (87%) declared to actively engage their employees in improvement programs [*Graph 32*].

Graph 32 *– Workforce's active involvement in improvement programs (N=210)*

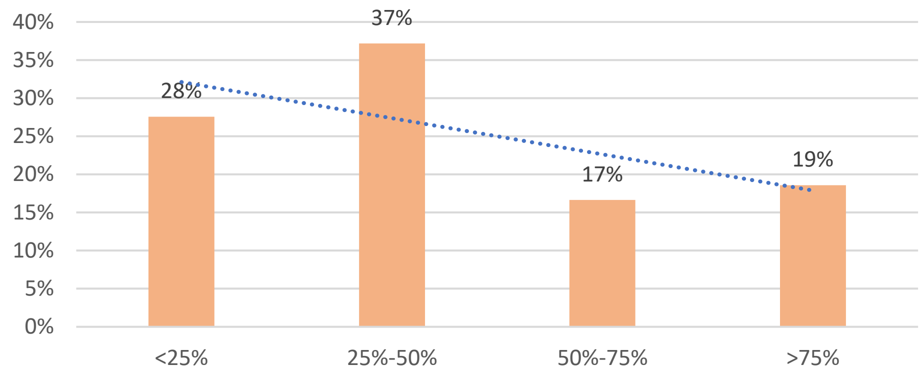


The issue delineated above is also confirmed by the lack of a structured suggestion system, which has not been implemented according to 63% of companies of the sample [*Graph 33*]. Such system is instead a core tool according to Lean practitioners, and it is key to continuous improvement programs (Dombrowski & Mielke, 2014), since it involves the people which are directly in contact with the manufacturing process; in addition, it gives employees and team members a sense of responsibility and accountability towards their job. As a result of this issue, the majority of firms struggle to actually and effectively implement the suggestions received by their workforce [*Graph 34*]. When combining these two dimensions, we can see how firms with a suggestion program in place are generally able to reach higher proportions of suggestion implementation [*Graph 35*].

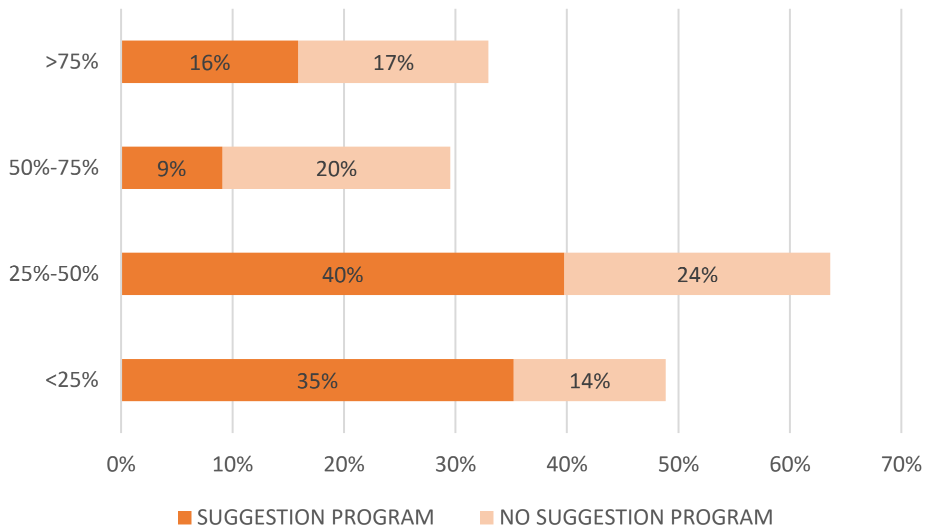
Graph 33 *– Presence of a structured suggestion system (N=204)*



Graph 34 *- Percentage of workforce feedback which is effectively implemented (N=156)*

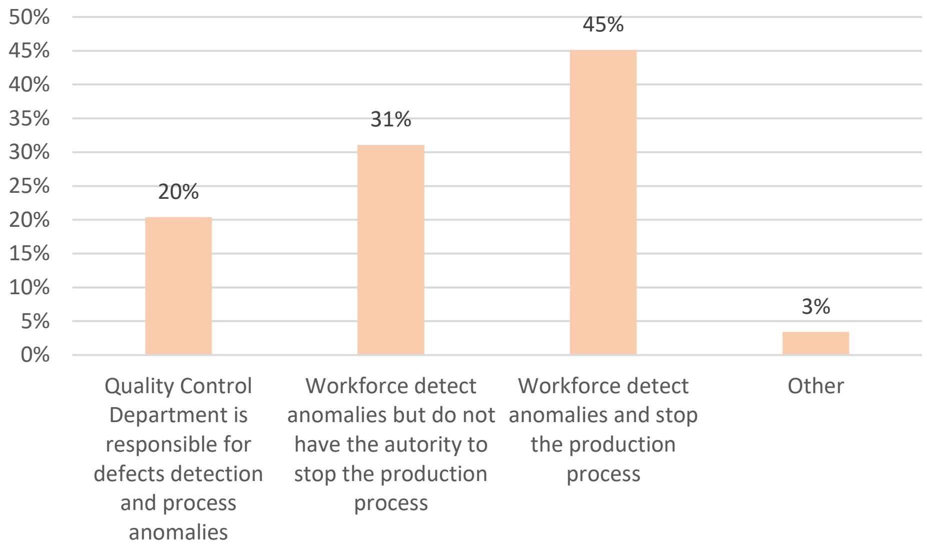


Graph 35 *– Percentage of feedback implemented with and without a suggestion program (N=156)*



A topic strictly connected to workforce autonomy and accountability is the one related to the approaches used for anomalies and errors detection. In Lean methodology, in order to guarantee smooth flows it is essential to spot irregularities and errors in the productive processes, before they turn into defective final products that will be identified in the post-production stage; therefore, the role of the workforce becomes vital to ensure such procedure, and they have to be given the authority to stop the working processes, to be able to spot and correct the anomalies immediately after having detected it. In *Graph 36* it is clearly visible that most companies (45%) prefer this method, while the 31% still allows workers to detect possible mistakes, but prevents them from arresting the process.

Graph 36 *- Approach to anomalies and problems detection (N=202)*



Finally, the last topic investigated in the survey relates to the types of approaches employed to allocate responsibilities and supervision tasks. Despite Lean structures prioritize flexibility, encouraging job rotation among its employees in order foster motivation and accountability, only 15 companies (7%) apply this method, and the majority of them (56%) still resorts to classical top-down approached characterized by centralized responsibility [*Graph 37*].

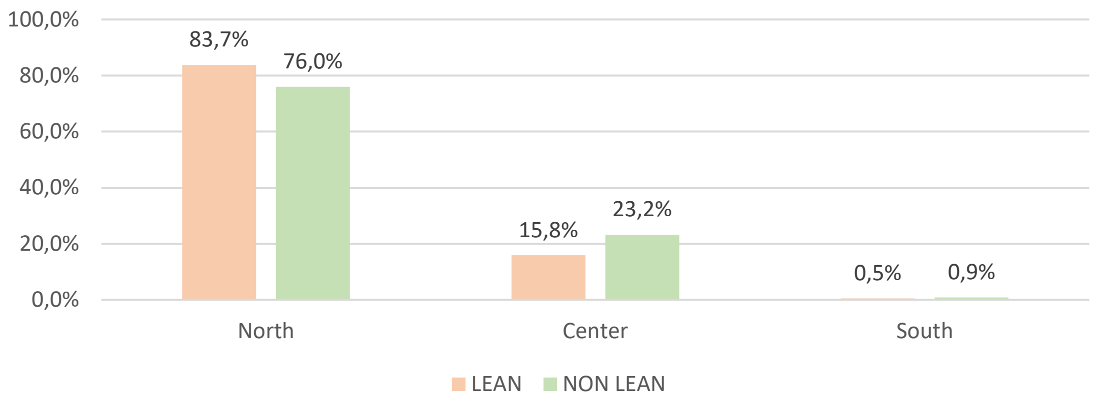
Graph 37 *– Approach to responsibilities and supervision allocation (N=206)*

3.4 Comparison between lean adopters and non-adopters

This section performs a further examination of the results of the survey, by performing an analysis based on lean adopter and the rest of the sample, with the aim of gathering insights and detecting differences between the two clusters.

