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LEAN MANUFACTURING ENHANCED BY INDUSTRY 4.0: FUTURE POTENTIAL AND RISKS OF INTEGRATION

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International Business Bachelor's Thesis
Supervisor: Patrick Simek
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ABSTRACT OF
BACHELOR'S THESIS

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Objectives

The main objective of this study was to explore the relationship between Lean Manufacturing and Industry 4.0. The current understanding of the concept of Lean was to be examined before the ways in which Industry 4.0 technologies can enhance Lean Manufacturing were explored. In addition, the key success factors for Industry 4.0 implementation in Lean Manufacturing were identified, through a qualitative research method.

Summary

The research interviewed Lean professionals and manufacturing company representatives from eight companies across different manufacturing industries. The study utilized semi-structured, in-depth interviews, which were recorded and coded through a thematic analysis method.

Conclusions

The study suggests that while Lean is greatly implemented across manufacturing industries, a unified understanding of the concept is missing amongst company managers in the sector. Industry 4.0 technologies hold large potential in being implemented with Lean Manufacturing, but a data-illiteracy problem is still evident. Companies must therefore concentrate on utilizing the data that technology has allowed the collecting of, to successfully synergise the two concepts.

Key words: Lean Manufacturing, Industry 4.0, Continuous Improvement, Data

Language: English

Grade:

Abbreviations

ICT	Information and Communications Technology
TPS	Toyota Production System
I4.0	Industry 4.0
LM	Lean Manufacturing
QGD	Quality Function Deployment
VSM	Value Stream Mapping
GEF	German Engineering Federation
JIT	Just-in-Time Manufacturing
IT	Information Technology
OT	Operational Technology
PNL	Profit & Loss

1. INTRODUCTION

1.1 Background

Considered one of the most efficient manufacturing systems, Lean has become a crucial part of the manufacturing industry through its simplicity and high effectiveness (Kolberg and Zühlke, 2015). The core idea behind Lean is the reduction of waste in a production process and the ultimate increase in the overall efficiency of the process through continuous improvement. The pressure from international competitors and the need to be capable of answering customer demands as agile as possible has led manufacturing companies around the world to adapt and implement Lean methods and principles across industries.

Driven by digitalisation, the manufacturing industry is on the verge of a new industrial revolution, the fourth industrial revolution. More commonly known as Industry 4.0 (I4.0), the revolution refers to technology-driven innovation and change in the organization's manufacturing systems. The innovations largely derive from the increased connectivity, collaboration, and advanced services and manufacturing technology (Malvasi & Schanetti, 2017). Portrayed benefits of I4.0 technologies have caused a drastic shift in how shop floors operate, although the true implications remain dimmed due to the recency of the concept (ibid).

The operational shift has led the manufacturing industry to try and fit the newly brought technologies to the pre-existing Lean philosophy, ultimately aiming for a harmonious synergy of the two concepts. Nearly 90% of the highest-grossing manufacturing companies reported to implement Lean methods and principles (Golchev, 2019), presenting the utter importance of the topic. The future competitiveness of companies, to a large extent, relies on how well they can adapt to the latest technologies brought by I4.0 and their ability to utilise it to its full potential. Kolberg & Zühlke (2015) recognise the value that the synergy of the two concepts can bring, which this thesis aims to study further.

1.2 Research Problem

This study aims to examine and explore the relationship between Lean Manufacturing and Industry 4.0 and develop an understanding of a unified framework. First, a literature review will provide a scientific base for the research, introducing the concepts individually and analysing their compatibility through current studies and literature available. The second part of the thesis will present exploratory research on the current state, future potential and future risks of combining the concepts.

1.3 Research Questions

This thesis attempts to answer the following research questions:

1. What is the current state of understanding Lean in the manufacturing industry?
2. What is the current state and future potential of Lean Manufacturing enhanced by Industry 4.0?
3. What are the key success factors in accomplishing a synergy of Lean manufacturing and Industry 4.0?

These questions will be further analysed through a review of the currently available literature and qualitative results of an exploratory study.

1.4 Research Objectives

The following research objectives are closely related to the research questions mentioned above and are the following:

1. To better understand how and to what level the concept of Lean is understood at manufacturing companies.
2. To identify the current state at which Lean Manufacturing is being enhanced by new technologies introduced through the fourth industrial revolution and how in the future, this technology and more developed technologies can supplement Lean Manufacturing.
3. To identify the essential factors to consider to accomplish a successful combination of Lean Manufacturing and Industry 4.0.

2.0 LITERATURE REVIEW

2.1 Introduction

This literature review has been conducted by combining previous research done on Lean manufacturing (LM), industry 4.0 and the interdependencies of the two, critically assessing and analysing them. The aim is to build a supporting scientific basis for the thesis by reviewing existing literature and further understanding the importance and possibilities that the fourth industrial revolution might offer to Lean manufacturing.

The literature review will begin by introducing the state of the current literature available on the topics at hand, more profoundly examining the literature focused on the interdependencies of the various tools of Lean manufacturing and Industry 4.0. It will then introduce the conceptual backgrounds of the general concepts of the review gathered from the available resources. At first, the concepts are discussed separately, followed by literature on the current understanding of the synergy of these concepts. After this, the author dives deeper into the specific tools of Lean manufacturing and Industry 4.0, defining them before presenting a cross-matrix of the literature on Kanban, a tool of Lean manufacturing and industry 4.0. Analysing these literature sources will then examine the various head-to-head interdependencies of the different tools of industry 4.0, like cloud computing and the internet of things, and the Kanban concepts. Lastly, the findings from the available research will be formed into a conclusion, after which a conceptual framework will be presented.

2.2 Conceptual Background

This section of the literature will provide important background on the main concepts, Lean manufacturing and industry 4.0, as well as a brief overview of the synergy of the two.

2.2.1 Lean Manufacturing

The a term, “Lean”, was first published in “Triumph of the Lean Production System” thesis by John F. Krafcik from MIT Sloan School of management in 1988. The paper in question uses the word to compare the Western manufacturing production systems to the innovative Japanese Toyota Production System. After world war two, in the

1950s, a man named Taiichi Ohno needed to develop a way of overcoming the economic crisis that the Japanese automotive industry was facing. He noticed that American car manufacturers could produce nine times the amount of vehicles as Toyota's manufacturers were in the same period of time (Leyh, Martin, and Schaffer, 2017). This was due to the large batch sizes of the manufacturers that compensated for the long setup times (ibid). Toyota then implemented measures to create a leaner production system, developing the idea of "Do More With Less". The piece of literature that introduced the TPS to western manufacturers was "The Machine that Changed the World" by James P. Womack, providing an alternative solution to the mass-production concept practised by large companies at the time, such as Ford (1990).

The core idea was to use a bare minimum of resources to acquire the highest possible efficiency and quality by concentrating on waste elimination, continuous improvement, reduction of inventory, improved productivity, maximising capacity and empowering workers (Wilson, 2015).

After reviewing the literature available on lean manufacturing, it is evident that the characteristics associated with the Lean concept differ among the authors. Between the various literature, Lean is defined as an approach, a practice, a system, a philosophy, a theory, a set of principles, a model, a process or a methodology. The author will refer to the characteristics and practices as a methodology to keep this literature review consistent.

2.2.2 Lean Principles

Womack and Jones (1997) identified five actions termed the "Principles of Lean", which describe the systematic identification and elimination of waste. These five principles, illustrated in Figure 1., act as reference points for the organisation of processes through Lean.

