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Exploring the Synergy between Industry 4.0, Quality 4.0, and Lean Production for Improved Quality in Manufacturing

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ABSTRACT:
The manufacturing industry has experienced significant changes with the advent of technological advancements. Industry 4.0 and Quality 4.0 have emerged as new paradigms focusing on the use of digital technologies to enhance efficiency and quality in manufacturing. Additionally, the long-established lean approach aims to minimize waste and improve overall quality. Integrating these approaches with Industry 4.0 and Quality 4.0 has the potential to transform the industry by optimizing quality, efficiency, and profitability. Therefore, this study aims to explore the interconnections between lean, Industry 4.0, and Quality 4.0, and their impact on quality in manufacturing. The research begins by providing the necessary background, starting with a comprehensive examination of the concept of quality. Subsequently, the study presents an overview of lean principles, followed by an analysis of the concepts of Industry 4.0 and Quality 4.0. The theoretical framework also explores the relationship between these concepts. Following the theoretical analysis, the empirical part of the study was conducted using a survey questionnaire. The survey was distributed to 190 medium-sized manufacturing companies in Finland, ultimately receiving responses from 44 organizations. This survey aimed to gather practical insights into the implementation of lean, Industry 4.0, and Quality 4.0 practices within the manufacturing context. Based on the findings derived from the survey data, lean tools have a broader adoption compared to Industry 4.0 and Quality 4.0 practices. Moreover, implementing these tools and practices has shown a positive impact on company performance, sparking a growing interest among companies to explore and implement additional tools. The survey also highlights a strong inclination among organizations to embrace Industry 4.0 and Quality 4.0 practices, showcasing their increasing recognition of the potential benefits and transformative capabilities of these innovative methodologies in driving organizational success.

KEYWORDS: Lean, Lean production, Industry 4.0, Quality 4.0, Toyota Production System

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Abbreviations

AI	Artificial intelligence
AR	Augmented reality
CAD	Computer-aided design
CPS	Cyber-physical system
HPC	High-performance computing
ICT	Information and communications technology
IoT	Internet of Things
IT	Information technology
JIT	Just-in-time
S&P	Standard & Poor’s
TPM	Total Productive Maintenance
TPS	Toyota Production System
TQM	Total Quality Management
VSM	Value Stream Mapping

1 Introduction

In recent years, the manufacturing industry has witnessed a rapid transformation due to the introduction of various technological advancements. Industry 4.0 and Quality 4.0 have emerged as the latest manufacturing paradigms that emphasize the use of digital technologies to optimize quality and efficiency. Lean, on the other hand, has been a longstanding approach that aims to reduce waste, minimize production costs, and improve overall quality. The integration of these approaches with Industry 4.0 and Quality 4.0 has the potential to revolutionize the manufacturing industry by improving quality, efficiency, and profitability.

Shridhara Bhat (2009) states the importance of quality as follows: “No quality, no sales. No sale, no profit. No profit, no jobs”. Therefore, quality is the cornerstone of success, without which it is difficult to succeed in the long-term. This is also reflected in the fact that the biggest challenge of today's companies is to produce quality products and services efficiently. Another cornerstone of success for manufacturing companies is efficiency, which can be improved by adopting lean techniques, as stated by Plenert (2006). By doing this a company can achieve various benefits such as eliminating waste, reducing cycle and flow time, increasing capacity, reducing inventories, increasing customer satisfaction, eliminating bottlenecks, and improving communication. (Plenert, 2006; Shridhara Bhat, 2009)

According to Rüßmann et al. (2015), Industry 4.0 has the potential to provide a more rapid response to customers' needs compared to the current methods. It also enhances the production process by increasing flexibility, productivity, speed, and quality. Industry 4.0 serves as a basis for adopting new business models, production processes, and other innovations. With the integration of Industry 4.0 technologies, industrial producers can offer customized products on a larger scale, which could result in mass customization. (Rüßmann et al. 2015)

Wagner, Herrmann and Thiede (2017) state that Industry 4.0 and lean production are two approaches that aim to improve the efficiency and productivity of industrial companies. Industry 4.0 involves the use of advanced technology such as automation and data exchange, while lean production focuses on streamlining processes and reducing waste. Although these two concepts align well, there is currently a lack of research on how to effectively integrate Industry 4.0 solutions into existing lean production systems. As a result, a framework that brings together the best practices of both Industry 4.0 and lean production is currently missing. (Wagner, Herrmann & Thiede, 2017)

Therefore, this thesis aims to explore the relationship between lean principles, Industry 4.0, and Quality 4.0. The focus of this thesis is on how these approaches can be integrated to improve quality and efficiency. The thesis will begin by reviewing the existing literature on quality, lean, Industry 4.0, and Quality 4.0. It will identify the gaps in the literature and develop a theoretical framework for integrating these approaches. The thesis will then collect and analyze data to test the research question. The data will be collected from a survey sent to Finnish medium-sized manufacturing companies. The analysis of the data will be used to draw conclusions and make recommendations for how these approaches can be integrated to improve manufacturing efficiency and quality.

The findings of this thesis will be relevant to manufacturing industries that seek to optimize their production processes and improve their competitiveness. The insights gained from this research can be used by manufacturing companies to develop strategies for integrating quality, lean, Industry 4.0, and Quality 4.0, to improve production efficiency and profitability.

1.1 Purpose of the Study

As mentioned earlier, the purpose of this study is to investigate the relationship between quality, lean, Industry 4.0, and Quality 4.0. The manufacturing industry is constantly evolving, and companies must adapt to remain competitive. Industry 4.0, with its focus on automation, data exchange, and smart technologies, is transforming the way production processes are managed. Quality 4.0, on the other hand, emphasizes the use of data analytics and advanced technologies to ensure product quality and meet customer expectations.

The study aims to identify the impact of Industry 4.0 and Quality 4.0 on quality and the role of lean practices in this context. Lean emphasizes the elimination of waste and continuous improvement to increase efficiency and productivity. By integrating lean practices with Industry 4.0 and Quality 4.0, manufacturers can streamline their production processes and deliver high-quality products that meet customer needs.

The study will employ a quantitative analysis technique. A survey will be used to gather data on the implementation of Industry 4.0 and Quality 4.0 practices, as well as the implementation of lean techniques. In-depth interviews will be conducted with manufacturing industry professionals to gain insights into their experiences with these approaches.

The findings of this study will have practical implications for manufacturers seeking to improve their over quality and competitiveness in the Industry 4.0 era. The results will inform the development of a framework that integrates lean production, Industry 4.0, and Quality 4.0 to optimize production processes and ensure product quality. This study will contribute to the existing literature on quality, lean practices, Industry 4.0, and Quality 4.0, and will provide a valuable resource for researchers, practitioners, and policymakers in the manufacturing industry.

1.2 Hypotheses of the Study

- H1: The implementation of Industry 4.0 and Quality 4.0 practices has a positive impact on overall quality in the manufacturing industry.

This hypothesis assumes that the implementation of Industry 4.0 and Quality 4.0 practices can lead to improvements in overall quality. These practices emphasize the use of data analytics and advanced technologies to ensure product quality, meet customer expectations, and improve efficiency and productivity.

- H2: Lean tools mediate the relationship between Industry 4.0/Quality 4.0 and overall quality in the manufacturing industry.

This hypothesis suggests that the implementation of Industry 4.0 and Quality 4.0 practices alone may not be sufficient to improve overall quality. Lean tools, which focus on eliminating waste and continuous improvement, can act as a mediator between these practices and quality. By integrating lean practices with Industry 4.0 and Quality 4.0, manufacturers can optimize production processes and enhance product quality.

- H3: The level of Industry 4.0 and Quality 4.0 implementation in a manufacturing company is positively correlated with the level of implementation of lean tools.

This hypothesis proposes that the implementation of Industry 4.0 and Quality 4.0 practices may lead to an increased implementation of lean tools in manufacturing companies. As these practices emphasize similar goals, such as reducing waste and improving efficiency, companies that adopt Industry 4.0 and Quality 4.0 practices may also be more likely to implement lean tools.

Overall, the study aims to test these hypotheses to gain a better understanding of the relationship between quality, lean production, Industry 4.0, and Quality 4.0 in the manufacturing industry.

1.3 Structure of the Study

The thesis will begin with an introduction that provides the background and context of the research, states the purpose of the study, and outlines the hypotheses and objectives of the study. The second chapter will present a comprehensive literature review that covers the definition and importance and theory of quality, principles of lean, key technologies of Industry 4.0, and principles of Quality 4.0. The chapter will also discuss the relationship between lean, Industry 4.0, and Quality 4.0, and the impact of these approaches on quality. The third chapter will detail the research methodology, including the research design and approach, sample selection, data analysis techniques, and any limitations of the research. The fourth chapter will present the results and analysis of the study, including an overview of the study sample and characteristics, analysis of the impact of each approach on quality, and comparison of the three approaches in terms of their impact on quality. The thesis will conclude with a summary of the key findings, implications for practice and future research, and final reflections and concluding remarks. A comprehensive list of all references cited in the thesis will be included, and appendices with additional information that supports the research will be provided.

2 Theoretical framework

This section of the thesis will examine the existing body of literature related to quality, lean, Industry 4.0, and Quality 4.0. The chapter begins by introducing the concept of quality, followed by a discussion of Total Quality Management (TQM). Then, the background of lean and its tools is explored. Afterward, the definitions of Industry 4.0 and Quality 4.0 are presented and their relevance to the manufacturing sector is discussed. Lastly, three case studies of combining lean production and Industry 4.0 are briefly introduced to conclude the chapter.

2.1 The concept of quality

When thinking of quality, people typically think of an excellent product or service that meets or exceeds our expectations. These expectations are influenced by the intended use and price of the product or service. When a product or service exceeds our expectations, we consider it to be quality. Therefore, quality is somewhat subjective and can be based on perception. (Besterfield et al. 2012)

The Institute of Leadership & Management (2003) has pointed out that the International Organization for Standardization ISO 9000:2000 provides an official definition of quality as the "degree to which a set of characteristics fulfils requirements". This definition can be summarized in several ways, such as: "fitness for purpose". Dale, van der Wiele and van Iwaarden (2011) further explains that the definition "fitness for purpose" was first used by Juran in 1988. Juran divides "fitness for purpose" into four groups: quality of design, quality of conformance, abilities, and field service. Emphasizing fitness for use is necessary to avoid over-specifying products and services, which can increase costs and hinder their effectiveness. The purchaser, customer, or user is responsible for determining the suitability of a product or service for its intended use. (Leadership & Management, 2003; Dale, van der Wiele & van Iwaarden, 2011)

According to Shridhara Bhat (2009), quality has become a crucial competitive advantage for companies. In the past, standards for quality were unclear and not strictly enforced, but today, contracts often specify specific quality standards that must be met. This has led to a shift in the focus of competition from just price to also include quality. Shridhara Bhat (2009) defines the word quality as follows:

- Q: Quest for excellence,
- U: Understanding customer's needs,
- A: Action to achieve customer's appreciation,
- L: Leadership – determination to be a leader,
- I: Involving all people,
- T: Team spirit to work for a common goal, and
- Y: Yardstick to measure progress.

In addition, Besterfield et al. (2012) present the following formula that can be used to determine quality:

$$Q = P/E$$

where Q = quality
P = performance
E = expectations

If the value of Q is greater than 1.0, it indicates that the customer has a positive opinion of the product or service. The values of P and E that contribute to Q are typically based on perception, with the company determining performance and the customer determining expectations. (Besterfield et al. 2012)

Shridhara Bhat (2009) states that the biggest challenge for company today is to produce quality products or services efficiently. Quality is a key objective in operations management, along with cost, flexibility, and delivery. It is also a key factor in customer satisfaction, which has a direct impact on profitability. Quality is considered the most important factor in the long-term success or failure of a company, as it can give a competitive advantage, reduce costs, increase productivity and profits, improve brand image, and create satisfied customers who will promote the company through word-of-mouth advertising. Overall, quality can be seen as an investment that will provide long-term benefits to the company. (Shridhara Bhat, 2009)

Dr. W. E. Deming is widely considered to be the most influential figure in the field of quality management. He is often synonymous with quality and Total Quality Management (TQM). Deming introduced Japanese managers to the principles of quality production and was one of the first to view quality management as an organization-wide activity rather than just a task for inspectors or a specialized quality assurance group. He believed that quality was a management responsibility and that it was the responsibility of managers to create systems and processes that produce high quality products and services. (Shridhara Bhat, 2009).