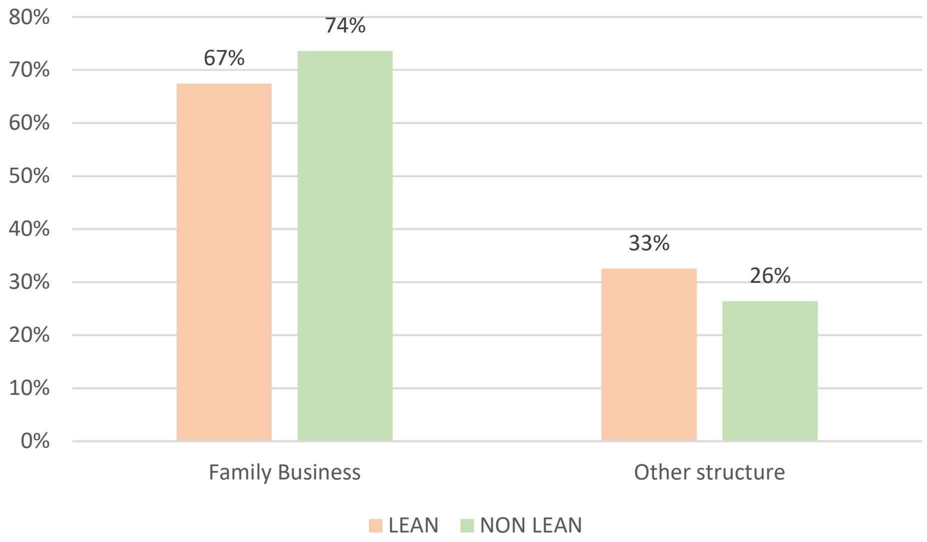
The first dimension concerns the distribution of the geographical location of the firms: it can be observed that, despite both groups being concentrated in the Northern part of Italy, Lean adopters are slightly more present in the North (84% versus 76% of non-Lean) [*Graph 38*].

Graph 38 *– Distribution of geographical location between lean adopters and non-adopters (N=454)*



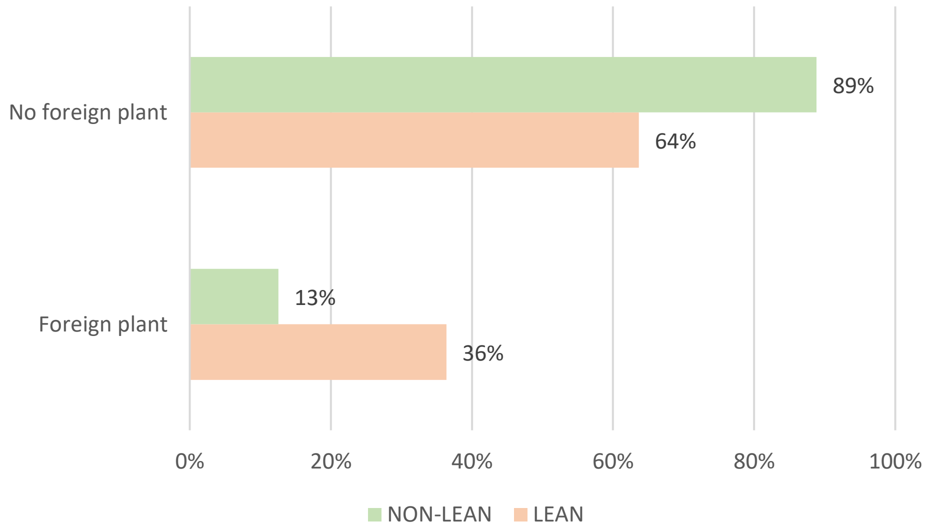
The following feature considered is the corporate governance of the sampled firms: from *Graph 39*, we can see that among non-Lean adopters we found a higher proportion of family businesses (74% versus 67% of Lean adopters); this is justified by the fact that family businesses are usually small organizations, and the implementation of Lean techniques is often a long and complex process, that such organizations might be impaired to perform.

Graph 39 *– Distribution of governance structure between lean adopters and non-adopters (N=449)*



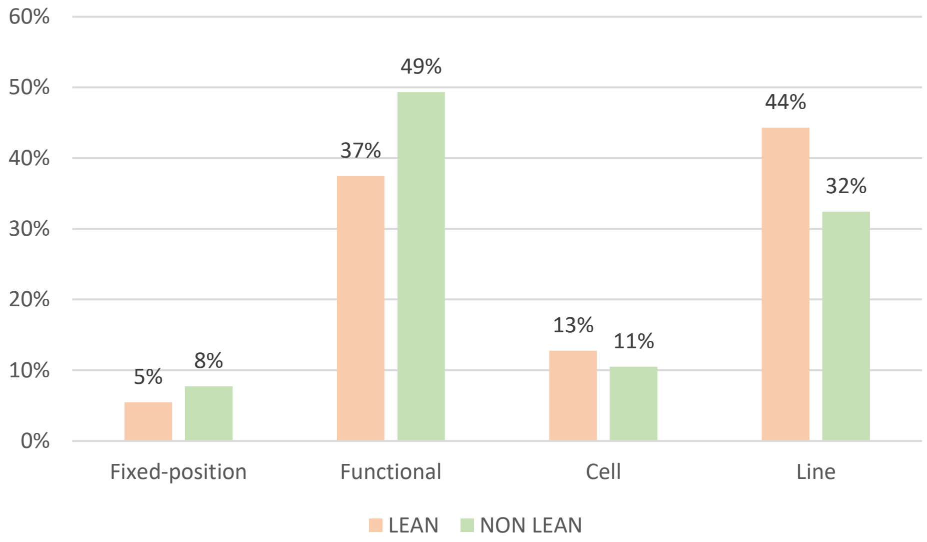
Additionally, when taking into account the presence of foreign plants, it can be witnessed how Lean adopters tend to have more foreign plants: companies with facilities abroad represent the minority of the sample (105 firms, 24% of the sample), with 80 Lean adopters and 25 non-Lean adopters [*Graph 40*]. Considering the 80 Lean firms,

Graph 40 *– Distribution of foreign plants between lean adopters and non-adopters (N=444)*