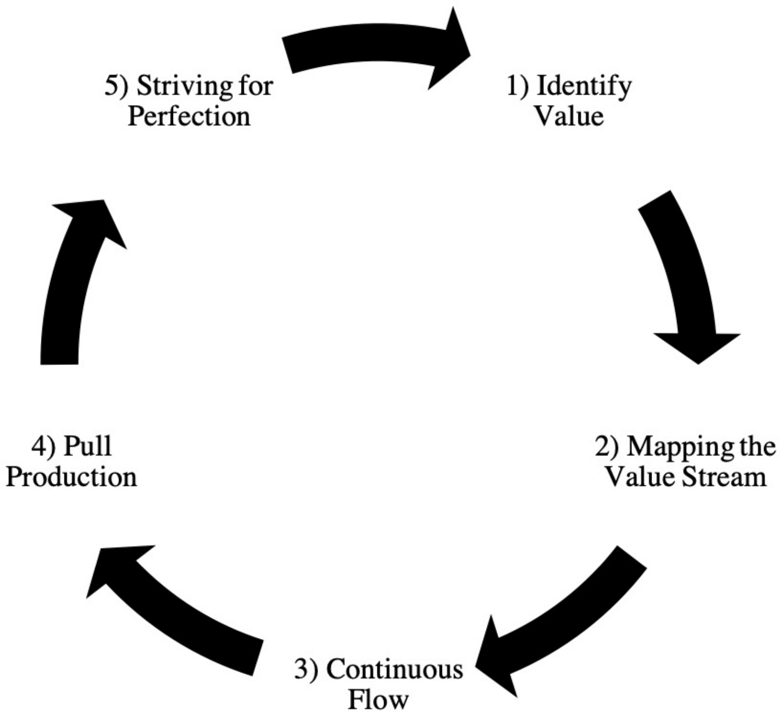

Figure 1.0: The five cycling actions for Lean Implementation (Adapted from Malavesi et al. 2017)

Identifying value is the first step in the waste eliminating process. It refers to the value a customer wants and is prepared to pay for. It is essential for the producer to understand what is important to the customer instead of what is convenient for the manufacturer, often using tools like Brainstorming or Quality Function Deployment (QGD). Most often, a customer does not want to pay for sources of waste, such as waiting time, transporting, or reworking; thus, recognising these wastes is essential. (Liker, 2006)

Mapping the Value Stream (VSM) identifies the value stream for each product separately. Value stream maps are visual tools that help determine the waste produced and understand the flow of materials and information (Wilson, 2015). The goal of the process is to identify the steps in the process that do not create value and eliminate them (Cerfolio, 2016).

Continuous Flow is next established by arranging the remaining value-adding steps into a flow without obstacles or interferences. John F. Krackfik describes in his 1988 article an ideal flow as *a one-piece flow*, where a product flows through a process according to its needs, without organisation or equipment, though usually only achieved by small machines and cell designs through tools like Kanban. These tools will later be discussed in this literature review. Malavasi (2016) states in his publication that “Everything that stops the flow is a waste, so it has to be identified in order to be removed; it is necessary that the process can proceed without constraints.”

Pull production focuses on the production being pulled by the actual market demand. In an ideal situation, a system should produce only when a customer orders, eliminating inventory completely (Sperman et al., 1992). Gupta et al. (2014), in their paper, “The Tip of the (Inventory) Iceberg”, considers pull production to be the most critical of the lean principles, due to inventory being the main source of waste in manufacturing organisations.

Striving for perfection is the fifth and final stage of the Lean implementation. The first four steps help identify and eliminate total waste from the processes, and the fifth principle focuses on continuously observing and retaining the steps as lean as possible. They should be continuously improving, as there is never an end to the process of reducing time, space, efforts, and errors (Osti, 2020). Malavasi (2016) describes in his article the concept of perfection in a lean perspective as being like *infinity*, “Reaching it is actually impossible, but the effort to do so inspires and provides a direction essential to make progress along the path.”

2.2.3 Industry 4.0

The term Industry 4.0 (I4.0), or more specifically *Industrie 4.0*, was first introduced by the GEF (German Engineering Federation) in 2011 at the Hannover Messe, the world's biggest industrial fair. Being such a recently identified term, the definitions between literature varies a fair amount. Commonly industry 4.0 is understood as the digitisation of the industry and communication of manufacturing through developed technologies; the fourth industrial revolution. The concept rose to be more applicable because of signs of the current practices of resource usage not being sustainable, possibly limiting production levels in the future (Gubán and Kovács, 2017; Lele, 2019). The promise of customised manufacturing at the same cost as mass production made I4.0 gain significant popularity as more studies emerged in academic and industrial sectors (Wang, 2016). According to Reinhard et al. (2016) and Zezulka et al. (2016), three main areas of Industry 4.0 affect the corporate world:

1. Digitisation of economic and industrial relations
2. The digital transformation of products and services
3. New models of market

Next, a closer look at the first aspect, the digitisation of economic and industrial relations with an emphasis on creating value in the field of Lean manufacturing, will be taken.

It is important to note that a great portion of the literature and significant research on I4.0 is in Germany, the United States and China, all well-developed countries with the world's fastest growing and largest economies. This indicates a high interest by countries with well-developed industries and an interest in becoming more sustainable, with Germany being the clear front runner. Many of the research activities on I4.0 concern the link between the developed technologies towards aspects of LM, which is also the general focus of this thesis.

2.3 The Synergy of Lean Manufacturing & Industry 4.0

The main idea of this thesis is to research the relationship between I4.0 and Lean manufacturing and enhanced value creation. LM is possibly the most significant paradigm in manufacturing in recent history. According to Womack et al. (1992), it has been argued that Industry 4.0 and the technologies it brings are the continuum of LM. Baumeister, Mittag and Roy (2015) state that LM and I4.0 are not theories that cancel each other out but rather synergies and aid the Lean methodologies used in manufacturing (Baumeister et al., 2015). In their study, Rüttimann and Stöckli (2016) predict that I4.0 has the potential to increase the overall flexibility of LM. The new possibilities enabled by the fourth industrial revolution in automation solutions for example, reignited research in the field (Kolberg et al., 2015). "The combination of lean production and Industry 4.0 exhibits excellent potential in advancing operations management and, especially, production control. " (Spenhoff et al., 2021). Lean, having originated from TPS in the 1950s, was not dependent on any information communication technologies (ICT); however, the positive impact of ICT solutions on the efficiency of production lines has since been studied and understood better (Kolberg et al., 2015; Buer et al., 2018).

A study performed by Staufen AG in 2016 surveyed 179 industrial companies, concluded that the similarity between a majority of I4.0 pioneers is the interest and implementation of a LM system. Similarly, Khanchanapong et al. (2014) suggest in the article "-- the unique and complementary effects of manufacturing technologies and lean practices on manufacturing operational performance" that advanced manufacturing technologies (AMTs) need to be supported by Lean practices to maximise performance increase in manufacturing. The idea of the two concepts merging and enhancing each other is illustrated in Figure 2.0 (Prinz et al., 2018). Due to the scarce amount of long-term research and studies done, the increased productivity efficiency can only be roughly estimated.

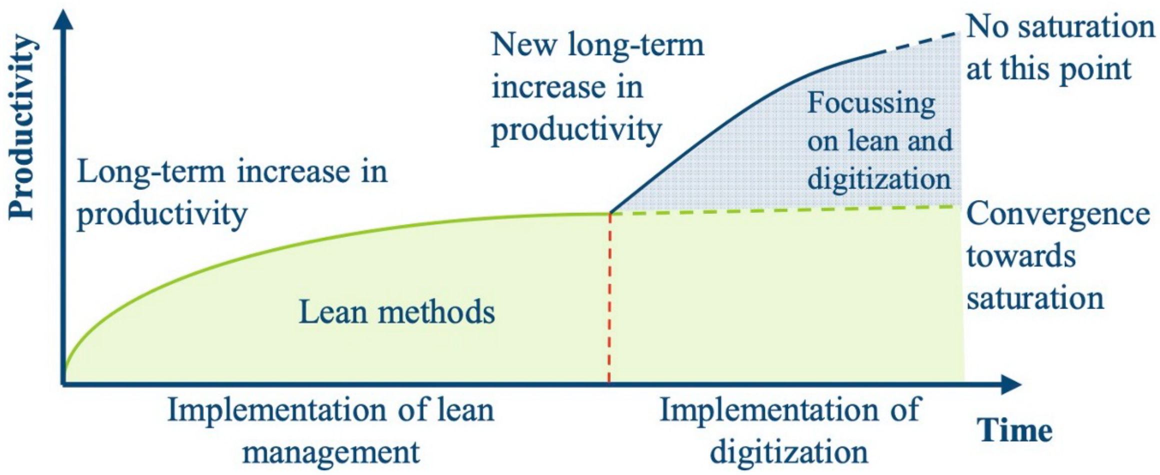

Figure 2.0: Possible productivity increase with Lean and Industry 4.0 implementations (Prinz et al. 2018).

2.4 Industry 4.0 Tools and Lean Methods

This part of the literature review will introduce the main tools and methods that construct I4.0 and LM.

2.4.1 House of Lean

On top of the earlier discussed five *principles of* lean, the Lean paradigm has been described and depicted in different ways throughout different literature. One of these is a figure called the "House of Lean", which was first illustrated in Liker's (2004) paper, "The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer", Liker illustrates the most common methods of LM in a house-like shape (Figure 3.0).