Deming also recognized that a company cannot simply inspect its way to producing high quality products, and that a combination of good design and effective production methods is necessary to achieve quality. He proposed a cycle of continuous improvement that includes product design, manufacturing, testing, and sales, followed by market surveys and redesign. Deming believed that higher quality leads to higher productivity and long-term competitive strength, a theory known as the Deming Chain reaction. Figure 1 below summarizes this theory. (Shridhara Bhat, 2009)

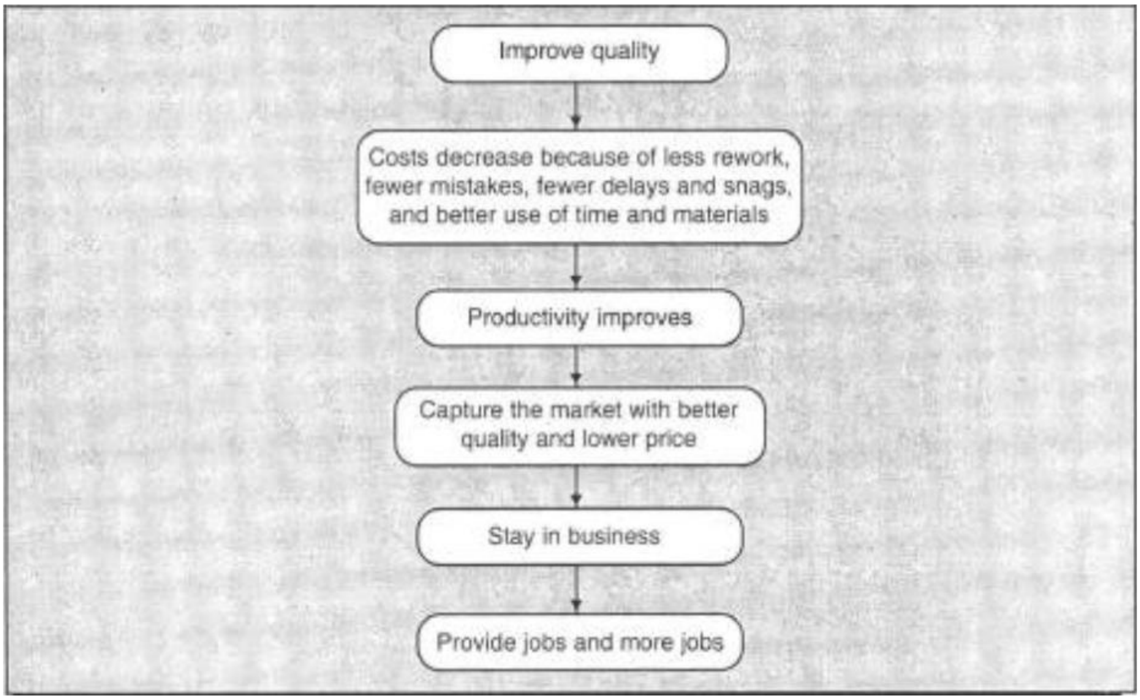

Figure 1. The Deming Chain reaction (Shridhara Bhat, 2009).

The theory being discussed states that improving quality can lead to lower costs. This is because improvements in quality can result in fewer errors, less rework, and better use of time and materials, which can lead to more efficient processes. Lower costs can then lead to increased productivity. The theory also suggests that with better quality and lower prices, a company can increase its market share and remain competitive, which can provide more job opportunities. (Shridhara Bhat, 2009).

To improve their quality, companies may wonder what steps to take. According to Soković et al. (2009), Ishikawa, a prominent figure in the field of quality management, was the first to introduce the seven quality tools in the 1960s. His original seven tools include stratification, which has later become more commonly called a flow chart or a run chart. These simple but effective tools are widely used as general management tools for continuous improvement. Magar and Dr. Shinde (2014) identify the seven quality tools as check sheet, histogram, control chart, cause-and-effect diagram, pareto diagram, scatter plot, and flow chart. While there are numerous other tools available, selecting the most appropriate tool for a company is the most essential part of the process. (Soković et al. 2009; Magar & Dr. Shinde, 2014)

2.1.1 Total Quality Management (TQM)

According to Kiran (2017), TQM gained widespread adoption during the industrial revolution due to the increased specialization of labor and the corresponding importance of producing high-quality products. In this period, workers became responsible for completing only a single operation in the production process rather than being responsible for the entire product. As a result, there was a greater emphasis on ensuring that each operation was carried out to the highest possible standard and thus TQM started to spread widely. (Kiran, 2017)

Naidu, Badu and Rajendra (2006) state that TQM is a method of doing business that seeks to improve the traditional approach and increase competitiveness. It involves changing the management practices and culture of a company in order to achieve success. TQM relies on common sense and it can be analyzed with the following words:

- Total – made up of the whole,
- Quality – degree of excellence a product or service provides, and
- Management – act, art, or manner of handling, controlling, directing etc. (Naidu, Badu & Rajendra, 2006)

Besterfield et al. (2012) state that TQM can provide several benefits to a company, as a study of Georgian manufacturing companies shows. According to the study, implementing TQM can lead to improved quality, increased employee and customer satisfaction, improved teamwork and working relationships, increased productivity and communication, improved profitability, and increased market share. This ten-year study by Hendricks and Singhai also found that there is a strong link between TQM and financial performance. In the study, a group of 600 publicly traded organizations that had won awards for effectively implementing TQM was compared with a control group of similar size and industry. The performance of both groups was compared over a five-year period before and after the award was given. The study found that while there was no difference between the two groups before the award was given, the group that received the award significantly outperformed the control group in the five years following the award. (Besterfield et al. 2012)

The study also found that the stock price performance of the group of award-winning organizations was 114%, while the S&P index increased by 80% over the same period. In addition, the study found that small organizations performed better than larger ones. However, recent studies have shown that only about 30% of manufacturing organizations have successfully implemented TQM. (Besterfield et al. 2012)

2.2 The background of Lean

The idea of "leanness" first emerged in the 1950s from the Japanese car company Toyota Motor Corporation, as noted by Monden (1983), Ohon (1988), and Shingo (1988). The concept gained popularity due to the limited resources and intense competition in the Japanese automobile market at that time. Toyota's emphasis on reducing waste and increasing efficiency ultimately led to the development of the Toyota Production System (TPS), which has had a significant impact on modern manufacturing practices around the world (Monden, 1983; Ohon, 1988; Shingo, 1988). However, the term “lean production” was first introduced decades later in the book “The Machine That Changed the World” authored by Womack, Jones, and Roos in 1990.

Plenert (2006) further explains that lean is a term that originated from a Japanese idea that has gone by various names such as the TPS, just-in-time (JIT), Pull Manufacturing, TQM, and others. Each of these labels encompasses some aspects of lean, and lean includes elements of these labels. However, the concept of lean we are familiar with today is not limited to any of these specific names. Nowadays, lean is known as a group of tools and practices that are used to streamline processes and eliminate waste. Not all of these tools are essential for every lean project. The role of a lean facilitator is to carefully select the appropriate combination of tools that will best achieve the desired outcome for a specific lean project. (Plenert, 2006)

Wang (2010) defines lean production as a method of producing goods that emphasizes using fewer resources than mass production. This means less waste, less human effort, less manufacturing space, fewer tools, and less engineering time needed to create new products. Its main goal is to reduce waste and improve customer satisfaction by focusing on eliminating Toyota's original “seven wastes”, including overproduction, excess inventory, waiting, transportation, unnecessary motion, overprocessing, and defects. TPS defines waste as any activity that doesn't add value to the final output or move the process closer to it. (Wang, 2010)

2.2.1 The power of lean production

Jackson and Jones (1996) explain that lean production has disrupted the traditional rules of mass production. Historically, it was assumed that higher quality goods would come with a higher price tag. However, the implementation of lean production systems has demonstrated that it is possible to produce high-quality products at a relatively lower cost. The creators of the TPS, Taiichi Ohno and Shigeo Shingo, were the pioneers of waste-eliminating methods that helped to establish the foundation of lean production. The success of Toyota and other companies that followed its lead in adopting these methods was the driving force behind the emergence of lean production. (Jackson & Jones, 1996)

According to Jackson and Jones (1996), implementing a lean production system can result in reduced costs, particularly indirect costs, while still maintaining quality standards and decreasing manufacturing cycle time. This means that a lean company can produce twice the number of products, with twice the quality, in half the time and space, all while cutting costs in half and maintaining only a fraction of the typical work-in-process inventory (Jackson & Jones, 1996). Shah and Ward (2007) further explain that the link between lean production and superior performance, as well as its ability to provide a competitive advantage, is widely recognized among both academics and practitioners. Even those who criticize the lean approach acknowledge that alternative production systems have not gained widespread acceptance, and they admit that lean production will become the norm for manufacturing in the 21st century (Shah & Ward, 2007).

Nicholas (2018) suggests that for many companies the concept of lean production is a major shift from their current practices and may seem unfamiliar or even intimidating. As such, the recommended approach to transitioning to lean production is not to attempt a complete overhaul all at once, but rather to proceed cautiously and selectively, implementing it in small increments through a continuous series of gradual improvements. This approach allows the company to gradually become more comfortable with lean production and to make necessary adjustments along the way. (Nicholas, 2018)

2.2.2 Jidoka – the autonomation philosophy

According to Santos, Wysk, and Torres (2006), lean is supported by three philosophies: JIT, kaizen (continuous improvements), and jidoka. Jidoka is a Japanese term that means "autonomation," an automated process that involves machinery inspecting each item after production, stopping production, and notifying humans if a defect is detected. As suggested Romero et al. (2019), the Jidoka process allows human operators to make a conscious decision between 'automation' and 'autonomation', giving them more time to focus on high-value activities and producing products of superior quality for external customers. (Santos, Wysk & Torres, 2006)

Baudin (2007) explains that the term jidoka has various meanings. One of the meanings is the separation of human activities from machine cycles, allowing operators to attend multiple machines in sequence, with the output of one machine being the input of the next. It also refers to a stepwise automation strategy that gradually reduces the amount of work done by humans in a production operation. Recently, at Toyota, jidoka has been used to automate tasks that are dirty, dangerous, or cause fatigue and repetitive stress injuries. The goal is to make operator jobs suitable for individuals of different heights and ages, with consistent productivity and quality throughout the work shift. (Baudin, 2007)

However, Baudin (2007) explains that defining jidoka accurately is challenging because Toyota's jidoka is an untranslatable play on words. When said out loud, it sounds the same as the standard Japanese word for automation but is written differently. Adding the radical for "human being" to the character for "move," results in the character for "work." This means that Toyota's jidoka includes the human being, while classical jidoka or "automation" does not. Therefore, in its broadest sense, jidoka can be defined to be the engineering of the way people work with machines. (Baudin, 2007)

Romero et al. (2019) states that the concept of Jidoka in the TPS is often misunderstood as simply stopping a process when a problem is detected. However, Jidoka is a vital principle that promotes continuous improvement and learning within a company. Modern Jidoka systems can improve the flexibility, quality, and productivity of manufacturing operations while also developing the capabilities of the workforce. Rather than replacing workers with automation, Jidoka aims to enhance their skills and knowledge. (Romero et al. 2019)

Ansari et al. (2018) see the potential of jidoka in the digitized future as they state that human-centered automation systems like jidoka combined with the advancements of Industry 4.0 technologies will lead to improved human-machine collaboration. This collaboration will be characterized by cyber-physical-social interactions, knowledge exchange, and reciprocal learning, and can be referred to as “Jidoka 4.0 Systems”. (Ansari et al. 2018)

2.2.3 Review of lean implementation and tools

Implementing lean production methods can be highly beneficial for companies in achieving their productivity goals through the use of practical and sustainable techniques and tools (Oliveira, Sá & Fernandes, 2017). However, before beginning this process, it is crucial to assess the company's current state and understand why a change is necessary Feld (2000). It is essential to identify the business drivers behind implementing Lean practices and to communicate these reasons to employees to ensure their engagement in the process. In summary, recognizing the need for change and effectively communicating the benefits of lean production can lead to successful implementation and improved productivity for companies. (Feld, 2000; Oliveira, Sá & Fernandes, 2017)

Value Stream Mapping (VSM) is a technique developed by Rother and Shook to create a visual representation of the flow of materials from raw material acquisition to final product delivery. The VSM map can identify waste, opportunities for improvement, and determine which lean tools to use. The four steps for using VSM are selecting a product or product family for improvement, creating a visual representation of the current state, creating a future state without inefficiencies, and developing a plan of action to achieve the future state. VSM is useful for identifying waste sources, analyzing system performance, and tracking important indicators such as lead times and setup times. It can also provide a common language for analysis and make material flow connections more visible. (Sundar, Balaji & Kumar, 2014; Oliveira, Sá & Fernandes, 2017)

Kanban is a component of the lean production system that aims to manage inventory levels, production, and the supply of components. It achieves this by ensuring that only what is necessary is delivered when it is needed, thus minimizing waste. The term "Kanban" comes from the Japanese word for card or signal and is a visual cue used in pull systems. Kanban is a lean technique that was originally developed in the automotive industry to "pull" materials from the production line in a "just-in-time" mindset. Essentially, this means that materials are restocked only when required, using signals or cards to communicate the need for replenishment. (Sundar, Balaji & Kumar, 2014; Oliveira, Sá & Fernandes, 2017)

Apart from the tools already discussed, there are several other lean tools available, such as Kaizen, 5S, and flow manufacturing, to name a few. First, Kaizen, a Japanese term for continuous improvement or change for the better, can be used to identify inefficiencies and apply effective countermeasures. 5S was created to organize workspaces and it involves five steps: Sort, Set in order, Shine, Standardize, and Sustain. The aim of 5S is to eliminate unnecessary items, establish designated locations, maintain cleanliness, set standards, and follow the method with discipline. Implementing 5S leads to reduced waste, improved quality, security, and hygiene. And finally, flow manufacturing involves producing one item at a time with a production rate that matches the cycle time and requires a U-line layout, multi-skilled operators, standardized cycle time, operator work designed for standing and walking, and cost-effective, user-friendly equipment for successful implementation. (Moore, 2007; Sundar, Balaji & Kumar, 2014; Oliveira, Sá & Fernandes, 2017)

In addition to the lean tools, Womack and Jones (1996) have proposed a thought process consisting of five steps (see Fig 2) that managers could use to guide a lean transformation in their companies. These five principles serve as a framework for implementing lean practices and improving efficiency.