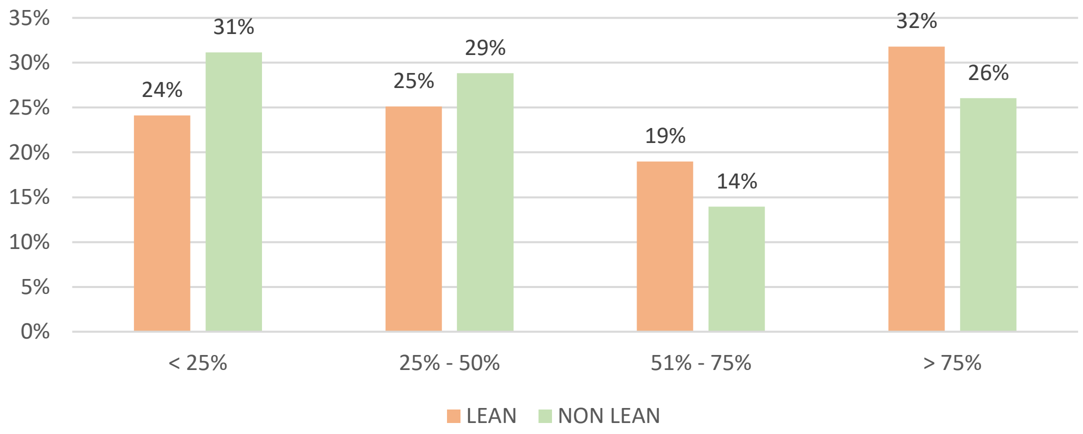
Going into more detail about the manufacturing strategy, we can see how the preponderant layout type differs among the two groups, with Lean companies favoring functional layout, while non-adopters preferring line layout [*Graph 41*]. It is worthy to note that cell layout, which is the most appropriate for Lean production since it allows job rotation and one-piece flow, is employed by a minority of the Lean sample, only the 13% (28 companies).

Graph 41 *– Distribution of layout types between lean adopters and non-adopters (N=438)*



Another dimension that must be investigated, since it is a core feature of the Lean methodology, is the one of job rotation. In line with what is expected, most of Lean firms are in the group with the highest percentage of rotation (32% of firms with more than 75% of rotating workers), while non-adopters are concentrated on lower proportions of rotation (with the majority of firms declaring to have up to 50% of workers rotation) [*Graph 42*].

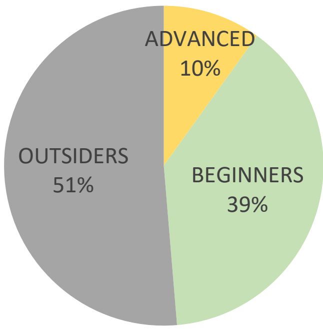
Graph 42 *– Distribution of workforce rotation between lean adopters and non-adopters (N=410)*



3.5 Sample identification – Section 3: The classification of Beginners and Advanced

In order to better categorize the sample and to capture the difference, the Lean group has to be furtherly divided. The classification has been made based on the number of Lean techniques employed by the firms, and a Pareto analysis was conducted to identify the benchmark. The result of the analysis distinguished Lean firms between Beginners and Advanced: the latter are the firms which employ a number of Lean techniques higher than 25. *Graph 43* shows the distribution of the sample according to this new classification.

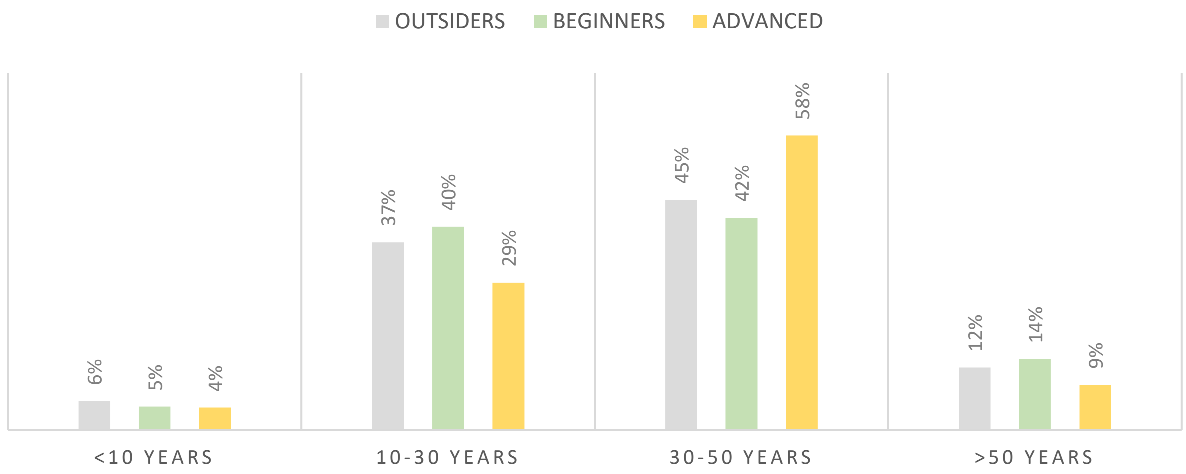
***Graph 43** – Distribution of sample between Outsiders, Beginners and Advanced (N=454)*



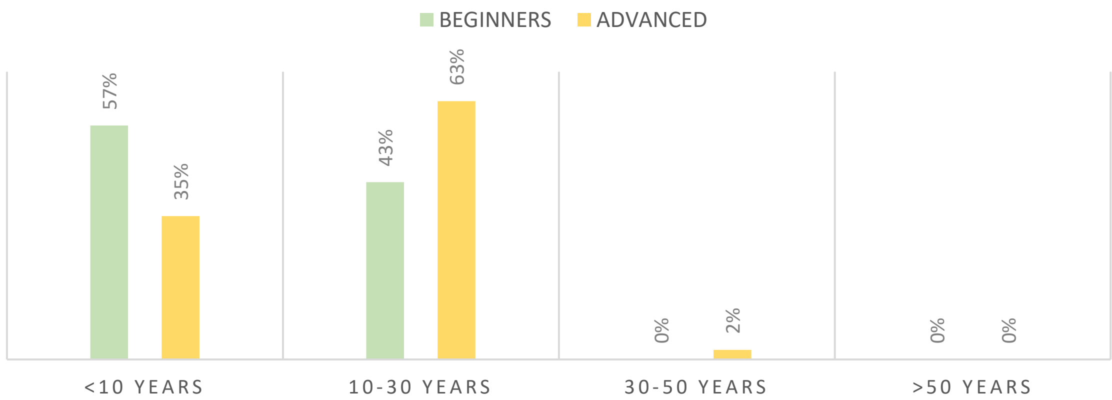
Such categorization will be used in the remaining of this section to underline the differences and feature of the sample.

Starting with the demographics and general features, the first analyzed characteristic is the seniority of the firm, expressed like before as the difference between the current year and the year of foundation of the company. *Graph 44* shows the age proportional distribution for each category, where it can be seen that Advanced firms are generally older that Beginners: however, the result can be justified by the fact that older firms have more time to implement Lean, and to incorporate more techniques. The same result is confirmed if we take into consideration the dimension of Leanness maturity for the Lean group: indeed, Advanced firm implement Lean production for a longer time than Beginners [Graph 45].