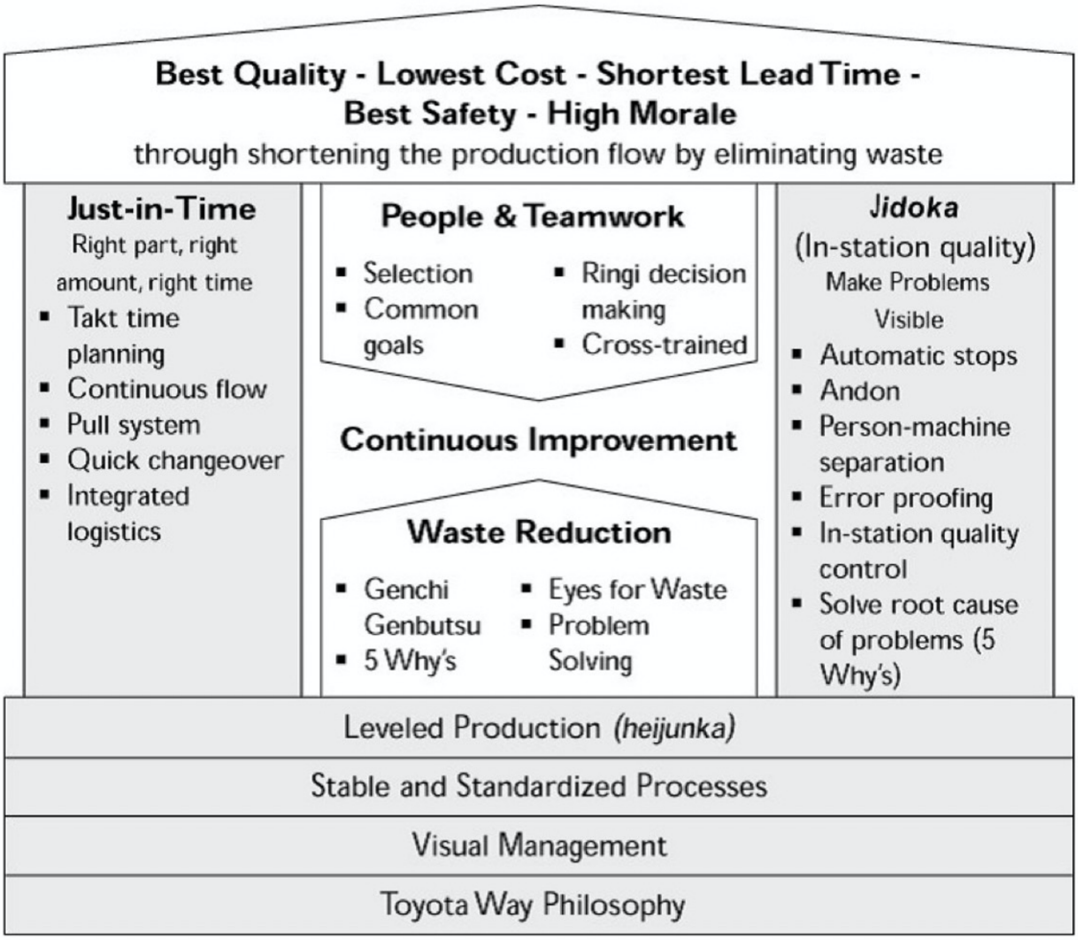

Figure 3.0: House of Lean Production (Liker, 2004)

The diagram consists of a foundation supporting two main pillars supporting a roof over the house, a structural system (Liker, 2004). The house's foundation (Lean production) has four main concepts: Levelled Production (Heijunka), Stable and Standardized Processes, Visual Management and the Toyota Way Philosophy. The two main supporting pillars are Just-in-Time (JIT) and Jidoka. There are people in the middle of the house as they pursue continuous improvement, solve problems, and eliminate waste. Lastly, the roof presents the goal of combining all of these and Lean production as a whole, "the best quality, lowest costs, shortest lead-time, highest safety and high morale" (Begam et al., 2013). A weak link in the house would weaken the whole structure, showing the importance of each element by itself and the general equilibrium of the system.

2.4.2 Industry 4.0 – Smart Manufacturing Technologies

Through the fourth industrial revolution and the implementation of emerging technologies such as wireless interconnectivity and communication between objects and wireless sensors, there has been a drastic increase in Cyber-Physical Systems in production (Godavarthi, 2016). This has transformed a lot of traditional production systems into Cyber-Physical Production Systems (CPPS) (Wagner, 2017).

As previously mentioned in this review, literature on both I4.0 and LM has inconsistencies in the different constructing parts of each of the concepts: methods, tools, practices, etc. In this academic work, the author will refer to them as tools of the different concepts. Also, inconsistencies in the literature on what these tools are varies. The Industry 4.0 Observatory of Politecnico Di Milano defines Industry 4.0 as "a vision of the future of Industry and Manufacturing in which Information Technologies are going to boost competitiveness and efficiency by interconnecting every resource (data, people and machinery) in the Value Chain" (Politecnico di Milano, 2017). Centric elements of the changing paradigm are the different digital technologies, the means of the Fourth Industrial Revolution, the *Smart Manufacturing Technologies.* They are defined by Politecnico di Milano (2017) as the starting point of the digitisation process of operations, including manufacturing, therefore being critical to understand for LM implementations and this literature review. From their point of view, the technologies in smart manufacturing can be divided into Information Technologies (IT) and Operational Technologies (OT). The tools of I4.0 can be found within these two subcategories of technologies presented below. Figure 4.0 illustrates the typically agreed tools connected with I4.0. Regarding the different Lean Manufacturing tools Kanban and CI, definitions will be provided later in the head-to-head interdependencies section of this paper.

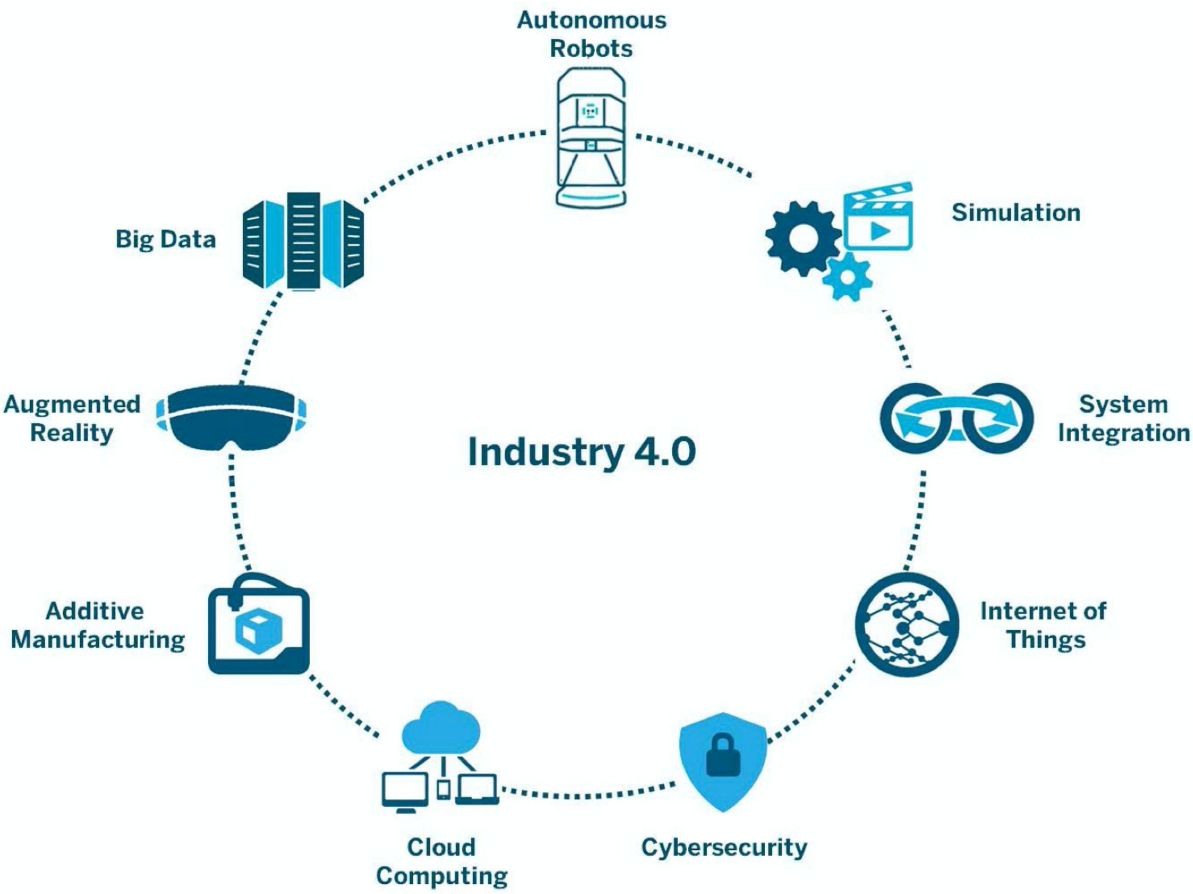

Figure 4

2.4.3 Information Technologies

Balakrishan (1999), in her paper “Manufacturing in the Digital Age: Exploiting Information Technologies for Product Realization”, suggests Information Technologies (IT) be the key enabler for future manufacturing enterprises and the transformer of organisations and markets. This seems to be a common idea amongst the literature, stating that IT reduces barriers to collaboration, leads time and physical movement, and enriches process governance. A common understanding in the literature is that IT includes the Industrial Internet of Things (IIoT), Industrial Analytics and Cloud Manufacturing (Malawasi, 2018).