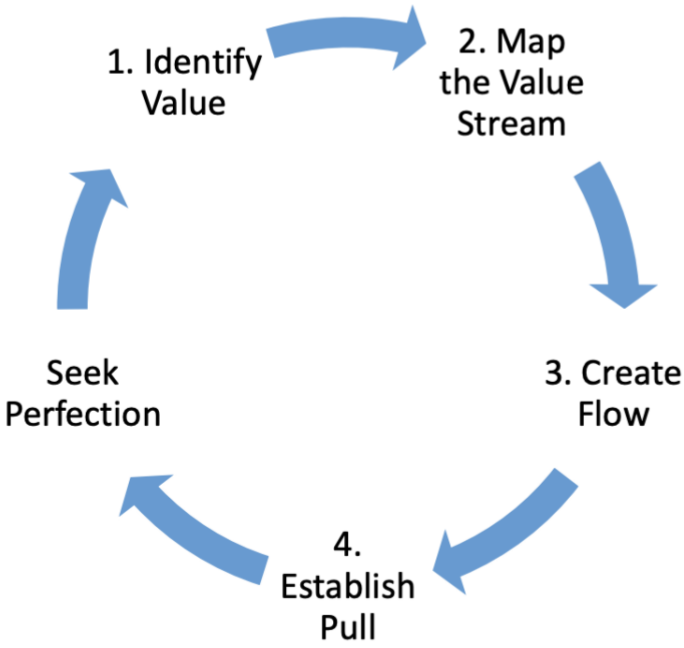

Figure 2. The five principles of lean transformation (Lean Enterprise Institute).

1. Identifying the value that the end customer seeks from the product family.
2. Determining all the processes involved in producing the product family and eliminating any unnecessary steps that do not add value.
3. Sequencing the value-creating processes to ensure that the product moves seamlessly towards the customer.
4. Introducing a pull-based system where the customers initiate the production process, ensuring that the product is delivered on time.
5. Repeating the process by defining value, streamlining processes, and eliminating waste until the state of perfection is achieved where there is no waste, and the value is perfect. (Womack & Jones, 1996)

Mann (2015) emphasizes the significance of a lean culture for the efficient implementation of a lean production process. He argues that most guidelines for lean production fail to include a crucial component: a lean management system to maintain it. A lean management system is responsible for upholding the benefits of implementing lean production. Mann (2015) further asserts that the physical changes resulting from a lean conversion are apparent, such as the relocation of equipment, reduced inventory, and changes in material supply, production scheduling, and standardized methods. However, the changes to management systems are less obvious and often overlooked, which is why many companies fail to adopt lean production. (Mann, 2015)

2.3 Industry 4.0

Industry 4.0 refers to the integration of production facilities, supply chains, and service systems to create value-added networks. The implementation of Industry 4.0 involves the use of emerging technologies such as big data analytics, autonomous robots, cyber physical infrastructure, simulation, horizontal and vertical integration, the Industrial Internet, cloud systems, additive manufacturing, and Augmented Reality (AR). The widespread use of the Internet of Things (IoT) is crucial for connecting dispersed devices and creating a computer-based environment. The coordination of these elements through data analytics and decision-making tools enables real-time automation in manufacturing and service processes. The implementation of Industry 4.0 will result in faster, more flexible, and more efficient processes, higher-quality goods at reduced costs, and ultimately change the competitiveness of a company. (Ustundag & Cevikcan, 2018; Rüßmann et al. 2015)

André (2019) states that Industry 4.0, also known as "Internet of Things" (IoT) or simply "Smart Manufacturing", information and communications technology (ICT), is having a major impact on modern manufacturing. This digital transformation of manufacturing is expected to change the way products are designed, produced, distributed, and consumed, and may even allow for the creation of customized and complex products. This is made possible by the rapid development of digital technology. Sergi et al. (2019) have also predicted that within the next five to seven years, we will begin to see the initial effects of the Industry 4.0 revolution in the global economy. In the following 10-15 years, we can expect to see significant changes brought about by these new technologies, which will render older technologies (from the 3.0 era) obsolete. The shifts brought about by the rise of Industry 4.0 will fundamentally alter the structure of the global economy. (André, 2019; Sergi et al. 2019)

According to André (2019), the manufacturing lines of Industry 4.0 include a range of elements, including:

- high-performance computing (HPC),
- computer-aided design (CAD),
- software tools for numerical modeling and design,
- artificial intelligence (AI),
- computer-aided manufacturing and automation software,
- enterprise resource planning systems,
- manufacturing execution systems and inventory management systems,
- additive manufacturing, and
- robotics.

These technologies allow for the use of generative design techniques, computer-aided innovation, training, expertise, and health, as well as the use of chatbots for trade. Additive manufacturing is a key component of Industry 4.0 because it enables the local production of complex parts from a digital file. (André, 2019)

Wyrwicka and Mrugalska (2017) discuss what actions producers should take to prepare for Industry 4.0. The answer seems straightforward: they should be flexible, use new technologies and processes, and have a faster return on investment. Additionally, producers should be ready for the digitization of the manufacturing sector, which is driven by four factors: the increase in data volumes, computational power, and connectivity, the emergence of analytics and business intelligence capabilities, new forms of human-machine interaction such as touch interfaces and augmented reality systems, and improvements in transferring digital instructions to the physical world like advanced robotics and 3-D printing. (Wyrwicka & Mrugalska, 2017)

2.3.1 Robotics and Augmented Reality in Industry 4.0

According to a study by Rejlíc et al. (2021), the use of Augmented Reality (AR) has been on the rise in different industries, mainly due to advancements in technology. AR involves the incorporation of virtual objects into the physical world, made possible through the use of transparent head-mounted devices (Santi et al. 2021). As illustrated on Fig 3, AR is being implemented in six key areas, including maintenance, assembly tasks, human-robot collaboration, manufacturing, training, and logistics (Rejlíc et al. 2021). Gallala, Hichri and Plapper (2019) suggest that maintenance activities make up a significant portion, approximately 60-70%, of the production life cycle. Unexpected machine breakdowns can be time-consuming and negatively affect productivity. Therefore, the adoption of AR technology has become essential in managing complex maintenance processes. (Gallala, Hichri & Plapper, 2019; Rejlíc et al. 2021; Santi et al. 2021)

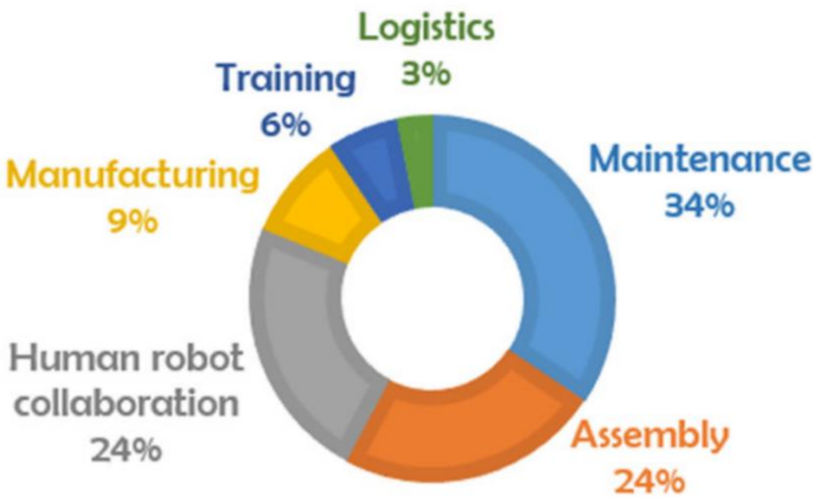

Figure 3. Areas of AR application (Reljíc et al. 2021).

Ustundag and Cevikcan (2018) state that in factories, human workers are often not able to keep up with the demands of modern production due to various factors such as their physical limitations and capabilities. As a result, companies are turning to industrial robots to improve their manufacturing processes. These robots are machines with automated intelligence and capabilities that can help increase production accuracy and speed while also reducing the risk of injuries. However, it is important to note that a collaborative effort between humans and robots is necessary for efficient and reliable manufacturing. In an Industry 4.0 factory, these robots can work collaboratively with human workers and other robots on an assembly line thanks to their advanced capabilities, which are enabled by information, networking, and sensor technologies. The way in which these robots work collaboratively and cooperatively, as well as their maintenance and use in assembly line applications, will shape the factories of the future. (Ustundag & Cevikcan, 2018)

Masood and Egger (2019) predict that the industrial AR market is set to grow rapidly with a compound annual growth rate of approximately 74% from 2018 to 2025. This growth is expected to continue or even accelerate as AR technology matures and its applications in the industry become more diverse. Despite the acknowledged importance of AR, implementing it for industrial purposes can be challenging. However, Ustundag and Cevikcan (2018) argue that the benefits of AR are significant and essential for the future. AR enables remote interactive collaboration, has low manufacturing and training costs, reduces operational errors, and speeds up product release times. By providing digital manuals or animations overlaid on the real world, AR has the potential to transform a variety of industries. (Ustundag & Cevikcan, 2018; Masood & Egger, 2019)

2.3.2 Quality 4.0

As stated by Carvalho et al. (2021), the concept of quality has evolved in recent years to encompass the digitalization of TQM and its impact on quality technology, processes, and individuals. Quality 4.0 can be defined as the application of Industry 4.0 technologies to the field of quality. It is important for quality professionals to have the skills to determine how and why information should be used, as the use of data must be guided by the process and not the other way around. Figure 4 below is designed to link the relationship between Quality Management practices and Industry 4.0 tools and technologies. (Carvalho et al. 2021)

I4.0 Tools and Technologies	Quality Management Practices							
	Management Commitment	Customer Involvement	Supplier Involvement	Employee involvement	Benchmarking techniques	Process Management	Information and Analysis	Formal strategic planning
Data science and statistics	X					X	X	X
Enabling technologies (IoT, IIoT, Integrated systems, VR, AR, cloud computing	X	X	X	X	X	X	X	X
Big Data	X	X	X			X	X	
Blockchain	X			X		X		X
AI	X			X			X	
ML	X						X	X
Neural Networks and Deep Learning	X					X	X	

Figure 4. Quality Management practices and Industry 4.0 technologies relationship (Carvalho et al. 2021).

As explained by Carvalho et al. (2021), the information in the table can help a user decide which tools and technologies to use when dealing with various quality management practices. By using Industry 4.0 technologies, the user can leverage the available data to improve the process and reduce the time spent searching for the most appropriate technologies and tools (Carvalho et al. 2021). Fonseca, Amaral and Oliveira (2021) further explain that y incorporating quality management principles into Industry 4.0, it is possible to enhance both the quality and productivity of the processes, leading to better results.