Graph 44 *– Distribution of age between Outsiders, Beginners and Advanced (N=446)*



Graph 45 *– Proportion of Leanness maturity between Beginners and Advanced (N=203)*

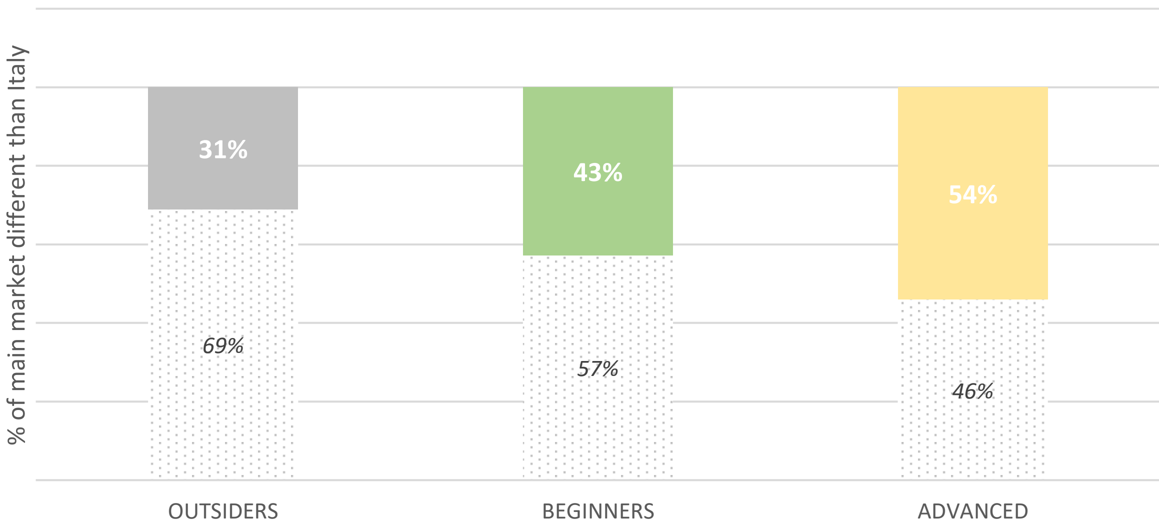


Instead, in *Graph 46* it is possible to analyze the size of the groups. As portrayed in the graph below, Advanced companies tend to be larger than Beginners. Such result is confirmed by literature, which highlights how the application of Lean in SMEs remains limited with respect to large enterprises (Yadav et al., 2019).

Graph 46 – Distribution of size between Outsiders, Beginners and Advanced (N=400)

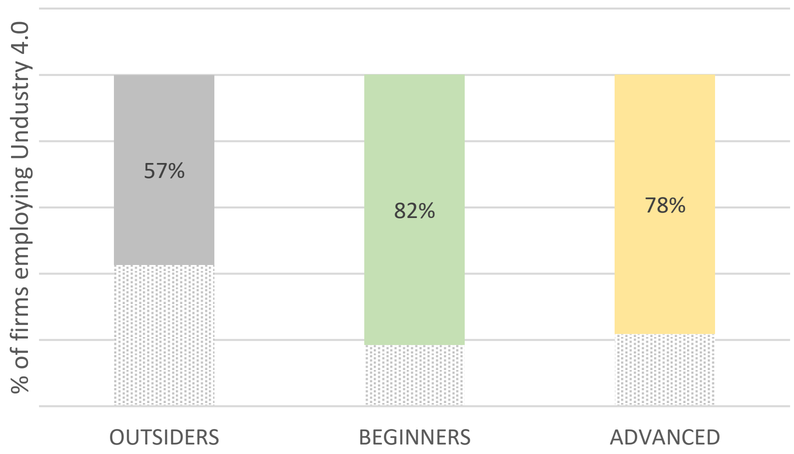
In order to try to understand whether Advanced companies are more internationalized, we analyze the main markets of the group: *Graph 47* depicts the percentage of firms who have indicated Italy as their main market. We can see a slight increase in the internationalization trend for Advanced firms, which have the lowest proportion of firms with Italian listed as their main market. Even though literature does not provide support in research concerning a possible correlation between Lean adoption and internationalization, we can presume that companies operating abroad might have a stronger necessity to remain competitive and efficient to successfully penetrate the market.

***Graph 47** – Italian main market of Outsiders, Beginners and Advanced (N=408)*

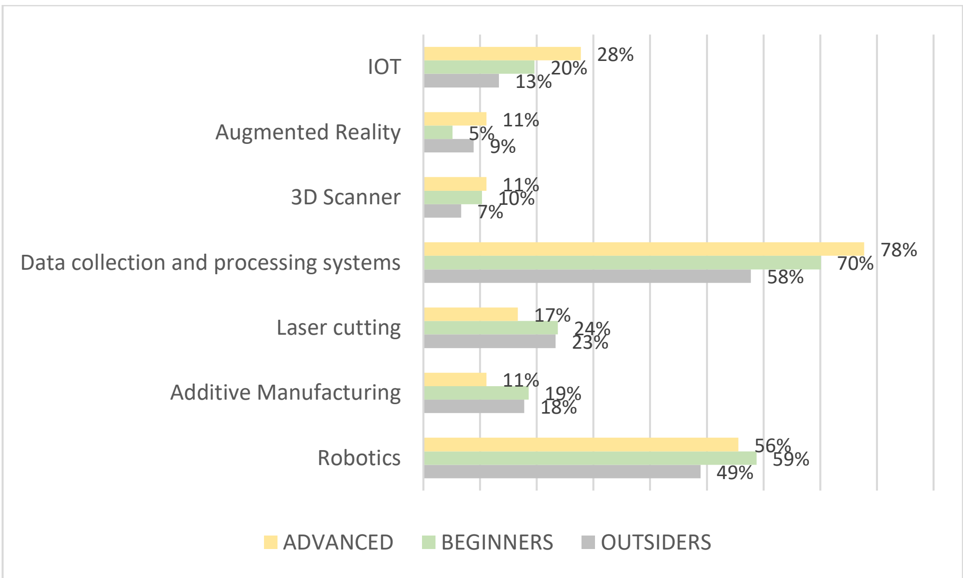


Finally, the relation between Lean and Industry 4.0 implementation is taken into account, given that literature has inferred the positive correlation between the two methodologies, encouraging their integration (Taghavi and Beauregard, 2020). From *Graph 48*, the difference in proportion between Lean and Outsiders can be seen, even though the divergence between Beginners and Advanced is not significant. Similar results are achieved when digging into the single techniques [*Graph 49*].