According to Jesche et al. (2017), the idea of IIoT is in every physical object acquiring a personal digital alter ego, maturing into Smart Objects. These smart objects can identify oneself, make error-diagnosis, collect and elaborate on data and communicate to centralised controllers. Smart objects and Smart networks are defined as Cyber-Physical Systems (CPS) (Baheti et al., 2011). Secondly, Industrial Analytics allow the elaboration of data and *Big Data* from IoT systems, supporting real-time decision making (Flath et al., 2018). Lastly, through the internet, cloud computing enables "--an open, shared and programmable access to resources, supporting production processes and the whole management of the supply chain" (Armbrust et al., 2010).

2.4.4 Operational Technologies

Operational Technologies enable interconnectivity between resources in production processes. It includes Advanced Human Machine Interface (HMI), Additive Manufacturing and Advanced Automation.

Firstly, HMIs are one of the key concepts associated with I4.0 (Rodrigues et al., 2019). They are referred to as wearable devices and interfaces capable of acquiring data, managing information vocally, visually or in a tactile format. An example of this is given in Downs' (2005) journal, "Using resistive touch screens for human/machine interface"; 3D scanners. Nee et al. (2012) talk about *Augmented Reality* and *Virtual Reality* as examples of HMIs, improving work procedures and conditions in manufacturing.
Secondly, additive manufacturing, or more commonly throughout literature referred to as 3D printing means the printing of solid 3D objects (Yoo et al., 2016). 3D printing has widely contributed to the advancements in customised manufacturing, enabling smaller, more customer-specific customisation in shorter times and reduced cost. According to Wong et al. (2012), additive manufacturing is found in four aspects of manufacturing: Rapid Manufacturing, Rapid Prototyping, Rapid Maintenance and Repair and Rapid Tooling.

Lastly, Advanced Automation refers to the automated production systems of I4.0. For example, Cobots or Collaborative Robots are becoming more and more common in relieving seasonal labour shortages in agriculture by handling herbs, seedlings, etc. (Ducket, 2018).

2.5 Interdependencies between LM and I4.0

Kanban is a Lean method focused on pull production, the flow of materials between workstations using signals (Abbadi et al., 2018). Although Kanban has been proven to be effective at reducing waste and enhancing production, the use of manual (non-digital) Kanban is prone to be negatively affected by human error. Therefore, it is due for an improvement through technological advancements brought by I4.0 (Murat, 2019). Being a centric concept in LM that ties together the five principles of lean, CI is a key enabler of the full integration of I4.0 tools in LM. For the mentioned reasons, these two methods of Lean Manufacturing have been further researched in the latter part of this literature review.

Some of the publications are based on studies where the method integration has been practised in specific cases. This section of the literature review aims to showcase the current research, what the results of these integrations have been and what is the gap between the known and the unknown. This will work as a base for the conceptual framework of the research done in the next part of this thesis.

It is important to note that the cross matrix only includes I4.0 tools that were studied and mentioned in the reviewed literature. Interaction between some tools of the two concepts is unfeasible, or the combination does not enhance the overall performance of the process in any substantial way, therefore not mentioned in this section of this literature review.

2.5.1 Kanban in Industry 4.0

Kanban was one of the first methodologies of Lean that was implemented in industrial companies, dealing with overproduction, transportation, excessive inventories and waiting (Ohno, 1978). Interpreted from Japanese, Kanban means “signal card”. It signals the start of production processes or some movement of materials in a supply chain.

Golchev (2018) describes Kanban merging with I4.0 as “-- the method [that] becomes the engine of not only the internal production and logistics processes but also of the entire horizontal and vertical supply chain in the companies that utilises it.” Applications of various I4.0 tools with Kanban have been studied and analysed in several public studies, which this literature review will discuss in greater detail. Some of the literature overlaps on the industry 4.0 integrated tools, but the ones with the highest impact on the specific study are discussed in the appropriate sections.

2.5.2 Kanban and IoT

The use of advanced telecommunication devices and Kanban has been researched in several studies, two of which will next be reviewed in greater detail.

We will first look at Kouri et al.'s case study, *The Principles and Planning Process of an Electronic Kanban System* (2008), which is the oldest piece of literature on merging the IoT and Kanban. The paper introduces an idea of an "E-Kanban system". The case study uses Radio Frequency Identification (RFID) as the main communication technology in the manufacturing and assembly process. The study is based on a simulation of an existing assembly line of a manufacturing company. The advantages of the so-called "E-Kanban system" over traditional Kanban are as follows:

- The hassle of people losing cards eliminated
- Prompt delivery
- Better efficiency in handling cards
- Material scarcity eliminated
- Enhanced transparency of production chain
- Improved supplier analyses

Thürer et al. (2016) present a case study, "Internet of Things (IoT) driven Kanban system for reverse logistics: solid waste collection", on the collection of solid waste using a Kanban system supported by IoT technology. Like in the study done by Kouri et al. (2008), Thürer also utilises RFID sensors in his study. In this paper, Thürer et al. provide a good example of how a combination of the architecture of Kanban and IoT being used together. This architecture is based around the use of wireless sensors communicating through Cloud Computing to "Smart Trucks", also tracked by General Packet Radio Service (GPRS) technology. In more detail, the calculation and communication of bins is performed through Cloud Computing. Next, the path of the Smart Trucks is determined, and the information is transferred wirelessly. Lastly the leveling of the bins is done by Heijunka, refreshed in real-time, again through wireless communication. It is concluded that the combination of IoT and Kanban helps the team overcome the main wastes of unnecessary motion.

Although discussing the improved process of solid waste collection, the case study does not include the effects of the implementation on quality and expenses, leaving room for further research.

2.5.3 Kanban and Cloud Computing

Cloud Computing is another tool of I4.0 that Kanban has been closely tied to in current literature, already mentioned in the above case study. Oktadini, N.R. et al. (2014) describe cloud computing as the most popular and used tool of I4.0, describing it as a tool connecting computation, software, data, and non-physical storage (Oktadini, et al. 2014). Next, three case studies on the integration of Kanban with cloud computing are discussed.

First, Azambuja et al. (2013) give an example architecture of a basic cloud computing powered supply chain in their paper "Enabling Lean Supply with a Cloud Computing Platform – An Exploratory Case Study". They use a Google Fusion Table cloud-based platform to monitor and compute information about the material flowing through the Pipe spools of the supply chain. The main advantages of the case study were concluded:

- Real-time updates from the supply chain process
- Reduction of Lead Time (Design to installation)
- Smoother operations in the organization

Secondly, Kolberg et al. (2016), in their review article "Towards a lean automation interface for workstations", propose a framework supported by automated workstations and *Cyber-Physical Systems* (CPS). On top of the architecture for a smart factory, the requirements for a Kanban system are listed. Concluding the case study, a list of advantages of the combination of cloud computing and Kanban are presented as such:

- Hassle of people losing cards eliminated
- Real-time data on the transit of materials

- Time needed to change physical Kanban cards eliminated

Another example of specific tool integration is provided in the paper “Opportunities for enhanced lean construction management using Internet of Things standards”, by Dave B. et al. (2015). The author proposes a lean operation model where Kanban cards are not necessarily digitalised, but instead, computer vision is used to capture levels of accomplishment in a construction site, which is then shared in real-time on a cloud platform called VisiLean. It triggers the movement of raw materials to the warehouse and ultimately to the site. This model exploits the advantages of Kanban through a Cloud platform. The article does not clearly state the measured performance improvements before and after the implementation, but only the potential of reduced time waste and excessive raw material waste.

In their case studies and article reviews, authors throughout available literature agree that organisations that utilize large amounts of data can lower costs and storage space significantly through Cloud services. The adaptation also results in faster data gathering and computing into useful information (e.g. Oktadini et al., 2014; Azambuja et al., 2013; Dave B. et al., 2015; Kolberg et al., 2016). Additionally, through Cloud Computing, industries are able to spread the effects of the Kanban system to the broader supply chain, enhancing the whole process.

2.5.4 Kanban and System Integration

In a practical case study by Aybakan et al. (2019), “Digitalization of the Kanban System”, the team studies a tier 1 supplier, Asin Turkey, through their transformation from traditional Kanban to digital Kanban. An electronic production management system that creates electronic Kanbans “e-Kanbans” according to shipped products calculates production’s start trigger levels and defines and ques production lots. The study first presents problems with traditional Kanban methods related to operation costs, adaptation and customer service. It then discusses the implementations and performance measures, after which the results are presented as cost reduction, improved customer service and adaptation through communication between the system and autonomous robots based on IoT technology.