Javaid et al. (2021) states that Quality 4.0 is an essential aspect for managing all types of manufacturing industries. This approach offers a great opportunity for enhancing the quality of manufacturing and business strategies. To improve efficiency and reduce rejection rate, it is important to identify and define the final products, manage dynamic consumer demands, and minimize the cost of materials and manufacturing. With the increasing integration of the IoT in the manufacturing process, quality control has become a transformative field. The ability to continuously monitor and regulate various systems and processes that impact product quality is dependent on effective quality management utilizing Quality 4.0 technologies. These technologies play a crucial role in promoting a culture where all workers take responsibility for quality and transparency. The key aspects of Quality 4.0 include maintaining the quality of the product throughout its life cycle and using artificial intelligence to track service levels by monitoring product consumption. In the future, transparent and visible support for top-level management will help to foster positive consumer perceptions towards Quality 4.0. (Javaid et al. 2021)

2.3.3 Industry 4.0 and Quality 4.0 practices in manufacturing industry

Zhong et al. (2017) state that there are three major advanced manufacturing technologies in the context of Industry 4.0, which are:

- Intelligent manufacturing: a manufacturing model that optimizes production and product transactions by utilizing advanced information and manufacturing technologies throughout the product life cycle to improve production efficiency, product quality, and service level, thus enhancing a manufacturing company's competitiveness in the global market,

- IoT-enabled manufacturing: a manufacturing model that converts production resources into smart manufacturing objects that can sense, interconnect, and interact with each other, allowing for efficient resource sharing and intelligent perception through human-to-human, human-to-machine, and machine-to-machine connections, thus enhancing manufacturing performance under Industry 4.0, and

- Cloud manufacturing: a manufacturing model that utilizes cloud computing, IoT, virtualization, and service-oriented technologies to transform manufacturing resources into services that can be shared and circulated throughout the

> extended life cycle of a product, providing on-demand manufacturing services from a networked and intelligent manufacturing system. (Zhong et al. 2017)

All three of the concepts mentioned above (intelligent manufacturing, IoT-enabled manufacturing, and cloud manufacturing) hold great significance in the context of Industry 4.0. However, Industry 4.0 is driving the importance of intelligent manufacturing as a key future perspective in both research and application, as it adds value to products and systems by leveraging cutting-edge technologies in traditional manufacturing and services. (Zhong et al. 2017)

Rüßmann et al. (2015) conducted a study aimed to give a measurable comprehension of the possible global effects of Industry 4.0. An analysis of the manufacturing landscape in Germany was conducted, which identified four key areas where the fourth wave of technological progress is expected to yield advantages. These four areas are productivity, revenue growth, investment, and employment. After examining the effects of Industry 4.0 on the German manufacturing industry, the analysis indicates that there will be a 6 percent rise in employment opportunities over the next decade (see Fig 5). This growth will particularly benefit the mechanical-engineering sector, with a projected increase in demand for employees of up to 10 percent within the same period. However, the necessary skills for these jobs will differ from those required in the past. Initially, the trend towards increased automation will displace some low-skilled workers performing repetitive tasks. Meanwhile, the industry's growing reliance on software, connectivity, and analytics will create a need for employees with software development and IT competencies. For instance, individuals with expertise in mechatronics and software skills will be in high demand. (Rüßmann et al. 2015).

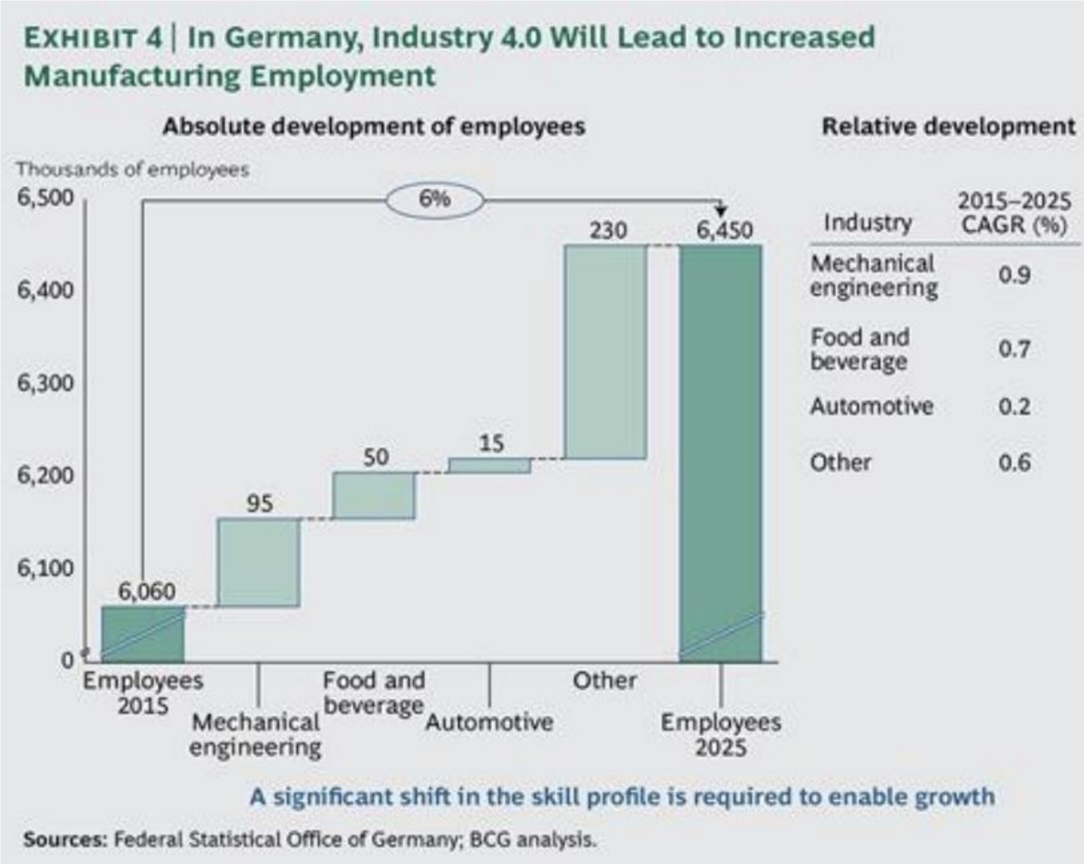

Figure 5. The estimated benefits of Industry 4.0 for manufacturing employment in Germany (Rüßmann et al. 2015).

In the figure provided below (Fig 6), Javaid et al. (2021) explore the qualitative aspects of implementing Quality 4.0 in the manufacturing environment. The main characteristics include cloud-based data management, process optimization, system automation, and technological advancements such as artificial intelligence, sensor technology, and virtual reality. These features aim to enhance the manufacturing domain and meet customer expectations. Other concepts such as 3D/4D printing, IoT, and virtual learning/training events also contribute to the successful implementation of a quality culture in manufacturing sites. (Javaid et al. 2021)

Figure 6. Key aspects of Quality 4.0 for manufacturing development (Javaid et al. 2021).

Javaid et al. (2021) argues that the survival of the manufacturing industry requires the adoption of Quality 4.0, with consistency being crucial in every aspect of the process. In this era of rapid change, Quality 4.0 is seen as a method of containment rather than prevention. Although Quality 4.0 is fascinating, it needs a collective quality strategy to prioritize quality in manufacturing, enhance accountability across the supply chain, and ensure consumer satisfaction. Some of its innovations will be utilized in the manufacturing sector in the future. (Javaid et al. 2021)

However, Escobar, McGovern and Morales-Mendez (2021) have a more reserved view towards Quality 4.0 in manufacturing. Many quality leaders are interested in implementing Quality 4.0 practices using artificial intelligence and big data, but surveys show that 80-87% of these projects do not develop a production-ready solution. Resistance to adoption can be caused by psychological reservations, infrastructural limitations, and business impediments. To mitigate this, a strategic vision and appropriate infrastructure are crucial, along with the support of organization culture and management. Local implementation of relevant aspects can help promote positive attitudes towards adoption. (Escobar, McGovern & Morales-Mendez, 2021)

2.4 The relation between Lean and Industry 4.0

The existing literature on the combination of lean and Industry 4.0 has used terms such as lean 4.0, lean automation, smart lean manufacturing, and Lean Industry 4.0. The majority of authors in this field agree that lean and Industry 4.0 are generally compatible. This is due to similarities in their goals, such as reducing complexity, and their common use of lean principles as a foundation. (Mayr et al. 2018)

Sony (2018) states that the concept of Industry 4.0 can be categorized based on the principles of vertical, horizontal, and end-to-end integration. Meanwhile, the five main principles for implementing Lean Manufacturing serve as a comprehensive guideline for its implementation. Before implementing the three integration mechanisms, waste must be eliminated, or else the automation process would be ineffective. Keeping this principle in mind, the model suggests Lean Manufacturing principles in all three forms of integration in Industry 4.0. Thus, the integration model of Industry 4.0 and Lean Manufacturing is illustrated in Figure 7 below, with a detailed explanation of the vertical, horizontal, and end-to-end engineering integration model and its connection to the five principles. (Sony, 2018)

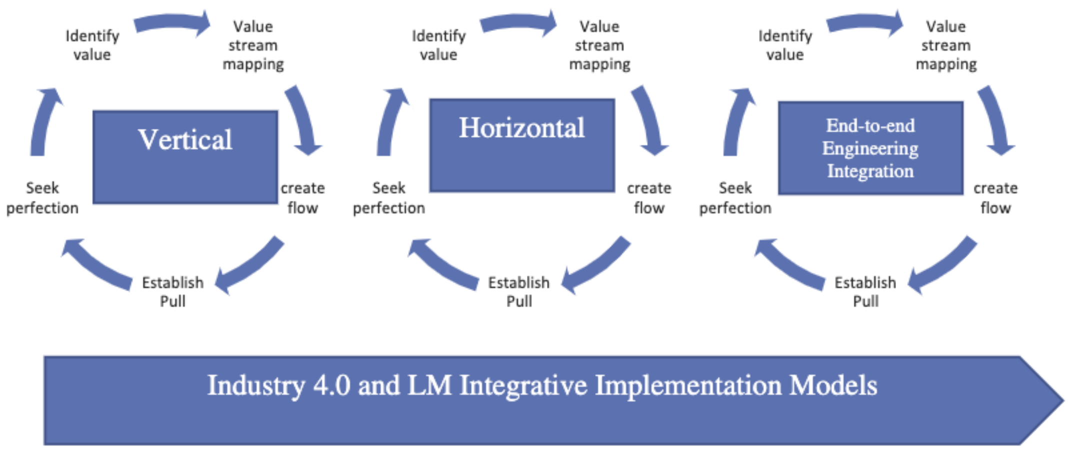

Figure 7. Industry 4.0 and LM integration (Sony, 2018).

Wagner, Herrmann and Thiede (2017) launched a research project to combine the concepts of Industry 4.0 and lean production by examining successful Industry 4.0 implementations in partnership with a major automotive company. The goal of the research is to develop a framework that can assist in identifying the most appropriate Industry 4.0 solutions for integration within a lean production system. The research shows that the integration of new information and communication technologies with lean production environments offers exciting opportunities. The research indicates that Industry 4.0 can reinforce and maintain the principles of lean production. The Industry 4.0 impact matrix on lean production systems serves as a starting point for designing and implementing Industry 4.0 solutions that work in tandem with efficient production processes. (Wagner, Herrmann & Thiede, 2017)

According to Ustundag and Cevikcan (2018), Industry 4.0 is not the solution for manufacturing systems that are poorly managed or structured. Instead, they propose that Industry 4.0 tools should be used in conjunction with successful lean production processes and effective information flow. Maintaining accurate and up-to-date data is crucial for the success of both Industry 4.0 and lean production. The authors observe that not all production facilities need high levels of automation, and it's important to understand how different forms of automation and machine design will impact the lean production system. The ideal production system should be designed to flow smoothly, with automation being chosen based on how it can enhance the flow. The authors conclude that selective automation can add value after lean improvements have been made, but it also reduces human variability. (Ustundag & Cevikcan, 2018)

As found by the research conducted by Kolberg and Zühlke (2015), the integration of industry 4.0 and lean production is a current and promising topic. However, there is a lack of a complete framework that merges Industry 4.0 solutions with lean production methods. There is a particular gap in having a comprehensive approach for seamlessly integrating manual and automated workstations. While CPS provides hardware solutions as a bridge between workstations, the communication protocols are only partially available, and there is no industry-wide standard for decentralized production control in lean production. To summarize, Industry 4.0 and lean production are not mutually exclusive but can, in fact, complement each other and deliver value to users. (Kolberg & Zühlke, 2015)

2.4.1 Case studies of combining lean production and Industry 4.0

Mrugalska and Wyrwicka (2017) present three different case studies of combining lean production and Industry 4.0. The first one of these is smart products, which gather data through their sensors and semantic technologies and use it to analyze repeating actions. These products are special as they are context-aware, self-organized, proactive and support the entire life cycle which helps in improving the process continuously. The data collected by these products can be used to see the manufacturing process and information flow for a specific set of products. By using this information, one can create a Current State Map which highlights the waste in a particular process, and plan for future improvements through VSM. Also, Smart Products can contain information using the Kanban method to control the production process. (Mrugalska & Wyrwicka, 2017)