Graph 48 *– Employment of 4.0 Industry (N=299)*

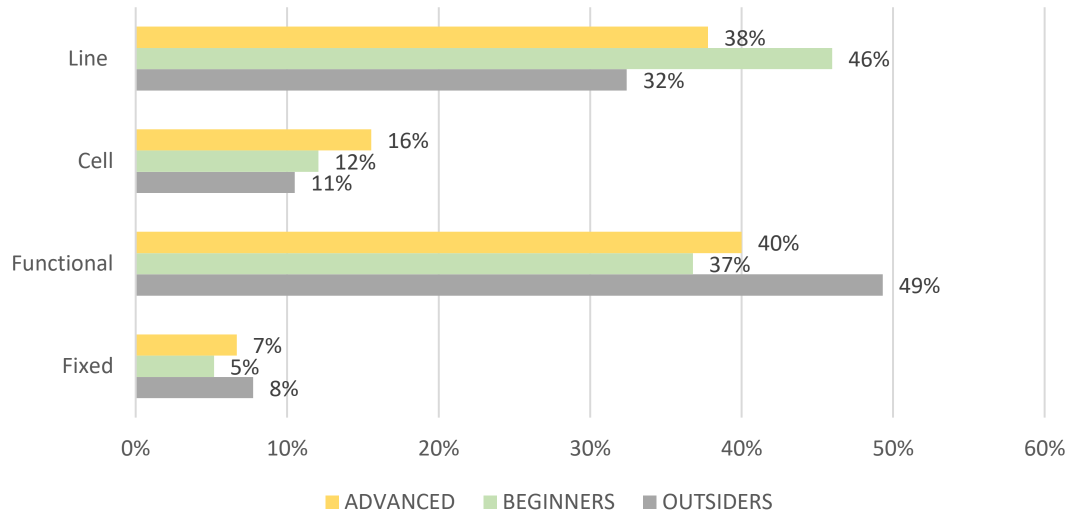


Graph 49 *– Typology of 4.0 Industry techniques (N=205)*



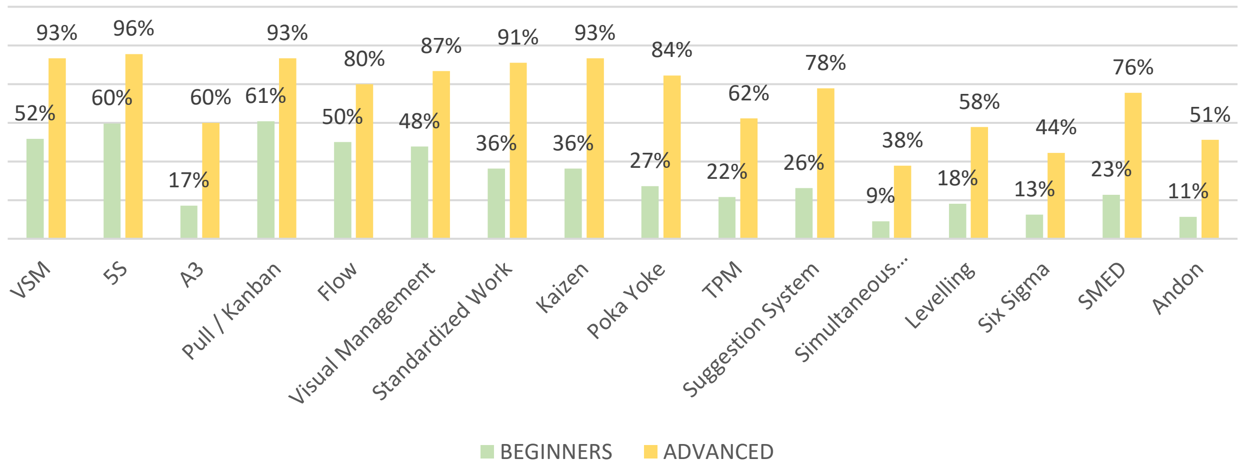
Focusing now mainly on the Beginner and Advanced groups, we will move the analysis to the Lean-related attributes. Starting with the layout typology, we can see from *Graph 50* that the difference in terms of layout choice between Beginners and Advanced is not particularly significant.

***Graph 50** – Distribution by layout type (N=438)*



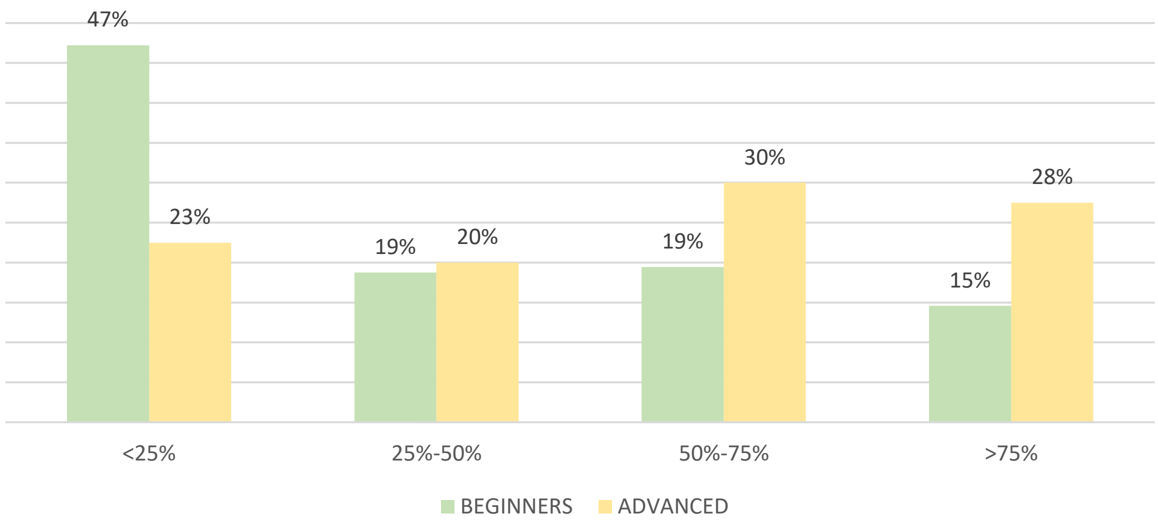
Analyzing now the Lean techniques employed by the firms, it appears clearly from *Graph 51* that there is a significant difference between Advanced and Beginners in the proportional implementation of Lean practices. Even though the top three highest-used techniques are the same for the two groups, namely 5S, Pull / Kanban and VSM. Some differences are recorded instead for Kaizen and Standardized Work, which see a percentage above 90% for Advanced companies, versus only a 36% of Beginners.

***Graph 51** – Distribution by Lean technique (N=221)*



Finally, the last dimension is related to the proportion of employees which is involved in improvement projects (such as Kaizen groups or training courses). In *Graph 52*, we can see that Advanced firms are more inclined to actively involve their workforce, and such result seems logical, since we can presume that Advanced adopters are better sensible and acquainted to Lean philosophy and principles, and therefore they understood the importance of the involvement of employees.

Graph 52 *– Percentage of employees involved in improvement projects (N=184)*



CHAPTER 4 – STATISTICAL ANALYSIS

4.1 Research objective

Once the dataset used for the analysis has been systematically described in order to give a better understanding of the sample, this paper progresses with the implementation of the statistical analysis that aims to test the validity of this research.

Since there is a lack of unanimity in the academic world on the effect of being Lean in case of external disruptions (and in particular, in the event of the pandemic of Covid-19), and more generally, on the interrelation between Lean and resiliency to crisis, the analysis has the purpose to provide an empirical investigation on the subject. The employed database contains 454 Italian manufacturing firms, with related economic and financial indicators covering the time range 2008 – 2020, with the data of the last two years taken in the Orbis database. Despite that, the time frame which is taken into consideration for the purpose of this analysis is generally limited to the years 2019 (as the last year pre-crisis) and 2020 (being the first year post-crisis).

The research question which is investigated is elicited as follows:

RQ: *Did Lean companies better survive the Covid-19 crisis?*

Which can be translated as *Are Lean companies more resilient?*

To perform such assessment, multiple linear regression has been employed, which is a statistical method that analyzes the causal relationship between a dependent variable and several independent variables. Moreover, an alternative non-parametric approach is provided.

The chapter begins with an initial presentation of the regression model, through the description of the different variables involved. Then, it is followed by an explanation of the equation used for the tested hypothesis, along with the presentation of the results. Finally, an alterative approach to linear regression is presented, using independent T-test.

4.2 Description of the regression model and of its components

The first thing in the analysis is to choose the right variables for the model, based on the information available in the dataset, which have either been enquired to organizations in the questionnaire, or they are referring to the economic-financial indicators which have been retrieved in the Orbis database. The different types of variables will be detailed below.