Although the integration of the technologies was studied and results presented, the process of integration was not discussed in detail. How the people were able to adapt to the new environment and new technological practices requires further research.

2.5.5 Continuous Improvement in Industry 4.0

The phrase Continuous Improvement comes from the Japanese word Kaizen and refers to a philosophy encouraging people to continuously improve themselves and their environment. CI is more of an attitude amongst the people within an organisation than a process (Vinodh, 2020). The idea of CI is in the members of an organisation being inspired to improve everyday performances through a continuous cycle, reaching an ultimate perfection. It is also considered to be a behaviour that must, instead of could, be done to achieve a fully Lean process cycle. The combined use of Continuous Improvement and the Industry 4.0 tools is not studied individually in any available case study or review but can be found as a part of the following academic publications.

Firstly Buer et al., in their paper “The Data-Driven Process Improvement Cycle: Using Digitalization for Continuous Improvement, (2018)”, CI improving data acquisition and management is suggested. Buer and collogues propose a five-step method of CI through digital tools: 1. Data collection 2. Data sharing 3. Data analysis 4. Data optimization 5. Feedback. The article presents a clear transition from the traditional approach to the I4.0 enhanced digital approach. Each step of the five-step method is supported by proposed I4.0 tools that can be used: Cloud computing, Smart sensors, Big data and Machine learning.

Davies et al. (2017) present another example of CI at the monitoring level, taking advantage of Augmented and Virtual Reality in work familiarisation processes. At the optimisation level, Stojanovic and Milenovic (2018) give an example of Big data analysis through numerical twin simulations in a CI process aimed at optimising problem-solving. However, the full potential of the use of AI is yet to be realised in the manufacturing environment (Goering et al., 2018). Another example of simulations is presented by Kamar and Kie (2018); in their case study “Use of a discrete-event simulation model during a Lean process: a case study in healthcare”, different real-time simulations of Kaizen practices were created to optimise the stocks, movements, overproduction and waiting in the process. Also, Cloud systems are mentioned as monitoring aid used in CI practices and machine condition predictions (Conti and Orcionu, 2019).

2.6 Findings from the Literature

The currently available literature on Lean, Industry 4.0 and integrating the two concepts promises a more intelligent and efficient future for manufacturing processes. While it is evident that the combination is a relatively new concept, some studies and research have already been conducted. It is also clear that a unified framework for LM and I4.0 integration is still missing. Further research needs to be done to establish a unified understanding of the concept of Lean 4.0.

As described, the compatibility of LM and I4.0 is approved by most authors. The integration of the two concepts can be summed up into two main ideas by different authors.

1. Lean is the necessary foundation for I4.0 (e.g. Kolberg and Zuhlke, 2015; Prinz et al., 2018; Liker, 2004)
2. I4.0 enhances the effectiveness of LM (e.g. Büer et al., 2018; Lyeh et al., 2020; Wagner et al., 2017; Sanders et al., 2016)

While I4.0 is widely considered to be a very applicable concept to LM, as both aim for waste and deficit reduction and both attempt to streamline processes, a clear, unified framework of the practical implementation of the transformation process from traditional LM to I4.0 enhanced LM is not stated and therefore leaves room for new research. The general strategic frameworks, as well as specific operational level methodologies of the integration, are missing.

An important finding from the current literature is the significance of data. A great deal of benefits that Industry 4.0 has brought to Lean manufacturing has to do with some part of the data process. Whether it is the collection of data with smart sensors (e.g. Buer et al., 2018), communicating the data wirelessly between devices (e.g. Kolberg et al., 2016), computing the data (e.g. Oktadini et al. 2014) or visualising the data through a virtual simulation (Kamar and Kie, 2018), data is most of the time present. This is why the focus of the research in this thesis will be on data processing.

2.7 Conceptual Framework

To fill current gaps in research, to get closer to a unified understanding of the concept of Lean 4.0, a conceptual framework has been designed (Figure 5.0). The framework focuses on defining the untapped future potential of integrating the two ideologies, concentrating on data processing, as that has been established as one of the main success factors of the combination. Data has been classified into three categories: data collection, visualisation, and usage. From each of these categories, the future potential and risks are to be evaluated to get a complete understanding of not only the possible benefits but also the possible negative effects. While this framework will not fully conceptualise and define the concept of Lean 4.0, it will bring research one step closer to it.

The thesis will demonstrate how specific tools of industry 4.0 enhance Lean manufacturing by first presenting how the two concepts are already well-established independently, but could and potentially are already resulting in improved production performance and lower waste rates.

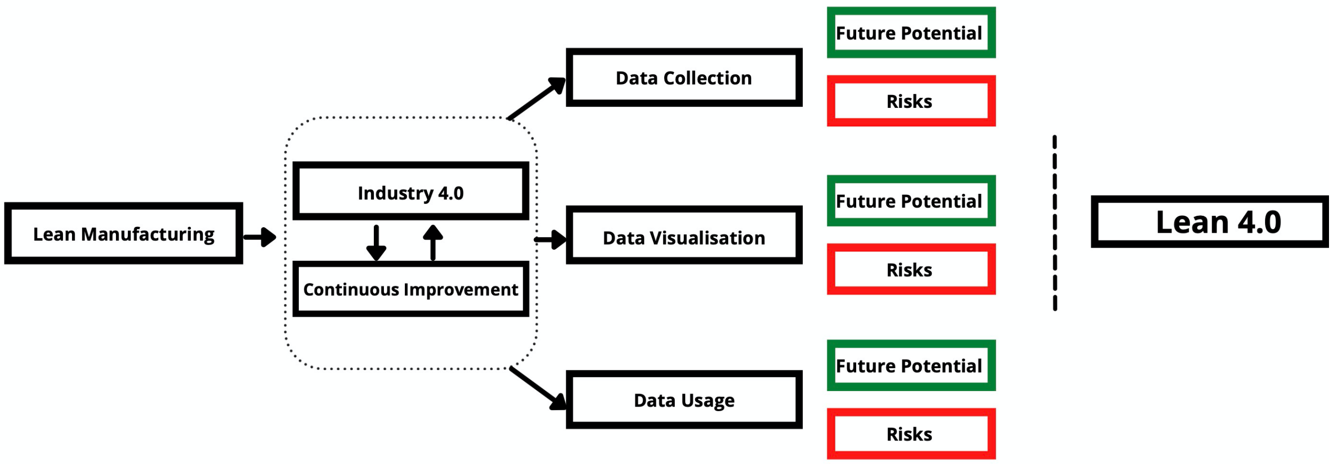

Figure 5.0: Conceptual Framework

3 METHODOLOGY

This study aimed to examine how the different tools and technologies of Industry 4.0 have affected Lean in the industry of manufacturing, with a focus on the collection, visualisation, and usage of data. In addition, the aim was also to get an overall picture of the current state of understanding of Lean in manufacturing companies. To support and answer the research questions and the objectives of the thesis, a qualitative study method was chosen, in combination with secondary data from currently available research.

In this section, the research methodology of the second part of the paper is reviewed and discussed. The section explains how the interview questions were designed and the data collected. Then a better description of the sample selection will be given, followed by an explanation of the data analyses method used. Lastly, the limitations of the methodology used are discussed. Details of the specific interview questions can be found in appendix 1 and 2.

3.1 Approach and Data Collection

This thesis used an explorative and qualitative research design to research and collect data. An exploratory research approach is explained by Saunders et al. (2019), to be especially advantageous when the aim is to clarify and deepen the understanding of an issue, phenomena, or problem, especially when the nature of the topic is unclear (Saunders et al., 2019). The exploratory nature of the study is also supported by the research questions (section 1.3) and the open-ended interview questions (available in the appendix).

As the primary data collection method, semi-structured interviews were conducted with people who acquired personal experiences, attitudes, and perceptions on the topic of Lean manufacturing and Industry 4.0. In a semi-structured interview, predetermined but open-ended questions are asked. The questions were designed to narrow from a broader discussion to more focused data-centric questions. Semi-structured interviews were chosen as the primary research method, as they are used to collect exploratory data on the related topic and triangulate and validate the findings from different sources. They are an effective method when the collected data is qualitative and open-ended, and the thoughts, feelings and beliefs of an interviewee are being explored (De Jonckheere and Vaughn, 2019).