The second one is smart machines that have the capability to have a smart panel that uses RFID UHF technology. This allows for the real-time detection of tagged Kanban cards, with a typical read-rate of 100%. The smart panel can also avoid detecting other tagged Kanban cards close to it but not placed on the panel. The continuous improvement of the production line is also made possible through the collection of data from machines using technologies such as actuators, sensors, and wireless video. This data is analyzed and processed in the cloud to provide better operational intelligence and to prevent mistakes, which is the concept of Poka Yoke. Additionally, the use of Plug'n'Produce technology allows for the implementation of the Single Minute Exchange of Die method in the entire production line. (Mrugalska & Wyrwicka, 2017)

And lastly, the third case study deals with augmented operator, which is designed to minimize the time between the occurrence of a failure and its notification. The Andon method, which is part of the Jidoka quality-control method and the lean approach, is used to achieve this goal. It involves using signal lights on an operator's smartwatch to provide real-time notifications of errors and their locations. These alerts can be stored in a database and used for future improvements. Additionally, failures can be detected by cyber-physical systems (CPS) with proper sensors, which then initiate automatic repair actions on other CPS. (Mrugalska & Wyrwicka, 2017)

Mrugalska and Wyrwicka (2017) suggest that lean production is a method that aims to produce high-quality products that meet customer satisfaction, while eliminating anything that does not add value, considered as waste. It provides a flexible solution for producing complex products and managing supply chains. To implement this, it is recommended to integrate IT systems at the production level with the planning level, customers, and suppliers through CPS technology, also known as Industry 4.0 (Mrugalska & Wyrwicka, 2017). And as their studies conclude, lean production and Industry 4.0 can indeed support each other and work seamlessly together. This also aligns with findings of the previously presented research conducted by Wagner, Herrmann, and Thiede (2017).

2.5 Summary of the theoretical framework

The concept of quality is often associated with excellent products or services that meet or exceed our expectations. These expectations are influenced by factors like the intended use and price of the product or service. Therefore, quality is subjective and based on perception. Quality has become a crucial competitive advantage for companies, with a shift from focusing solely on price to also considering quality. Improving quality can lead to lower costs, as fewer errors, less rework, and better resource utilization result in more efficient processes. Total Quality Management (TQM) aims to improve traditional approaches and enhance competitiveness by transforming management practices and company culture.

Lean, derived from Japanese ideas, has been known by various names such as TPS, JIT, Pull Manufacturing, and TQM. While each label encompasses certain aspects of lean, the concept itself is not limited to any specific name. Today, lean is understood as a set of tools and practices utilized to streamline processes and eliminate waste. Lean production emphasizes using fewer resources compared to mass production. It aims to minimize waste, human effort, manufacturing space, tools, and engineering time in the production of goods. The main goal is to enhance customer satisfaction by targeting the elimination of Toyota's original "seven wastes," including overproduction, excess inventory, waiting, transportation, unnecessary motion, overprocessing, and defects.

Industry 4.0 refers to the integration of production facilities, supply chains, and service systems through emerging technologies. These technologies include big data analytics, autonomous robots, cyber physical infrastructure, simulation, integration systems, the Industrial Internet, cloud systems, additive manufacturing, and Augmented Reality (AR). The implementation of Industry 4.0 allows for real-time automation and decision-making, resulting in faster, more flexible, and efficient processes, higher-quality goods at reduced costs, and a shift in a company's competitiveness. Industry 4.0, also known as IoT or Smart Manufacturing, is transforming modern manufacturing by changing the way products are designed, produced, distributed, and consumed. The rapid development of digital technology enables the creation of customized and complex products. The impact of Industry 4.0 is expected to revolutionize the global economy within the next decade, rendering older technologies obsolete and fundamentally altering the economic structure.

Quality 4.0 refers to the application of Industry 4.0 technologies in the field of quality management. It is essential for quality professionals to understand how to use information effectively, ensuring that data is guided by the process and not the other way around. Quality 4.0 plays a crucial role in managing manufacturing industries and offers opportunities to enhance manufacturing quality and business strategies. Effective quality management utilizing Quality 4.0 technologies enables continuous monitoring and regulation of systems and processes that impact product quality. These technologies foster a culture where all workers take responsibility for quality and transparency. Key aspects of Quality 4.0 include maintaining product quality throughout its life cycle and using artificial intelligence to track service levels by monitoring product consumption. In the future, visible support from top-level management will contribute to positive consumer perceptions of Quality 4.0.

The initial part of the theory emphasizes the importance of quality, which serves as a fundamental element in the thesis. Quality 4.0 can be understood as a natural progression towards a more technology-driven approach. It involves the integration of technology and human expertise to enhance the quality of an organization. Quality 4.0 represents the anticipated advancements in quality management and organizational excellence in the era of Industry 4.0. Thus, it is a subset of the broader concept of Industry 4.0.

Similarly, lean principles are reimagined in a way that aligns with the requirements of Industry 4.0, such as reducing complexity. Both lean and Industry 4.0 share common ground in their utilization of lean principles as a foundation. However, Industry 4.0 alone cannot solve issues in poorly managed or structured manufacturing systems. Instead, Industry 4.0 tools should be employed in conjunction with effective lean production processes and efficient information flow. The accuracy and timeliness of data are vital for the success of both Industry 4.0 and lean production. To summarize, Industry 4.0 and lean production are not mutually exclusive but can complement each other, providing value to users when implemented together.

3 Methodology

This chapter presents the methodology employed in the research study, which aims to investigate the utilization of lean practices, Industry 4.0 practices, and Quality 4.0 practices in medium-sized Finnish manufacturing companies. In this empirical research, a quantitative survey method has been selected. This chapter outlines the research approach, sample selection, data collection process, and data analysis techniques utilized in this study. Lastly, the discussion delves into the validation and reliability of the obtained data and results. The objective is to provide a comprehensive understanding of the current state of these practices in the selected companies and their impact on operational efficiency and quality management.

3.1 Research approach

As mentioned previously, the research adopts quantitative methods, which means focusing on identifying statistical patterns and relationships among variables, as stated by Alasuutari (2011). In contrast, qualitative research encompasses various techniques, including intensive interviews and in-depth analysis of historical materials (King et al. 1994). When comparing qualitative and quantitative approaches, Hood (2006) argues that words are inherently less precise than numbers, making them susceptible to subjective interpretation and potential biases in the results.

However, it is important to note that the questionnaire also incorporates a single open-ended question, resembling the approach commonly associated with qualitative research. This question is designed to allow respondents to provide more nuanced and unrestricted responses. As Alasuutari (2011) highlights, it is important to recognize that employing a quantitative research approach does not necessarily exclude the utilization of qualitative methods.

3.2 Research design

The final survey consisted of a total of 13 questions. The survey addressed three main topics: lean, Industry 4.0, and Quality 4.0. For each topic, the respondents were initially asked whether they were familiar with the respective term. Subsequently, they were asked whether their company implemented these practices, and if so, they were given the opportunity to provide further details about the specific tools they utilized. A few examples of these tools were provided, which were also mentioned earlier in the theoretical part of the survey. However, respondents were also given the option to specify other tools if they were not listed as response choices. Following this, the survey inquired about the perceived impact of these tools on the company's performance. Predefined answer options were provided, but respondents also had the freedom to provide their own responses. Towards the end of the survey, an open-ended question was included, allowing respondents to offer any valuable additional information that might not have been covered in the survey otherwise.

Prior to distributing the questionnaire to the selected companies, a pretest was conducted involving three Finnish manufacturing firms, who belonged to the target group. The objective of the pretest was to assess the clarity and ease of understanding of the questions, as well as to determine the time required to complete the survey. The test respondents completed the form and provided valuable feedback regarding the questions. This feedback was then utilized to refine and improve the wording of certain questions in the questionnaire.

3.3 Sample selection

The sample for this study comprised medium-sized manufacturing companies in Finland. The sampling frame consisted of a list of registered manufacturing firms obtained from a database called Vainu. The sample was selected using a combination of stratified and random sampling techniques. Stratification was employed to ensure representation from different industries, such as automotive, electronics, machinery, and food processing. Random sampling was then applied to select the desired number of companies from each stratum. The sample size was determined based on considerations of practicality and the available resources. A total of 190 medium-sized manufacturing companies were included in the sample.

Subsequently, these firms were sent an email containing the questionnaire. The email addresses were obtained from the previously mentioned Vainu database and primarily targeted the decision makers within each company. A generous time frame of two weeks was provided to the respondents to complete the questionnaire. To ensure maximum participation, a gentle reminder was sent after the first week had elapsed. Following the deadline, a total of 44 responses were received, which corresponds to a response rate of 23%.

3.4 Data analysis

The main focus of this study was to visually depict the level of implementation of lean, Industry 4.0, and Quality 4.0 practices within the targeted organizations. To achieve this, the specific tools employed by these organizations, their aspirations for implementing these practices, and the observed impacts were thoroughly examined. The aim was to provide a comprehensive understanding of how these practices are embraced and their overall significance within the surveyed organizations. The data analysis was carried out utilizing Microsoft Excel to facilitate the interpretation and presentation of the results.

To simplify the data analysis process and facilitate further examination, an initial analysis was conducted using descriptive methods. This involved summarizing the data by calculating percentages, averages, minimums, maximums, deviations, and other relevant statistical measures. These descriptive statistics provided a concise and informative overview of the data, allowing for a better understanding of its key characteristics and trends.

Following that, the data was examined by comparing how the three main aspects of the thesis, namely lean, Industry 4.0, and Quality 4.0, are interconnected. The objective of this analysis was to identify any relationships between these variables. Through these calculations, the study aimed to address the third hypotheses formulated in the thesis. This approach facilitated a deeper comprehension of how the utilization of these aspects together can impact a company's performance.

3.5 Reliability and validity

The low response rate of the survey indeed poses challenges to the reliability and validity of the research, which in turn raises concerns about the representativeness and generalizability of the findings. Unfortunately, there was limited control over this issue, and a longer research duration might have potentially helped to increase the response rate. However, measures were taken within the research to address reliability and validity, such as conducting a pretest. The pretest allowed for adjustments and refinements to be made to the survey instrument, ensuring that it was clear, coherent, and effective in capturing the desired information.

In addition, special emphasis was placed on maintaining the objectivity of the survey questions. By designing the questions to be as objective as possible, the aim was to minimize subjectivity and potential biases that could influence the respondents' answers. This focus on objectivity enhances the collection of reliable and unbiased data, ultimately strengthening the validity and reliability of the research findings. Despite the challenges posed by the low response rate, the steps taken in the form of a pretest and the emphasis on objectivity contribute to the overall reliability and validity of the research.

Furthermore, the research incorporates a robust and comprehensive theoretical framework. This framework is constructed by drawing upon a diverse range of sources, including academic literature, industry reports, and expert opinions. By integrating multiple sources, the study strengthens its foundation and enhances its credibility by aligning with established theories, concepts, and best practices within the field. This comprehensive theoretical framework not only provides a solid conceptual basis for the research but also enables a deeper understanding of the research subject and facilitates the interpretation of the survey results within a broader context.

4 Results

This chapter aims to present the findings obtained from the survey, which will be used to address the hypotheses established earlier in this paper. The exploration begins by examining the level of implementation of lean tools as well as industry 4.0 and quality 4.0 practices among medium-sized manufacturing firms in Finland. This analysis involves assessing the percentage of sampled firms that have implemented these practices. Furthermore, the chapter will highlight the most prevalent practices and tools, and the impacts reported by the respondents. This analysis aims to delve deeper into how the surveyed firms perceive the effectiveness and influence of these practices on their operations.

4.1 Implementation of lean practices

As previously mentioned, the survey was distributed to a total of 190 companies, out of which 44 responded, resulting in a response rate of 23%. Table 1 below illustrates the percentage view of respondents' prior familiarity with lean, presented in the form of a pie chart. As depicted in the chart, it can be seen that lean is a familiar term to all 44 companies.