4.2.1 Dependent variable

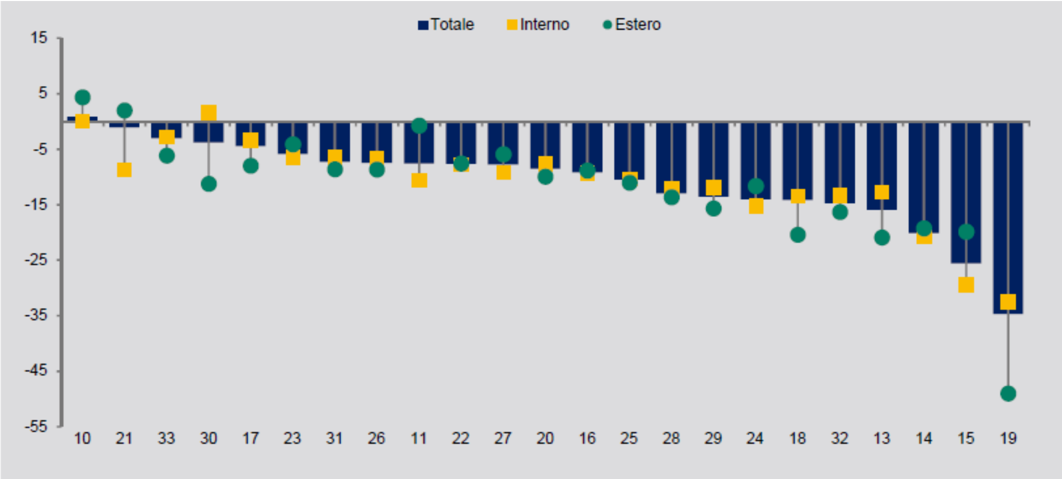
Dependent variables (also called response or y-variables) represent the effect in the regression model; their value is dependent on the changes of the independent variables, since it represents what is recorded and observed after the manipulation of the independent variables. For this specific hypothesis and regression model, the needed dependent variable is related to the organizational resilience, in order to assess how it varies depending on the feature of such companies, and more specifically, depending on whether companies are Lean or not.

Therefore, the greatest challenge in this regression model concerns the identification of an appropriate independent variable, which must express a suitable index for organizational resilience with the data at our disposal. The first and most straightforward performance indicator corresponds to the percentage annual variation in revenues from 2019 (last year before Covid) and 2020 (first year post Covid), calculated as shown in the equation below.

$$REV\ VAR = \frac{REV_{2020} - REV_{2019}}{REV_{2019}}$$

Similarly, other related performance indicators are related to the percentage variation of EBITDA (a profitability index that represents the profit before the financial costs, taxes, devaluations, and depreciations) and ROE (calculated as the ratio between net income and book value of equity, representing the company's ability to efficiently generate profits). The annual variations for such indicators are calculated in the same way as the equation above.

After a first analysis of the most basic financial performance indicators, we need however to identify an appropriate resilience index to test the main hypothesis of the research. Since not all the sectors have been equally affected by the crisis, we identified the variation in profits in 2020 for all sectors, based on the ATECO two-digits classification, as seen in *Figure 11* below.



Fonte: Elaborazioni su dati Istat, Indagine mensile sul fatturato delle imprese industriali
(a) 10=Alimentari; 11=Bevande; 13=Tessile; 14=Abbigliamento; 15=Pelle; 16=Legno; 17=Carta; 18=Stampa; 19=Coke e petroliferi; 20=Chimica; 21=Farmaceutica; 22=Gomma e plastica; 23=Minerali non metalliferi; 24=Metallurgia; 25=Prodotti in metallo; 26=Elettronica; 27=Apparecchiature elettriche; 28=Macchinari; 29=Autoveicoli; 30=Altri mezzi di trasporto; 31=Mobili; 32=Altre manifatturiere; 33=Riparazione e manutenzione di macchinari e apparecchiature.

Figure 11 *– 2020 profit variation by manufacturing sector (source: ISTAT)*

Therefore, we constructed a more precise metric, where the 2020 annual profit variation of each single firm is put in relation with the variation of the whole sector where it belongs, as detailed in the equation below:

$$RESILIENCE\ INDEX_1 = {}^{REV\ VARIATION_{FIRM}}\!/_{REV\ VARIATION_{SECTOR}}$$

Additional tested resilience indicators, given the availability of limited data and the scarcity of empirical literature on the subject, are the following:

- Based on the literature review on resilience indicators, the most suitable for this analysis is the one proposed by Barroso et al. (2015), which has already been unfolded in Chapter 2. This indicator ranges from 0 to 1 (where 1 is maximum resilience) and it is focused on the performance variation that covers the time range from the pre-risk situation to the recovery. In this case, we used an approximation by employing only the years 2019 (as the pre-crisis moment) and 2020, in order to give a first index of resilience. Also, we used as performance indicators the company's revenues. The formula for such indicators is detailed in the equation below:

$$RESILIENCE\ INDEX_2 = 1 - \frac{\sum_{t_0}^{t_1}(1 - {}^{P_{it}}\!/_{P_i})}{P_i(t_1 - t_0)}$$

- Since resilience entails the ability of a firm to face disruptions without significant impacts in performance, we also calculated for each firm on the sample its "theoretical" 2020 revenue (based on the CAGR of the last 10 years, where available), and put it into comparison with its actual revenue, as detailed in the equation below:

$$RESILIENCE\ INDEX_3 = (THEORETICAL\ REVENUE_{2020} - ACTUAL\ REVENUE_{2020}) / THEORETICAL\ REVENUE_{2020})$$

where $THEORETICAL\ REVENUE_{2020} = CAGR * \ ACTUAL\ REVENUE_{2019}$

4.2.2 Independent variable

The independent variable (also called explanatory or predictor or x-variables) represents the cause in the regression model. They are the variables manipulated to discover the changes in the correlation model, and their values are not influenced by any other variables of the model. In our empirical research, the independent variable is whether a company is Lean or not. However, to refine the analysis, we identified two categories of Lean firms depending on the dimension of Lean intensity, and in particular on the numbers of Lean techniques employed. As already described in Chapter 3, we distinguish the Lean firms between Beginner and Advanced. Therefore, the independent variable is represented by a categorical variable with the following values:

- Outsiders (non-Lean companies) which represent the baseline
- Beginners are those Lean firms which employs less than 25 Lean techniques
- Advanced are those Lean firms which employ more than 25 Lean practices

4.2.3 Control variables

A common problem in regression for the explanatory variable is the so-called omitted variable bias, which occurs when relevant regressors are not included in the model, thus attributing the effect of the missing variables on those which are included. The two conditions which have to be satisfied for such bias to happen are that the explanatory variable must be correlated with the omitted variable, and that the omitted variable must be a determinant of the dependent variable. Thus, in multiple regression, it is essential to insert control variables as predictors, which represent those elements which are held constant to demonstrate that they do not influence the final result. For this regression model, the selected control variables represents those organizational features which could have an impact on firm's performance. All the variables are taken based on the answers of the survey, and they are presumably constant.

- **Geographical location**: categorical variable which assumes the value "0" if the company belongs to North-East of Italy, value "1" is it belongs to North-West, and value "2" is it belongs to Center-South
- **Family business**: Dummy variable which assumes the value "1" is the company is a family business, or the value "0" otherwise
- **Size**: continuous variable intended as the number of employees of the sampled companies
- **Age**: continuous variable calculated as the difference between the current year and the year of foundation of each company
- **Foreign Plant**: Dummy variable which assumes the value "1" if the company owns a plant abroad, or the value "0" otherwise
- **Main Market**: Dummy variable which assumes the value "1" if the company has Italy as its main market, or the value "0" otherwise

All the variables are summarized in Table 7 below.