Two different sets of similarly structured questions were designed for two different sample selections, later discussed in section 3.2. First, eight representatives of manufacturing companies of various sizes were chosen to be interviewed. The interviewees' positions in their representative companies varied between production manager, chief executive officer and chief operating officer. The first interviews aimed to get practical insight into the state of understanding and implementation of Lean and Industry 4.0 technologies in manufacturing companies. For the second part, a selection of three experienced individuals, later discussed in section 3.2., was interviewed on their view of the current and potential future trends in combining Lean manufacturing and Industry 4.0. The questions were slightly altered to explore and exploit the experience that the three experienced individuals have had in the field, visiting hundreds of factories, and working in the field for 10 to over 25 years.

The interview for the company managers consisted of seven open-ended questions. The first question introduced the person in question and the size of the company, using the number of employees. The next question explored the state of Lean practices in the company's manufacturing processes while also presenting the level of knowledge of the concept of the interviewee. The third question explores whether the Lean methods practised have been upgraded in the company in the past years. The fourth question discussed the use of professional consultation services in the implementation process of Lean. The following three questions discuss the upgradation of Lean methods in the companies, with the sixth question explicitly focusing on data collection, visualisation, and usage. Then the different ways of measuring the benefits of Lean approaches are talked about before discussing the challenges that technology used in Lean practices brings. Lastly, the view of the interviewee on the future potential and risks of the combination of I4.0 and LM is asked. The second set of questions asked from the panel of experienced Lean professionals was modified from the first set of questions to discuss the overall state of Lean in manufacturing companies. Both sets of questions are presented in the appendices section.

The eight company representatives and the respected companies are kept anonymous to each other and the reader before, during and after the interview process. This will help eliminate any dominative or authoritative impact on other interviewees. It allows for free expression and a more robust presentation of their professional viewpoint. Only the sizes and specific manufacturing industries of the representative's companies are given, as that is essential information considering the analyses.

The three individuals with over ten years of experience all agreed to a non-anonymous interview, standing behind their statements, thus increasing the reliability of their answers.

3.2 Sample Selection

The sampling for the company representatives was done on one criterion:

1. The respondent needs to have extensive knowledge and understanding of the manufacturing processes of the represented company.

The experienced panel of Lean professionals was done on one criterion:

1. The respondent must have extensive knowledge of Lean Manufacturing and experience working with Lean in manufacturing for an extended period (minimum of 10 years).

Only one criterion was set for both sets of respondents, as the aim was to collect rich data from a diversified group of people of varying ages, experiences and exposure levels. Due to the unclear definition, the word "expert" has been avoided in this paper (Hasson et al., 2000); instead, the three people with over ten years of experience in Lean Manufacturing are referred to as "a panel of experienced individuals". Their names and years of experience in Lean are presented below in Table 1. More than ten interviewees have been deemed necessary for this study to reach a sufficient saturation level.

Interviewee Number	Date of Interview	Name	Years of Experience
1	10.2.2022	Brad Elhart	20
2	6.3.2022	Isto Sahi	15
3	8.3.2022	Miguel Teixeira	10

Table 1. The interviewed panel of experienced individuals

A total of eight company representatives were interviewed, with the sizes of the companies varying from 22 to 13 000 workers and one million to 296 million euros in yearly revenue. The varying size allows for a comparison of answers between the different size companies. Three different manufacturing industries, plastic, metal and automotive, were represented, with plastic manufacturing being the most common.

3.3 Data Analyses

Each interview, lasting between fifteen minutes and one hour, was done online, recorded, and processed separately, identifying categories, reoccurring themes, and contrasting points between the interviewees. The calls were analysed in multiple iterations, first identifying keywords and then key trends under each question asked. These key points were then transcribed and colour-coded for easier analysis.

A thematic data analyses strategy has been implemented to process the collected data. This method allows for both systematic and flexible data analyses that facilitates an exploratory study. The identification of key themes and patterns also provokes directions for further exploration of the topic (Saunders et al., 2019).

3.4 Limitations of Methodology

One limitation of a qualitative study over a quantitative one is the risk of bias. Company representatives might feel an urge to defend their companies, thus giving a more positive perspective of matters than what it is in reality (Szolnoki and Hoffman, 2013). However, the companies are protected by the anonymity of the representatives and the company names, providing an opportunity for more truthful answers.

Secondly, the companies interviewed were Finnish for the most part. Culture influences organisations, with Lean being practised in different ways around the world

(Hardcopf and Shah, 2014). Therefore, focusing the research area mostly on one country restricts the understanding of the general state of Lean in manufacturing companies globally. However, the interviewed panel of experienced individuals with over ten years of experience in Lean were all from different countries, allowing for a more global picture of the general state.

Lastly, the extent of the research could be expanded. Analysing data from only eleven conducted interviews restricts the depth and accuracy of the analyses, which is an overall limitation of a qualitative research method.

4 FINDINGS

The interviews were designed to find answers to the set research questions and provoke further research on the topic. This section of the thesis will go over the findings of the research, divided into subsections based on the dominant trends and themes that emerged from the answers. Key points and arguments from the interviewees are presented with specific quotes from the interviews. Each statement will be cited according to the interviewee number presented previously, in table 1 and in the next section, table 2, where the role of the person, specific manufacturing industry of the company and the size of the company can be seen. Only the three experienced individuals will be cited using their names.

4.1 Current state of Lean Manufacturing

Of the eight companies interviewed, only one (11) said to not practice any Lean in their manufacturing process. The seven other companies (4-10) said they implement at least some aspects of Lean in their operations. This varied from a simple implementation of 5S in the working environment (7) to the whole company being built on the bases of a Lean philosophy (4). The most common Lean practice within manufacturing companies focused on eliminating waste. Six out of the eight companies put effort into reducing waste in inventory, distances moved, quality control or collected data, for example. Three of the companies mentioned using the 5Ss of lean; sort, set in order, shine, standardise, and sustain. An attitude towards implementing separate Lean tools was evidently more common than the idea of thinking of Lean as a philosophy.

Similarly to the literature (Wilson, 2015), Miguel Teixeira, one of the Lean-experienced individuals, explains how he has seen Lean manufacturing spread from only the automotive industry to all sorts of manufacturing. This is supported by Isto Sahi, who says almost all companies implement some aspects of Lean. The interviewed company representatives also represented three different manufacturing industries, of which two were not automotive-related.

In the data collected, the size of the company in question did not seem to correlate to the level of Lean implementation in the manufacturing processes, as can be seen in table 2. However, the employment of specialised Lean departments was mentioned by Teixeira to only have spread amongst larger companies due to the high costs. One small-sized company with only ten employees was found to not implement any Lean practices, mainly due to the lack of resources and knowledge.

From an industry perspective, representatives from three different manufacturing industries, automobile, plastic, and metal, were interviewed. The automobile industry, as expected due to the origin of Lean being in automobile factories, presented a medium to a high level of implementation of LM practices. Metal manufacturing showed both a low and a high level of implementation. Lastly, the plastic manufacturing industry showed the highest level of implementation and interest in Lean practices.

Interviewee Number	Interview Date	Role	Manufacturing Industry	Size of Company	Level of Implementation
4	3.3.2022	Chief Operations Manager	Metal	29 employees (Small)	High
5	20.2.2022	Chief Executive Officer	Plastic	22 employees (Small)	High

6	6.3.2022	Operations Manager	Automobile	7000 employees (Large)	High
7	8.3.2022	Production Manager	Metal	300 employees (Mid)	Low
8	4.3.2022	Production Manager	Plastic	144 employees (Mid)	Medium
9	8.3.2022	Production Manager	Automobile	5000 employees (large)	Medium
10	9.3.2022	Chief Operations Manager	Plastic	151 employees (Mid)	High
11	3.3.2022	Chief Executive Officer	Undefined	10 employees (Small)	No Lean

Table 2

The level of Lean implementation was only described by the company representatives and no specific metric was used. A unified understanding of what Lean and its implementation mean in practice is evidently missing in the manufacturing industry. This statement is supported by the panel of experienced individuals, who all agreed that a company might claim to fully practice Lean manufacturing, even if only one aspect of the concept was in use. This presents a likelihood of inconsistency in the answers of the participants. However, the amount of Lean-linked practices used in a company was considered when examining low, medium and high levels of implementation. Isto Sahi states,

> *"Almost all companies implement some aspects of Lean, but more often than not, the core understanding of the philosophy is missing."*

While the understanding of the concept, as stated by Dombrowski et al. (2017), has increased and spread across industries, a true and unified understanding still seems to be missing. Some interviewees understood Lean simply as any form of process enhancement, while Isto Sahi, a senior Lean consultant with over 15 years of experience in the industry, said that at least 500 active days of practising Lean is needed to understand the concept. He described it as a phenomenon where the more you understand the concept, the more you understand you do not understand the concept.