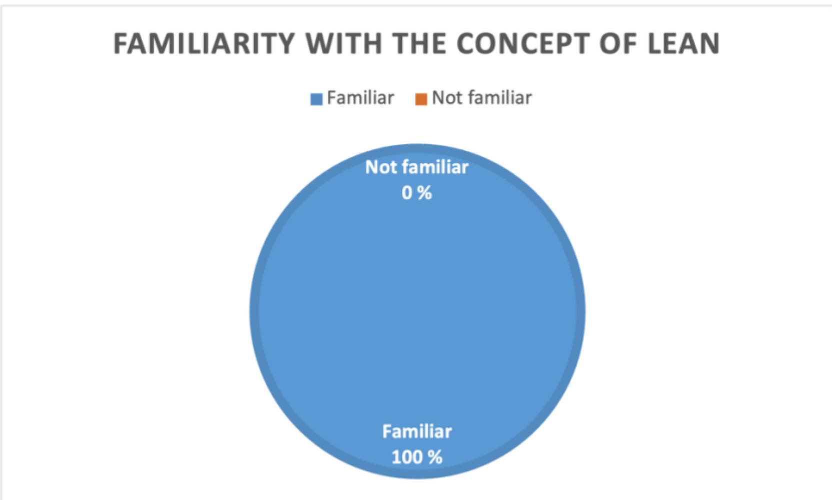

Table 1. Familiarity with the concept of lean.

Next, the companies were asked whether they had implemented lean tools in their own businesses. As shown in Table 2, the pie chart indicates that the majority of the companies do not utilize lean tools. Out of the respondents, 23 indicated that their company does not use lean tools, while 21 responded affirmatively, resulting in a percentage distribution of 52% and 48%, respectively.

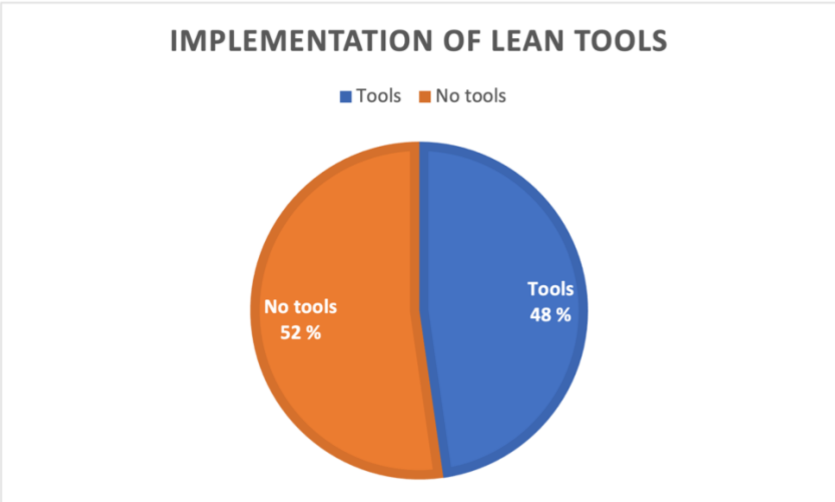

Table 2. Implementation of lean tools.

Next, these 21 companies that had responded affirmatively to the previous question provided more detailed information regarding the specific lean tools they use. Data on the number of tools used by the respondents was collected from this question, and the results are presented in Table 3, a pie chart. Among the respondents, two companies listed a total of two tools, five companies listed three tools, seven companies listed four tools, three companies listed five tools, one company listed six tools, two companies listed seven tools, and one company listed an impressive eight tools. As depicted in the chart, the most common number of lean tools among the respondents was four, with three tools also being a popular quantity.

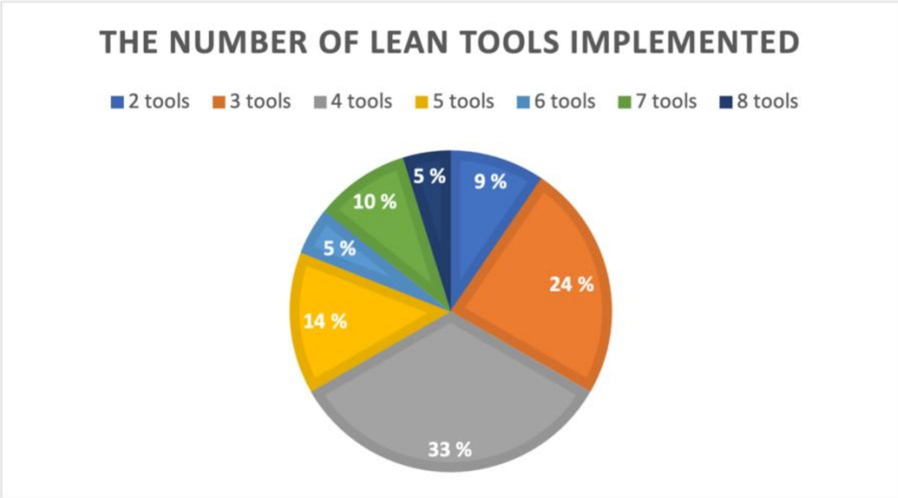

Table 3. The number of lean tools implemented.

Table 4 below illustrates, in the form of a bar chart, the lean tools implemented by the respondents. Each bar represents the number of companies, out of the 21 that reported utilizing lean tools, that use the specific tool. In addition to the predefined response choices provided in the question, the respondents mentioned five other tools: JIT, poka yoke, TPM, bottleneck analysis, and takt time. However, the option of flow manufacturing, which was included in the response choices, did not receive any responses.

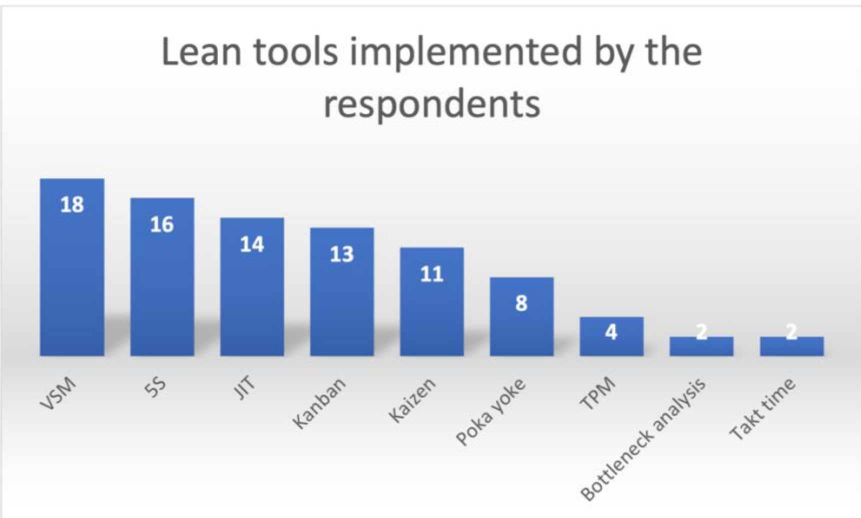

Table 4. Lean tools implemented by the respondents.

Lastly, the respondents were asked about their perception of how lean tools have impacted their performance. Table 5 below represents the responses of the respondents, with each bar indicating the number of companies out of the 21 that selected the particular option. In addition to the predefined response choices provided in the question, the respondents also mentioned "increased competitiveness" and "improved teamwork" as additional positive outcomes resulting from the use of lean tools.

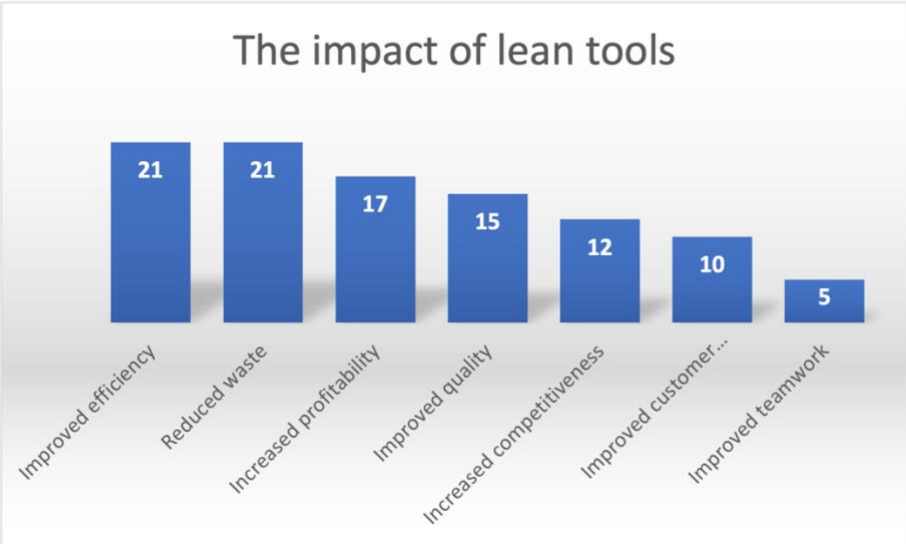

Table 5. The impact of lean tools.

4.2 Implementation of Industry 4.0 practices

Moving on, the survey then proceeded to inquire about Industry 4.0-related questions. Initially, they were asked if the term itself was familiar to them. In comparison to lean, the familiarity with Industry 4.0 slightly decreased, as two out of the 44 responding companies indicated that the term was unfamiliar to them. The remaining 42 companies confirmed their familiarity with the term. The percentages were distributed as 95% and 5%, as illustrated in Table 6 below.

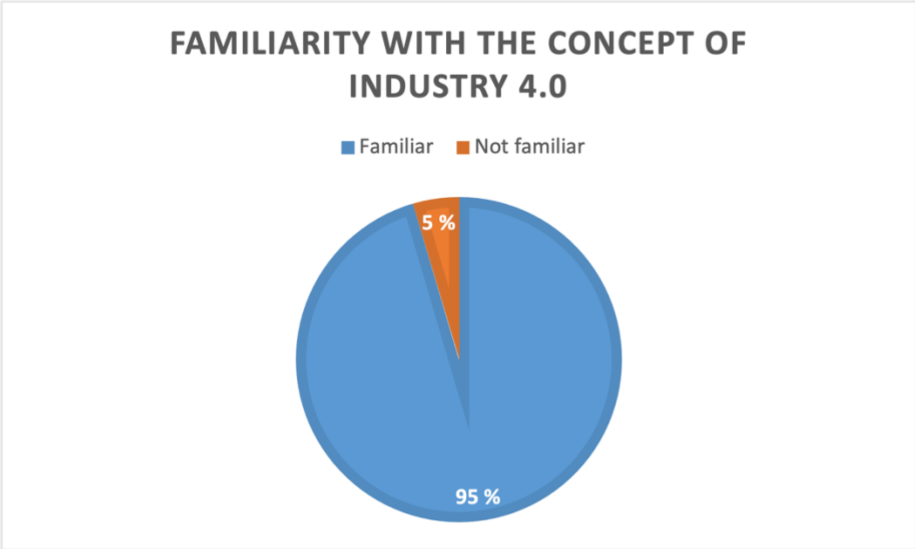

Table 6. Familiarity with the concept of Industry 4.0.

Next, the companies were asked whether they had implemented Industry 4.0 practices in their own businesses. As expected, the figures slightly decreased compared to lean, with 14 companies responding positively to utilizing Industry 4.0 methods. The distribution was thus 68% and 32%, as depicted in Table 7 below.

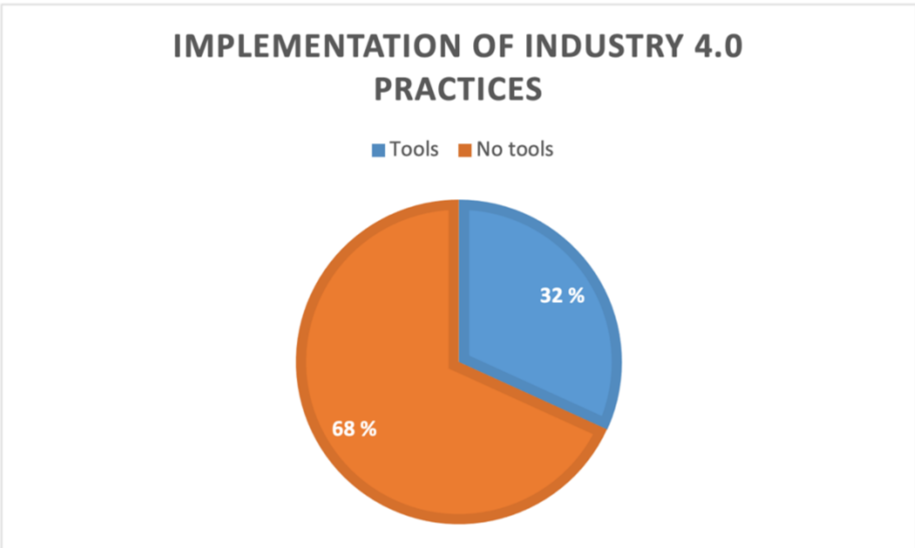

Table 7. Implementation of Industry 4.0 practices.