***TABLE** 7 - Summary of the employed variables in the regression model*

VARIABLE	*TYPE OF REGRESSION VARIABLE*	*TYPOLOGY*
Revenue variation	Dependent	Continuous
EBITDA variation	Dependent	Continuous
ROE variation	Dependent	Continuous
Resilience Index_1	Dependent	Continuous
Resilience Index_2	Dependent	Continuous (ranging from 0 to 1)
Resilience Index_3	Dependent	Continuous
Lean Intensity	Independent	Categorical 0=Outsiders 1=Beginners 2=Advanced
Family Business (corporate governance)	Control	Dummy 0=No family business 1=Family Business

Geographical location	Control	Categorical 0= North-East 1= North-West 2= Center/South
Age	Control	Continuous
Size (number of employees)	Control	Continuous
Foreign Plant	Control	Dummy 0=No foreign plant 1=Foreign plant
Main Market	Control	Dummy 1= Italy as main market 0=Other market as main market

4.3 Research Method and the tested regression models

After having presented and outlined the different types of variables, we can describe the statistical analyses performed to test the research hypothesis. The first employed model is the multiple linear regression, where the coefficients of the model are predicted through the OLS estimator, which minimizes the sum of the errors' squares. The four assumptions associated with such model are linearity of the relationship between the dependent and independent variables, homoscedasticity (the residuals' variance is the same for any value of the predictor), independence of observations, and normality in the distribution of the response variable). The generic regression model equation is detailed in the equation below:

$$Y = \beta_0 + \beta_1 LEAN\ VARIABLE + \beta_2 CONTROL\ VARIABLES + \varepsilon$$

More specifically, the tested regression model based on the research hypothesis is expressed as:

$$Y = \beta_0 + \beta_1 LEAN\ CATEGORIES + \beta_2 Age + \beta_3 Size + \beta_4 Family\ Business + \beta_5 Geographical\ Location + \beta_6 Foreign\ Plant + \beta_7 Main\ Market + \varepsilon$$

The employed dataset consists of 454 companies. Of that, 50 companies were not found in the Orbis database, for which therefore it was impossible to retrieve more recent data for 2019 and 2020; thus, they have been deleted from the dataset. As a result, the total number of companies considered is 404. Moreover, for each independent variable, additional manipulations have been performed: more specifically, missing data and outliers have been deleted. For the outliers, the data trimming action was accomplished by identifying the 25^{th} and 75^{th} percentiles, which were used in turn to calculate the upper and lower limits.

The number of final observations is indicated for every model.

As explained in the paragraph above, the first basic independent variables are related to simple performance indicator, namely annual revenue variation, which again is expressed in the following equation:

$$REV\ VAR = \frac{REV_{2020} - REV_{2019}}{REV_{2019}}$$

Table 8 presents the results with such independent variable.

TABLE 8 *– Multiple Linear Regression with Y = REVENUE VARIATION (N=400)*

REVENUE VARIATION	Beta	Standard Error	t	p
Intercept	-0.12102	0.0278	-4.3539	<.001*
LEAN CATEGORIES	(Reference level: Outsiders)			
ADVANCED	0.08866	0.0399	2.2198	0.027*
BEGINNERS	0.02239	0.0237	0.9446	0.345
Age	2.46e-4	1.05e-4	2.3412	0.020*
Size	-1.04e-5	4.93e-5	-0.2106	0.833
Family Business	0.02510	0.0230	1.0921	0.275
Geographical Location	(Reference level: North-East)			
North-West	-0.04689	0.0281	-1.6667	0.096^
Center-South	-0.03853	0.0377	-1.0217	0.308
Foreign Plant	0.00181	0.0281	0.0643	0.949
Main market	0.01508	0.0223	0.6772	0.499
R-squared		*0.0365*		

*Significance at 0.05 level; ^Significance at 0.1 level

From the result, we can observe a positive significant impact of Lean intensity on economic performance (in this case embodied by revenue variation): indeed, Advanced Lean firms show a statistically significant coefficient (with a p-value lover that 5%). We can observe a minor but positive effect also for Beginners, but the result is not statistically significant.

Among control variables, the only significant result is embodied by Age, which shows a little but positive impact on revenue variation: therefore, it seems to suggest that older organizations can react better to crisis.

However, the significance of results is not proved for other economic performance indicators, such as the variation in EBITDA or ROE. Results are synthetically presented in the table below.

TABLE 9 – Multiple Linear Regression with additional dependent variables

	EBITDA VARIATION (N=360)	ROE VARIATION (N=329)
Intercept	-0.0699 (0.0658)	-0.28507 * (0.0954)
LEAN CATEGORIES	(Reference level: Outsiders)	
Advanced	0.0782 (0.0955)	0.20714 (0.1342)
Beginners	0.0402 (0.0563)	0.10727 (0.0809)
Age	8.27e-5 (2.36e-4)	7.48e-5 (3.26e-4)
Size	9.72e-5 (1.24e-4)	1.26e-4 (1.57e-4)
Family business	0.0977 ^ (0.0551)	-0.00773 (0.0780)
GEOGRAPHICAL LOCATION	(Reference level: North-East)	
North-west	0.0201 (0.0676)	0.00908 (0.0977)
Center-south	0.0548 (0.0953)	-0.07078 (0.1332)
Foreign plant	-0.0800 (0.0661)	0.01752 (0.0950)
Main market	-0.1160 ^ (0.0526)	-0.06773 (0.0760)
R-squared	*0.0327*	*0.0275*

Standard error in parenthesis; *Significance at 0.05 level; ^Significance at 0.1 level

Table 10 instead presents the results for resilience indicators (1) and (3). For Resilience Index_2, the condition of normality in distribution could not be respected, therefore it was excluded from the analysis and will be tackled in the next paragraph.

TABLE 10 – Multiple Linear Regression with resilience indicators

	RESILIENCE INDEX_1 (N=352)	RESILIENCE INDEX_3 (N=335)
Intercept	0.9693 * (0.178)	0.16127 * (0.0271)
LEAN CATEGORIES	(Reference level: Outsiders)	
Advanced	-0.2408 (0.260)	-0.08012 * (0.0284)
Beginners	-0.0367 (0.153)	-0.01066 (0.0167)
Age	-5.53e-4 (6.33e-4)	-6.88e-4 (5.73e-4)
Size	-3.40e-5 (3.20e-4)	-4.28e-7 (4.61e-5)
Family business	-0.0509 (0.147)	0.00553 (0.0166)
GEOGRAPHICAL LOCATION	(Reference level: North-East)	
North-west	0.3858 * (0.180)	0.02650 (0.0204)
Center-south	0.1882 (0.254)	0.02702 (0.0278)

Foreign plant	-0.1341 (0.178)	-0.00200 (0.0197)
Main market	-0.0546 (0.143)	-0.02074 (0.0162)
R-squared	*0.0226*	*0.0446*

Standard error in parenthesis; *Significance at 0.05 level

As we can see from the numbers, the model employing the Resilience Index (3) as independent variable presents significant results only for Advanced organizations. The relationship is negative, meaning that Advanced Lean firms are able to maintain their revenue growth in 2020 close to the one based on the CAGR, therefore showing resilience to the Covid-19 disruptions.

It is important to note however that the extensive data trimming performed on these resilience indicators suggested that the condition of normal distribution was not entirely respected, therefore suggesting the employment of a different statistical method to refine the analysis. The alternative approach will be explained in the next paragraph.

4.4 An alternative approach: the Mann-Whitney U test

As already stated before, a necessary condition for the multiple linear regression is the normal distribution of the dependent variable. During the preliminary analysis of the descriptive values concerning the three resilience indicators, we observed a strong abnormality in distribution. This was confirmed also by the skewness values displayed in Table 11 (which are strongly outside the interval [-0.5; +0.5]), as well as by the Q-Q plots below (in which for normally distributed data, observations should roughly lie on the straight line).