4.2 Measuring Lean

Before presenting the results of Industry 4.0 technologies merging with Lean manufacturing in section 4.3, it is essential to understand how the benefit brought by Lean can be measured. A significant finding from the interviews was that there is no one way in which benefits are being measured, and the methods differ between companies, industries and cultures. When considering the performance of the business, the one agreed upon measuring metric was the company's overall financial results before and after implementation. However, while some companies ruled this to be the only factor of importance, some interviewees mentioned factors affecting the financial results on a deeper level and other metrics such as health and safety (2, 3, 6).

Teixeira divided the different types of measuring methods into two categories, hard and soft savings. Hard savings are the ones that have a direct impact on the PNL (profit and loss) of a company. These include savings from the elimination of outsourcing, shortening employees' working hours, etc. Soft savings, on the other hand, focus on the behavioural changes within a company. These savings do not derive from direct savings but rather the long-term savings of having the right processes in place. Teixeira explains this through an example:

> *"From a savings or a direct financial point of view, you will not get any savings from workers having extra time to clean, maintain machines, etc. – same people and same hours … However, this could reduce the amount of repairs, healthcare costs, spare part costs, etc."*

Another factor affecting the measuring methods pointed out by Teixeira was the cultural differences. He stated that in Eastern cultures, the soft savings of a company play a more significant role and in the American culture, hard savings are prioritised, while Europe is in the middle. An American company may for example concentrate more on reducing outsourcing to foreign countries, making everything in-house to save money, while a Japanese company could put a higher focus on building the overall culture of a company before direct financial savings.

4.3 Lean Manufacturing Changed by Industry 4.0

All participants of the interviews discussed Lean methods being upgraded in the past years. A fundamental improvement connecting the answers was the adaptation of Lean practices to the specific company's needs. Teixeira mentions the ability to tailor the Lean process to the particular needs of a company as one of the key improvements of Lean practices in the last decade. Different aspects and tools of Lean have been separated from the general philosophy and then adapted to the needs of specific processes in companies. In one company (5), a change from only using value stream mapping (VSM) to a deeper philosophical and personal level of understanding through workforce and manager training was in progress. Other companies also told Lean training to be a part of their current process enhancing plans, showing a desire and trend towards a deeper understanding of Lean.

4.3.1 The Implementation of Data

A central theme between many of the answers was the use of various digital tools, from computer software to machine sensors. There has been a transition from traditional lean practices to ones enhanced by digital tools. Brad Elhart, a lean consultant with over 25 years of experience in Lean, mentions the importance of the transition to digital Lean practices:

> *“If you are implementing Lean and ignoring the type of capability that technology can offer, you are missing huge opportunities.”*

He also defends the use of digital technologies over more traditional pen and pencil methods by saying:

> *“Just because something has to be on the floor and visual, does not mean it has to be tracked by pencil and paper.”*

The two other experienced individuals also brought up the importance of the use of digital technologies, reasoning that they are more equipped to perform complex tasks than humans are in most scenarios. However, multiple challenges to the implications were also brought up, which will later be discussed in section 5.2. Similarly to what was concluded in the literature review, a binding concept between I4.0 and LM is data. As presented in the conceptual framework in section 2.7, in the interview process, data were divided into three different sectors: collection, visualisation and usage. How I4.0 technologies have enhanced LM in these sectors are discussed separately below, after which additional points brought up in the interviews are given.

4.3.1.1 Collection

A clear trend of a drastically increased amount of data collected was evident in the interview answers. Factories use digitally intelligent machines filled with sensors, measuring even the most minor changes and movements (3). Some of the collected interview answers show that manual data collection has almost completely been replaced by digital tools (5, 6). This use of digital sensors has eliminated the risk of human error in logging data. However, some data, like work hours, are still manually written down, only onto digital software so that the data can be digitally stored and used later. The collection of data through digital tools has not presented to be the bottleneck of the process, but rather the one part that has been fully exploited to a high level, where more data is collected than what is being used or necessary. This topic will be discussed in greater detail later in sections 5.2 and 5.3.

4.3.1.2 Visualisation

Not only is data being digitally collected in real-time, one of the most impactful enhancements of digital technologies in Lean manufacturing has been the ability to visualise and therefore use data in real-time. Digital monitors are being planted around factories next to workstations, depicting various data collected in real-time, helping to keep the employees on track and motivated. Like traditionally in Lean, data is simplified and colour-coded to show the bigger picture faster, with no language barriers. Elhart advocates the use of blue and orange instead of the more common red and green signals, due to cultural differences in meanings and a high likelihood of red-green colour-blindness, stating that 8 per cent of the male population is red-green colour blind.

4.3.1.3 Usage

Firstly, collected data is used to create predictive models that can, for example, inform when parts of machinery need to be replaced. As an example, a machine supplier might claim that a bearing on a machine must be changed after five years, but a digitally created predictive model can realise the bearing to last for seven years, directly saving the company money from not having to change the bearing after every five years, but seven (3). However, this does require very capable and costly data analysts, not currently available in most companies.

Secondly, the possibility to see and use collected and analysed data in real-time has brought opportunities for companies. Sahi mentions the benefits of using real-time VSM over weekly or even monthly VSM exercises. Real-time VSM allows employees to make decisions and react quicker. This is supported by one of the companies (10), using real-time data to track if a process is in line to achieve the weekly, monthly, or yearly objective. In case there is a need for speeding up a process for example, the team can react instantly instead of realising the need for acceleration of processes too late to reach the objective on time.

The use of digital tools in Lean manufacturing processes has also made it easier to monitor the dependencies of occurrences (5). For example, finding a reason for machine downtime or low-quality output is quicker and easier through digital means.

4.3.1.4 Transfer of Data

The enhanced ability to transfer data digitally and wirelessly through IoT was brought up by several interviewees (10, 7, 5). Today's manufacturing environment has changed to companies having multiple factories in various locations. Through IoT and software, data can be shared in real-time without the need to be on-site. This allows offices and factories to stay connected and up to date on necessary information. The importance of remote working capabilities has been especially proven during the Covid-19 pandemic, making the ease of data transfer more valuable.

4.3.2 Case Example: Plastic Manufacturing

As plastic manufacturing was the most represented industry amongst the interviewees chosen for the research, a specific shop floor example of the implementation of data in a plastic moulding factory is provided.

The following shop floor example presents a case from a small-sized plastic manufacturing company (5) collecting, visualising, and using data from a rotational moulding machine through digital means, enabling an enhanced reduction of energy waste.

At the beginning of 2021, the company had developed a new digital sensor system that enabled the collection of several data variations from a rotational plastic moulding machine. Two of the measurements the sensors were collecting were the inner temperature of a plastic mould and the heat-up burner's propane consumption. For one year, the sensors collected data from the machine without a specific use case. At the beginning of 2022, a professional data analyst was brought in and shown the data the machine was collecting. The correlation between the previously mentioned measurements was examined, resulting in the discovery that the inner temperature of the mould stayed sufficient to finish moulding the plastic product, even if the burner was turned off earlier in the cycle. Turning the burner off sooner and running it for an overall shorter time period during each cycle reduced the amount of propane gas used per kilo of plastic processing by 700 litres per cycle, or 12.5%, ultimately making the process significantly more cost-efficient.

The needed time to keep the burner on was determined through trial and error, based on the measurements collected by the sensors. A software was explicitly developed to calculate and present the correlation between the temperature of the mould and the burner's runtime, which was presented in real-time, on a digital board near the machine. The quality of the output was then examined in comparison to the data presented on the board, ultimately resulting in finding the optimal runtime of the burner. Plastic manufacturing contains highly energy-intensive processes, further increasing the importance of energy optimisation in the industry.

The case presents a specific example of how data is currently being used in the plastic manufacturing industry to optimise waste reduction and the potential of making use of currently available data collection in the future, further analysed in section 5.1.

5 DISCUSSION AND ANALYSES

This chapter will analyse and discuss the empirical findings of the study. The research questions in section 1.3 provide a basis for the analyses and discussion. The analysis is reflective of the information provided in the literature review and further analysed through the answers of the interviewees. The discussions have been founded on reoccurring themes and topics observed from the research findings and opposing ideas of participants. The discussion will be the generalisation of the participant's experience-based views on the possibilities, challenges, and risks of the merging of I4.0 and LM, as well as the key success factors.