Next, out of the 44 respondent companies, 14 of them, who reported utilizing Industry 4.0 practices, provided further details about the specific practices they employ. The data was then used to create a diagram, displayed in Table 8 below, illustrating the number of practices each company utilizes. As depicted in the diagram, five companies utilize only one practice, six companies utilize two practices, two companies utilize three practices, while one company utilizes an impressive four practices.

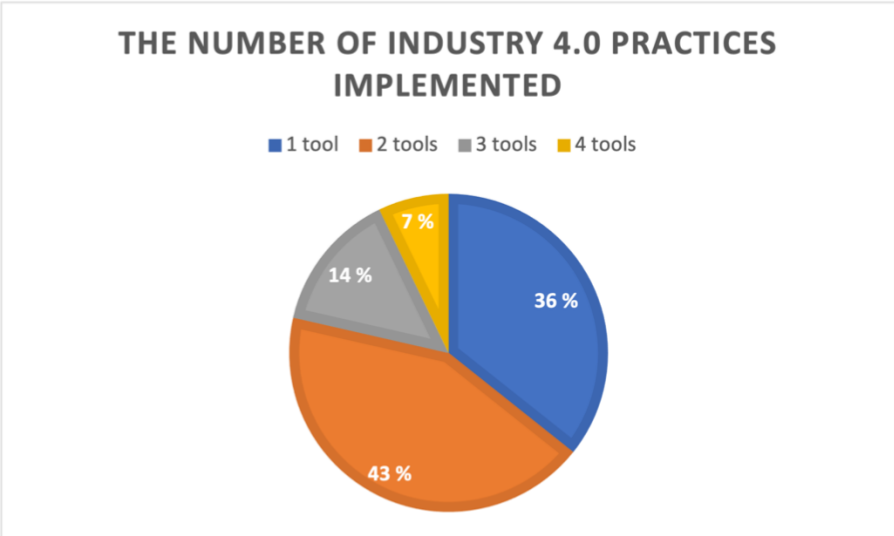

Table 8. The number of Industry 4.0 practices implemented.

Table 9 represents the Industry 4.0 practices that respondents utilize. As depicted in the diagram, cyber security is significantly the most popular practice of choice. This option was not originally included in the predefined response choices, meaning that respondents themselves added it. This was also the most common answer among the respondents who reported only one practice.

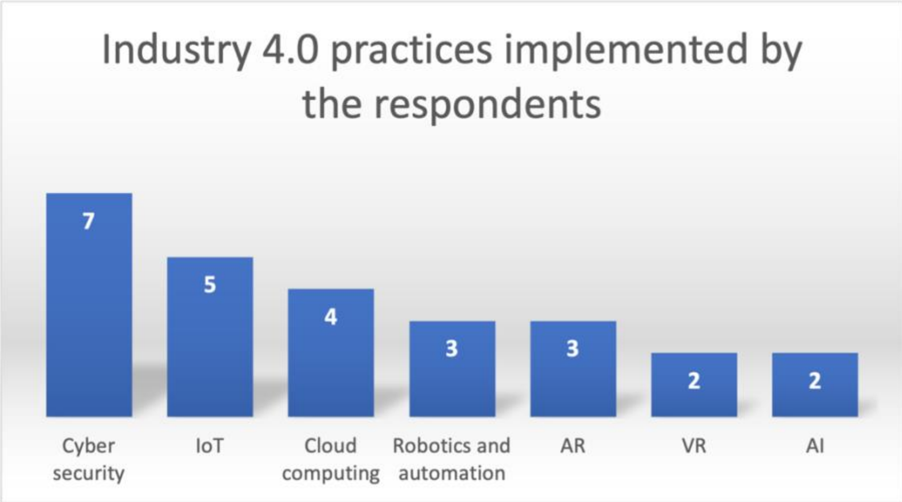

Table 9. Industry 4.0 practices implemented by the respondents.

Finally, respondents listed the impacts they have observed from utilizing industry 4.0 practices, as shown below on Table 10. The most common response was improved efficiency, chosen by every respondent. In addition to the predefined response options, there were mentions of increased competitiveness, as well as, as expected, seven companies indicating improved cybersecurity, matching the number of companies that reported utilizing this practice.

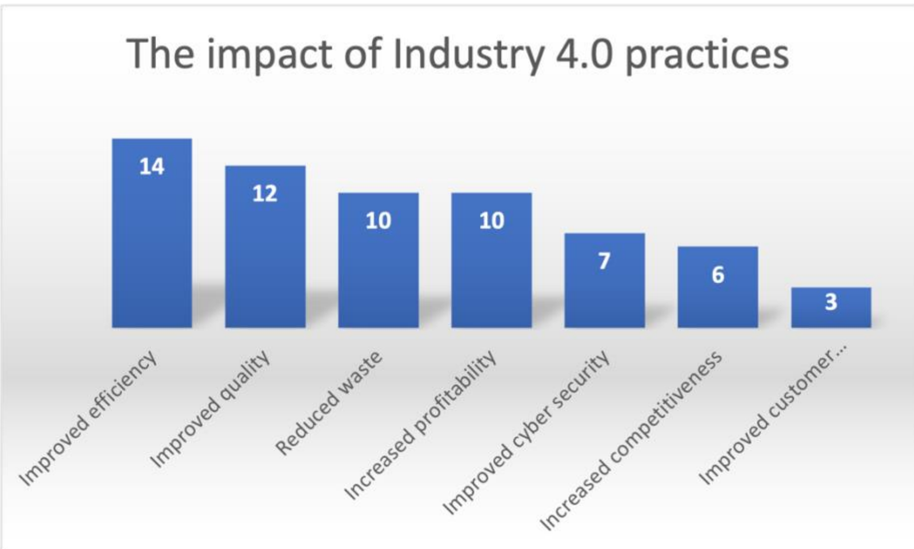

Table 10. The impact of Industry 4.0 practices.

4.3 Implementation of Quality 4.0 practices

Finally, the companies were asked about their familiarity with Quality 4.0. As per the usual approach, companies were first asked whether they were familiar with the term itself. The familiarity with the term remained steady, with two respondents responding that they were not familiar with it previously, as shown in Table 11.

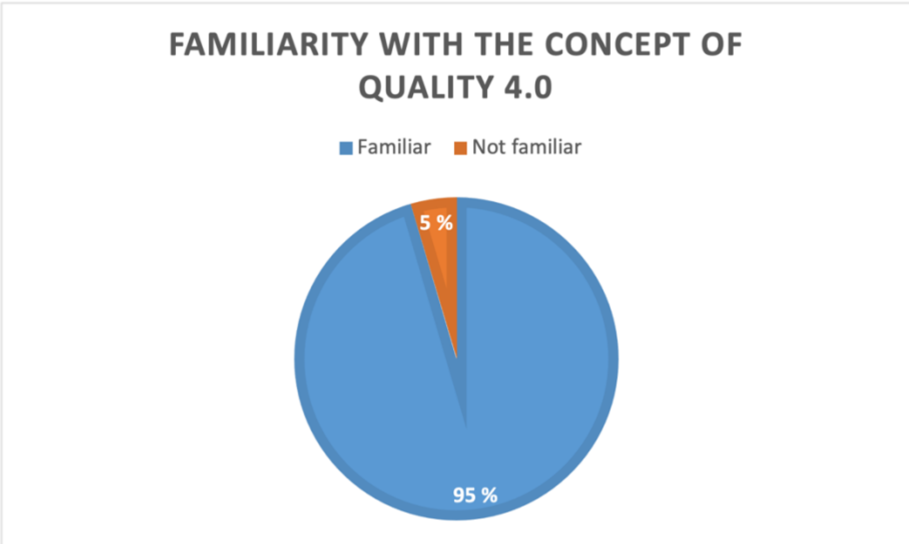

Table 11. Familiarity with the concept of Quality 4.0.

Next, the companies were asked whether they have implemented Quality 4.0 methods in their businesses. Out of the 44 respondent companies, seven indicated that they are utilizing Quality 4.0 methods. This means that 84% of the companies are currently not utilizing these methods, as depicted in Table 12.

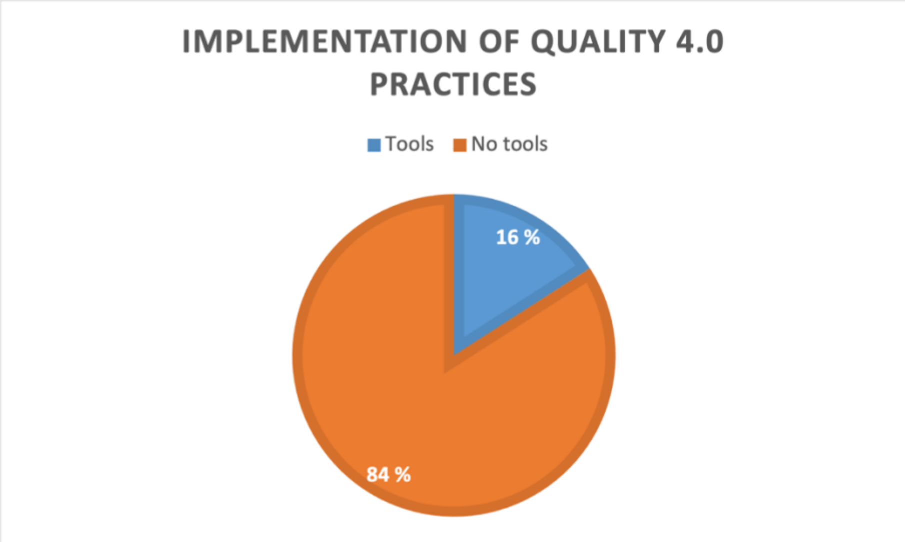

Table 12. Implementation of Quality 4.0 practices.

Next, the seven companies that responded affirmatively to utilizing Quality 4.0 practices were given the opportunity to specify which practices they employ. From this data, yet again, a pie chart was created to illustrate the number of practices utilized by each company. As shown in Table 13, five companies listed only one practice, while two companies reported utilizing two practices.

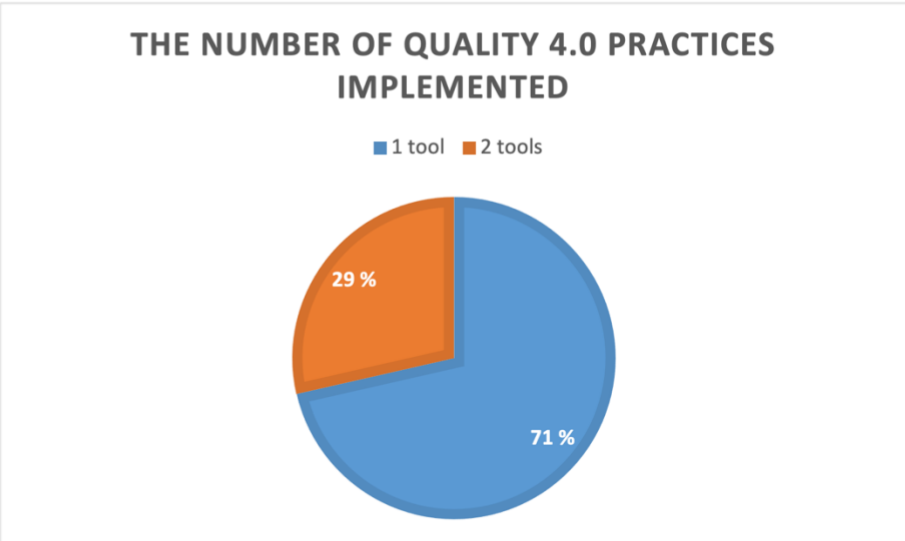

Table 13. The number of Quality 4.0 practices implemented.

Table 14 illustrates the Quality 4.0 practices utilized by these seven companies. As depicted in the diagram, additive manufacturing emerges as the most popular tool, while the remaining responses are fairly evenly distributed. No additional answers were provided beyond the provided response options for this question.