***TABLE 11** – Skewness and kurtosis values for resilience indicators*

	RESILIENCE INDEX (1)	**RESILIENCE INDEX (2)**	**RESILIENCE INDEX (3)**
N	399	400	369
Skewness	-2.77	16.6	-2.09
Kurtosis	27.6	301	13.3
Shapiro-Wilk p	<0.001	<0.001	<0.001

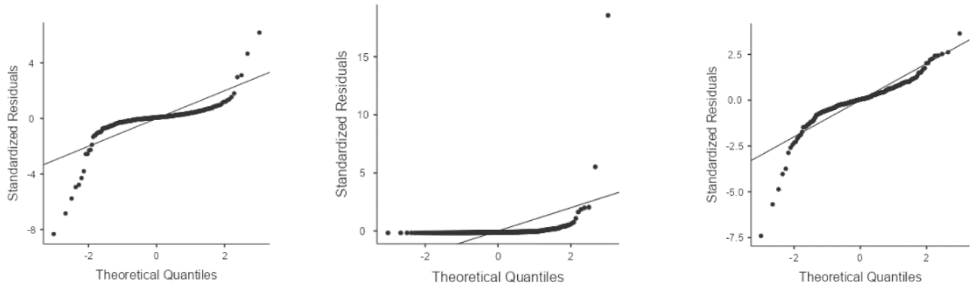


Figure 12 *- Q-Q plots for proposed resilience indicators*

For this reason, for these three resilience indicators a different approach was adopted, called the Mann-Whitney test. It is a non-parametric model (which is an alternative to the parametric t test for independent samples), and it allows to get more robust indexes in case of anomalies or asymmetries, by employing the median value. The test is useful to measure whether two samples are coming from different populations (Carvalho et al., 2016).

In this case, we tested separately two grouping variables: the first one was the Lean dichotomic variable (which distinguished between Lean and Not Lean), while the second was a variable which grouped together Outsiders and Beginners, using Advanced companies as the testing variable. Results are explicated in the tables below.

TABLE 12 *- Independent samples for Mann-Whitney test (Lean vs Outsiders)*

	N	Median	Statistic	p
RESILIENCE INDEX_1				
Lean	195	0.734	18.035	0.107
Outsiders	204	0.921		
RESILIENCE INDEX_2				
Lean	195	6.94e-8	13.335	<0.001*
Outsiders	205	3.83e-8		
RESILIENCE INDEX_3				
Lean	180	0.101	14.236	0.007*
Outsiders	189	0.135		

*Significance at 0.05 level

TABLE 13 *- Independent samples for Mann-Whitney test (Advanced vs Outsiders+Beginners)*

	N	Median	Statistic	P
RESILIENCE INDEX_1				
Outsiders + Beginners	358	0.867	5.987	0.053
Advanced	41	0.414		

RESILIENCE INDEX_2				
Outsiders + Beginners	359	1.58e-8	3.831	<0.001*
Advanced	41	5.71e-8		
RESILIENCE INDEX_3				
Outsiders + Beginners	330	0.126	4.435	0.002*
Advanced	39	0.0543		

*Significance at 0.05 level

For Resilience Index (1) results are still scarcely significant, meaning that the differences in the medians between the two groups are not statistically relevant.

Instead, in both Resilience Indexes 2 and 3 we register p-values below the significance level (0.05), therefore inferring the existence of statistically significant differences between the two groups in both the tested cases. In particular, by looking at median values, we can see for Resiliency Index (2) that Lean and Advanced firms have values closer to 1, showing more resilience than the other group. For Resiliency Index (3), instead, we can see that Lean and Advanced firms show a lower median (more accentuated for the latter), meaning that they tend to have actual revenues for 2020 closer to their CAGR growth values.

CHAPTER 5 – CONCLUSIONS

5.1 Main empirical results

Lean is a relatively new methodology, which has been extensively applied by firms worldwide as an alternative approach to the traditional production methods, as a tool that can aid organizations to benefit from consistent operational improvements. The amplified efficiency and flexibility could benefit firms in a business environment which is characterized by an increased speed of change. However, the augmented frequency of low-probability, high-severity events, like the recent pandemic of Covid-19, has pushed companies to reconsider their capabilities pool to better face the new organizational challenges.

The impact of the Lean approach in case of disruptions (exemplified by the Covid pandemic) has been discussed in recent literature with contrasting results. Thus, the objective of this paper was to assess whether being Lean helps an organization to better survive crisis and disruptive events; in particular, it focuses on the recent Covid-19 pandemic.

The main challenge for this research was to find an appropriate resilience index based on the available data. Literature on the subject reveals a scarcity of research, and the available works containing proposals about resilience indicators employ either logistic and supply chain-specific measures, or complex models, or they rely on surveys aimed specifically at investigating the resilience within the sample. There is therefore a scarcity of research regarding the relationship between resilience and the firm’s economic-financial performance, and more specifically how the economic KPIs can be utilized to return a measure for resilience. Hence, in the presented analysis a set of resilience indexes is proposed, based either on literature findings as well as on discretionary proposals.

Empirical results reveal that there is no systematic evidence of the positive correlation between Lean and resilience. However, findings suggest that Advanced companies reacted better to the crisis, inferring that the dimension of leanness intensity has an important role.

5.2 Limitations and future research opportunities

This dissertation presents some limitations which might have an impact in the research general applicability.

First, the considered sample is based on a questionnaire submitted to several Italian manufacturing companies. Therefore, the scope of the research is limited to one country, and to only one sector. Moreover, the results are based on the survey's answers, which are dependent on the respondents' subjectivity.

Secondly, the economic and financial indicators for the organizations of the sample were available only until 2020. Therefore, the only possible comparison was between the last year pre-pandemic and the first year post-pandemic.

Thirdly, the classification of Lean companies between Beginners and Advanced through the dimension of Leanness intensity (which was used as the independent variable of the regression model) was based on a discretional methodology, which could have modified the final results of the analysis.

Lastly, as already outlined above, the main limitation of this research was related to the identification of an appropriate resilience index which represented the dependent variable of the regression model.

However, this empirical dissertation provides guidelines and direction for future research opportunities. The pandemic of Covid-19 is an extremely recent phenomenon, and therefore requires additional insights and in-depth analysis. Given the worldwide nature of the pandemic, it would be meaningful to expand the sample size in order to include other countries. Moreover, the analysis could be extended also in other sectors, to see if some differences in results are observed. It would also be noteworthy to perform the empirical investigation later in time, to include the performance indicators also of the years 2021 and 2022, to see the evolvement of the firms' performance, and to build more sophisticated resilience indicators that can include also the recovery period.

Finally, literature must expand the empirical research on resilience, to reach a unified view of this relatively novel concept, in order to proceed to the identification of appropriate indicators. Moreover, the correlation between resilience and lean production must be further investigated as well, so that firms can learn how to better integrate (or even modify) their Lean approach to increase their resiliency.

The recent pandemic must not be considered as an isolated singularity, but rather as an expression of the changing environment, and as an anticipation of the future business environment, characterized by an "*underlying condition of risk*" (OECD, 2003) where disruptive and unpredictable phenomena will be always more frequent, and where key abilities will evolve continuously. Therefore, organizations, firms and supply chains worldwide must equip themselves and create appropriate resilient capabilities to face a future that is not so distant.

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