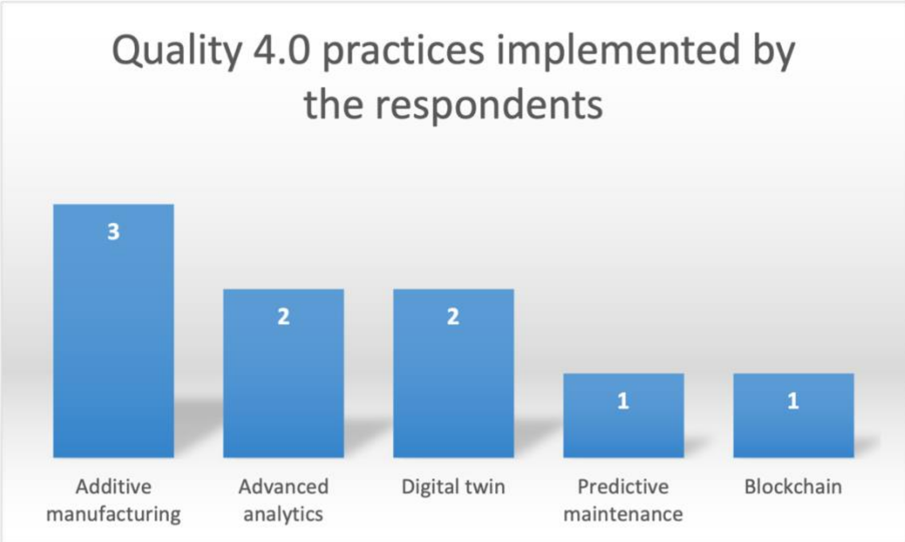

Table 14. Quality 4.0 practices implemented by the respondents.

Finally, the respondents also provided answers regarding the impacts of Quality 4.0 practices on their companies, as shown in Table 15. The most popular response option was improved quality, selected by all seven companies. Additionally, other options received strong support, with all of them chosen by more than half of the companies. No responses beyond the provided response options were given for this question.

Table 15. The impact of Quality 4.0 practices.

4.4 Open comment

At the end of the survey, there was one open-ended question where respondents could freely share their thoughts and experiences regarding these practices in their companies. The majority of respondents, including those who have utilized these practices and those who haven't yet, answered this question. One prominent theme that emerged from the responses was the interest in the topic and the potential benefits of implementing these practices in their own companies.

Several companies that indicated they were not currently utilizing these practices mentioned that they have had discussions about implementing them. On the other hand, companies that reported utilizing at least one of these three practices mentioned finding them beneficial. Many respondents also mentioned that they have only recently begun experimenting with these practices, particularly in the context of Industry 4.0 and Quality 4.0.

Overall, the open-ended responses reflected a curiosity and willingness to explore the implementation of these practices, with some already experiencing positive outcomes, while others are in the early stages of implementation.

4.5 Interconnection of lean, Industry 4.0, and Quality 4.0

Table 16 below shows a bar chart illustrating the total number of Industry 4.0 and Quality 4.0 practices implemented for each company compared to the number of lean tools implemented by the same company. The chart includes all 21 companies that reported utilizing these tools in their operations. The combined number of Industry 4.0 and Quality 4.0 practices utilized by each individual company is represented by the blue bars. The companies are arranged from left to right in descending order based on the total number of Industry 4.0 and Quality 4.0 practices utilized. The orange bars in the chart represent the number of lean tools implemented by each company. When examining the chart, a clear trend emerges among the companies, with few exceptions. It becomes evident that the more Industry 4.0 and Quality 4.0 practices a company utilizes, the greater number of lean tools they also use.

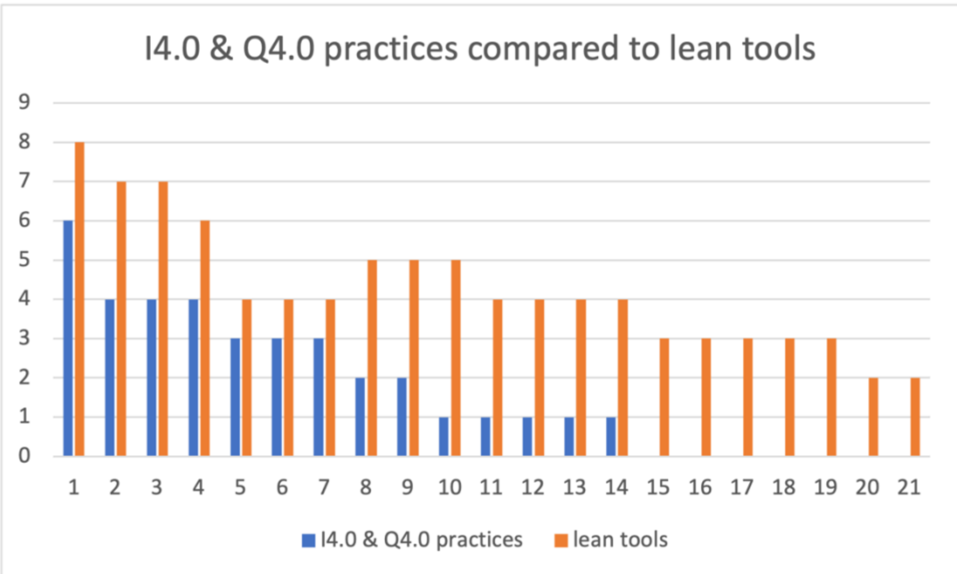

Table 16. The number of Industry 4.0 and Quality 4.0 practices implemented compared to the number of lean tools implemented.

5 Conclusion

This chapter presents a comprehensive overview of the research and highlights the key findings obtained from the survey questionnaire. The conclusions drawn in this chapter are aligned with the three hypotheses mentioned in the introduction of the thesis. Additionally, the chapter discusses the limitations of the research, acknowledging any constraints or factors that may have impacted the results. Furthermore, it offers a suggestion for future research, identifying potential areas that would benefit from further investigation or exploration.

5.1 Concluding the results

In conclusion, the survey provided valuable insights into the utilization and perceptions of lean, Industry 4.0, and Quality 4.0 practices among the participating companies. The findings revealed that lean tools were more widely adopted compared to Industry 4.0 and Quality 4.0 practices. It was observed that all respondents were familiar with lean tools, whereas a clear majority of participants also exhibited awareness of Industry 4.0 and Quality 4.0 approaches.

Among the companies that indicated utilizing these practices, there was a diverse range in the number of tools implemented. In the case of lean tools, it was observed that the most frequently employed number was four, indicating a relatively comprehensive adoption of lean practices. However, when it comes to Industry 4.0 and Quality 4.0 practices, the utilization was relatively limited, with only a small number of companies incorporating them into their operations. Among these companies, it was found that the most common scenario was the implementation of a single tool, suggesting a more focused approach to integrating Industry 4.0 and Quality 4.0 practices.

The first hypothesis of this study assumes that the implementation of Industry 4.0 and Quality 4.0 practices can result in improvements in overall quality. To answer this hypothesis, the survey included a specific question for both of these practices, inquiring about their impact on company’s performance. One of the response options provided was "improved quality." Out of the 14 companies that reported utilizing Industry 4.0 practices, a significant majority of 12 companies (86% of the respondents) indicated that they experienced improved quality as a result of implementing these practices. Similarly, all 7 companies that mentioned utilizing Quality 4.0 practices reported experiencing improved quality. Therefore, based on the survey responses, it can be inferred that both Industry 4.0 and Quality 4.0 practices have a positive impact on quality in the manufacturing industry.

The second hypothesis suggests that the implementation of Industry 4.0 and Quality 4.0 practices alone may not be sufficient to improve overall quality. In this context, lean tools, which focus on waste reduction and continuous improvement, can play a crucial role as a mediator between these practices and quality enhancement. By integrating lean practices with Industry 4.0 and Quality 4.0 approaches, manufacturers have the potential to optimize their production processes and enhance product quality. The responses provided by the survey participants support this hypothesis. When asked about the impact of lean tools on their company's performance, 15 out of 21 companies (71% of respondents) indicated that lean tools had improved their quality. Additionally, all 21 companies reported experiencing improved efficiency as a result of implementing lean tools. This highlights the effectiveness of lean tools in optimizing production processes and aligns with the notion that lean practices can enhance the overall performance and quality of manufacturing companies.

The third and last hypothesis of this study suggests that the implementation of Industry 4.0 and Quality 4.0 practices may lead to an increased utilization of lean tools in manufacturing companies due to their shared objectives. To answer this hypothesis, the survey examined the total number of Industry 4.0 and Quality 4.0 tools implemented by the participating companies and compared it to the number of lean tools they implemented. The survey findings revealed a clear trend indicating that the more Industry 4.0 and Quality 4.0 tools a company had implemented, the greater the number of lean tools they also utilized. For example, a company that implemented a total of six Industry 4.0 and Quality 4.0 tools also utilized eight lean tools. On the other hand, companies that did not adopt any Industry 4.0 or Quality 4.0 practices utilized a maximum of three lean tools.

Overall, the impacts of implementing these practices were predominantly positive, as indicated by the survey responses. Improved efficiency and quality were consistently mentioned as the main benefits experienced by the companies. This finding suggests that lean, Industry 4.0, and Quality 4.0 practices have the potential to enhance operational performance and deliver tangible improvements in various aspects of organizational functioning.

Furthermore, the survey highlighted a significant level of interest and enthusiasm among the respondents regarding the exploration and implementation of these practices within their respective organizations. Many companies expressed a clear intention to adopt Industry 4.0 and Quality 4.0 practices in the future, indicating a growing awareness and acknowledgment of the potential advantages associated with these innovative approaches. The strong interest expressed by the respondents suggests that there is a growing recognition of the transformative power of these practices and their potential to drive organizational success.

The results highlight the ongoing evolution of manufacturing practices, with lean tools being more prevalent and established, while Industry 4.0 and Quality 4.0 practices are still gaining traction. The findings provide valuable insights for companies looking to enhance their operational efficiency and competitiveness through the implementation of these practices. It is evident that organizations are increasingly embracing the potential of these innovative practices to drive transformative outcomes.

5.1.1 Research limitations and future research

The primary limitation of this study lies in its small sample size. With only 44 organizations responding to the survey, which represents approximately 23% of all the organizations approached, the generalizability of the findings becomes challenging. While some generalizations can be made to a certain extent, the limited sample size restricts the broader applicability of the results. Furthermore, it's important to note that this research specifically focused on medium-sized companies, thus there may be a need for more tailored and individualized studies targeting either larger or smaller organizations to gain a more comprehensive understanding of their specific dynamics and practices.

One suggestion for future research is to conduct an in-depth investigation into the long-term impact of implementing lean, Industry 4.0, and Quality 4.0 practices on organizational performance. This research can involve assessing how these practices contribute to various critical factors, including cost reduction, product quality improvement, customer satisfaction, and overall competitiveness, over an extended period of time. Conducting comprehensive research on the long-term impact of implementing lean, Industry 4.0, and Quality 4.0 practices can provide organizations with valuable insights into the sustained benefits and outcomes associated with these practices. Understanding their influence on cost reduction, product quality improvement, customer satisfaction, and overall competitiveness over an extended period can help organizations make informed decisions, develop effective strategies, and drive continuous improvement initiatives to achieve long-term success.

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Appendices

Attachment 1. Survey questions

1. Company name:

2. Are you familiar with the concept of lean production?
   a. Yes
   b. No

3. Have you implemented lean production practices in your company?
   a. Yes
   b. No

3b. If yes, which lean tools have you implemented? (Select all that apply)
   a. Value Stream Mapping
   b. Kanban
   c. Kaizen
   d. 5S
   e. Flow manufacturing
   f. Other (please specify)

3c. How has the implementation of lean production practices impacted your company's performance? (Select all that apply)
   a. Improved efficiency
   b. Reduced waste
   c. Improved quality
   d. Improved customer satisfaction
   e. Increased profitability
   f. Other (please specify)

4. Are you familiar with Industry 4.0?
   a. Yes
   b. No

5. Have you implemented any Industry 4.0 technologies in your company?
   a. Yes
   b. No

5b. If yes, which Industry 4.0 technologies have you implemented? (Select all that apply)
   a. Robotics and automation
   b. Internet of Things (IoT)
   c. Artificial Intelligence (AI)
   d. Augmented Reality (AR)
   e. Virtual Reality (VR)
   f. Cloud Computing
   g. Other (please specify)

5c. How has the implementation of Industry 4.0 technologies impacted your company's performance? (Select all that apply)

a. Improved efficiency
b. Reduced waste
c. Improved quality
d. Improved customer satisfaction
e. Increased profitability
f. Other (please specify)

6. Are you familiar with the concept of Quality 4.0?
   a. Yes
   b. No

7. Have you implemented any Quality 4.0 practices in your company?
   b. No

7b. If yes, which Quality 4.0 practices have you implemented? (Select all that apply)

a. Advanced Analytics
b. Digital Twin
c. Predictive Maintenance
d. Blockchain
e. Additive Manufacturing
f. Other (please specify)

7c. How has the implementation of Quality 4.0 practices impacted your company's performance? (Select all that apply)

a. Improved efficiency
b. Reduced waste
c. Improved quality
d. Improved customer satisfaction
e. Increased profitability
f. Other (please specify)

8. Open comment - Here, you can provide any additional information or comments regarding these practices in your company.