5.1 Possibilities

A reoccurring idea amongst the interviewees was the advancement of technology not being optimised to its full potential in Lean manufacturing practices. Brad Elhart, with extensive experience in both I4.0 and LM, describes a current disconnect between the concepts:

> *"I think there is a disconnect between Lean deployment and the tools that are available technologically, and that gap should be closed by bringing the Lean community up to the 21st century in terms of recognising that there are tools at their disposal that would absolutely be, not just an enhancement, but harmonious with lean deployment"*

One of the future potentials discussed by multiple interview participants was the increasing overall ability to use collected data (1, 2, 3, 5, 10). Data collection has reached a point where a significant mismatch is present between the amount of data collected and the amount of data used. Isto Sahi explains the increasing ability through an experience he had as the head of development at a manufacturing factory. He had backed the purchase of a robotic eyesight system for the factory's forklifts, with the potential future use of the data the robotic eyesight could collect. While initially the purchase only saved the company around 1000 dollars (an amount lower than the investment cost) in a year, by helping avoid one incident, two years later, the collected and stored data was used to redesign the staff planning of the factory. From the collected data, they were able to determine the number of workers needed for specific tasks. As data analyses abilities increase, a trend toward a more data-based decision-making manufacturing environment was emphasised. The same was represented by the case example in section 4.3.1.

Secondly, digitalised and automated data collection is pointed out by several participants. Words like fast, quick, instantaneous, real-time were used to describe the new possibilities in data collection. The ability of a future smart factory to collect, analyse and display data in real-time will play a significant role in the enhancement of manufacturing practices in the fast-changing manufacturing environments. Kolberg and Zühlke also support this claim in their 2015 article “Lean Automation enabled by Industry 4.0 Technologies”. The automated processes will help reduce human error and produce more accurate results than humans (1, 4, 5, 6, 10). Humans for example get increasingly tired throughout their shifts and make cognitive errors, which robots do not.

The ability to collect data in real-time also presents the opportunity of creating increasingly accurate digital simulations with predictive models of processes to enhance supply chain decision making (3). Two of the participants mentioned the possibility to reduce machine downtime with the use of predictive models by forecasting machine maintenances (3, 7). One of the participants (10) discusses the use of digital twins and performing simulation-based forecasting in a digital world being a quick and cost-efficient way of optimising throughput times, as AI technology could perform millions of trial-and-error processes in seconds. This is supported by Stojanovic and Milenovic (2018) and their idea of numerical twin simulations, as well as in Goering et al.’s paper “McKinsey & Company”, where they state that the full potential of AI in the manufacturing industry has not yet been realised, as discussed in section 2.5 of the literature review. However, this is opposed by Elhart, who says the lack of data limits the capabilities of AI to create reliable enough predictions. The lack of data resulting from the small number of transactions:

“It is difficult for me to see different AI and machine learning-type applications as there is not enough data in my view. A couple of hundred transactions a day, for example, is not enough.”

While there are future potential uses for AI and machine learning technologies in the manufacturing environment, and they are in parts already being used in building predictive models, the small number of transactions still does not allow for reliable enough forecasting in all cases. With the improvement of AI technologies, however, when human-like intelligence can be mimicked to a greater extent, digital twins could allow for more transactions to be mimicked and the accuracy of predictive models to advance. Elhart continues, stating that with some machines performing thousands of daily actions, AI-created simulations can be reliable enough for decision-making. For example, Coca-Cola produces thousands of soda cans every hour 24 hours of the week in a single production line, and AI is able to create reliable digital simulations of the production line, allowing for decisions to be made on the maintenances of specific parts of the production line.

With the automation of processes comes a transformation in the workforce and job descriptions at factories. One of the participants (4) describes the change:

“Jobs are transforming from doing to monitoring.”

While this does present a threat to a significant part of the workforce, later discussed in section 5.3, opportunities caused by this transformation were also discussed by several participants. Firstly, as people will not be required to work 5 x 8h days on one machine, but for example 3 x 4h days, they will have time to concentrate on the earlier mentioned “soft savings” (3, 4). They will have time to clean up factory spaces and maintain machines, potentially lowering future maintenance costs or increasing the health and safety of a factory. Secondly, as a result of Europe’s population getting older, the labour force in the European Union is shrinking. Automation in manufacturing could help reduce the negative effects of this phenomenon, as less labour force would be required (10). In the future, it is believed that a transformation of factory workers into robotic and software experts will take place (4).

5.2 Challenges

5.2.1 Data Illiteracy Problem

The ability to collect more accurate data quicker with digital tools has brought up new challenges on the data analyses side. All participants agreed that a lot more data could be and is being collected than is 1. being used 2. needed. The problem, described by Elhart as a “data illiteracy challenge”, has multiple levels to it, discussed by the participants. Firstly, a great deal of rich data ends up wasted due to a lack of know-how in data analyses (1). Sahi mentions that many manufacturing companies cannot make data-based decisions due to the lack of understanding of computer-generated reports. Teixeira supports this, stating:

> *“There is a lack of people capable of turning collected data into actionable insights. … The challenge is not in collecting or visualising data, which have been highly enhanced by digital tools, but knowing which data to use for optimal decision-making.”*

Another problem arising from the data-illiteracy challenge is the number of financial investments into data collecting machinery (3, 10). Teixeira discusses how companies are sold into purchasing costly digital tools that provide an excessive amount of unused data. All the company representatives mentioned the excessive collection of data and the inability to use it in their respective companies. The extreme financial investment issues were also mentioned by Sahi, stating that often the use of cheap post-it notes is a better alternative to computed data visualised on monitors, for example. Elhart states that there is a generational problem where students are not being taught proper data analyses in schools, and therefore it will take a generation or more to fix the data analyses problem on a managerial level. He describes the current state of the manufacturing industry:

> *“Technology is way out front compared to where humans are in terms of their ability to use it.”*

5.2.2 Interconnected System

Three of the seven interviewees mentioned the lack of an interconnected IT system as a challenge in integrating digital technologies in their manufacturing processes (5, 4, 10). One of the participants (4) describes the challenge through an example: in the company's factory, the syringes of their machines do not share data anywhere except monitors on the machines themselves, only allowing the employees to see the data in real-time, but not react or make decisions based on it. Today's factories consist of several separate digital tools that are not connected in a single unified system, reducing the capability to find interconnections between the parts and analyse them together. A factor affecting the interconnectivity challenge is the lack of open-source software, where companies could tailor the programs to their specific needs and connect all programs in a factory to a unified company-specific software.

5.2.3 Change Management Aspect

Thirdly, a change management aspect is always present when considering implementing new practices in a working environment. Despite the benefits that a digital transformation often brings to companies and its users, the resistance to change was brought up by four of the seven company representatives implementing Lean. Lean practices bring an aspect of increased monitoring of employee actions, which is intrusive, causing the loss of trust between managers and employees (5). As digital tools have enhanced the monitoring abilities of managers, the distrust has only grown. For example, the exact time an employee spends at a specific section of a work process is monitored, forcing constant pressure on the worker.

Other challenges brought up by individual participants were

1. Labour shortage in the IT sector, slowing down the digital transformation (8).
2. Language barrier of single-language digital systems in a multinational work environment (9).
3. The poor user experience of software (4)

5.3 Risks

Firstly, an overload of data was discussed by all interview participants, and the different possible risks of this were discussed by some. Sahi emphasises the importance of recognising the true value of data before using it. He quotes H. Thomas Johnson, saying, “Perhaps what you measure is what you get. More likely, what you measure is all you’ll get. What you don’t (or can’t) measure is lost”. He explains how throughout his experience, he has found that manufacturing companies often use too many measurement metrics rather than focusing on the ones that matter. He gives an example where a factory was using eight different metrics to measure their performance. In the end, only two, reliability of delivery and consumer satisfaction, were determined to be necessary. The overload of data and lack of data literacy can lead to a company “drowning in data” (5) and missing the critical data.

The high initial investment into data-collecting technologies ends up going to waste due to the lack of data analyses skills and/or recognition of valuable data. Teixeira claims “only 3 – 5 per cent of companies actually derive savings from this”, this being digital technologies in Lean. Especially for smaller companies with no resources to expand their IT departments and data analysis, investing in I4.0 technologies to enhance their Lean practices seems wasteful, and understanding the basics of Lean manufacturing and traditional methods should be a priority (2).

Some of the interviewees mentioned the risk of losing ownership and transparency through the implementation of digital, especially process-automating, technologies (3, 5, 7). Teixeira explains how one of the key elements of Lean was originally to create ownership and transparency over processes and how there is a risk of losing this effect through automating and therefore skipping the interactive practices of traditional Lean. Through automation and loss of ownership, there is also the risk of losing basic know-how of the factory processes, which might be useful in the case of a malfunction. For example, considering only a single worker at a factory knows the ins and outs of an automated machine that malfunctions, only this person might be able to fix and restart a whole production line. This person might not be available and therefore could stop the production completely for an extended period of time. One of the participants (7) describes the phenomena:

> *"Even though GPS devices have improved drastically, it will still be important to be able to use a traditional map."*

Through automation, most participants also agreed on the possible worker unemployment risk. The number of factory workers will drastically reduce through automated manufacturing processes, as monitoring processes are not as labour-heavy. The education requirements of employees will increase, as more employees will be needed for IT services, development, robotic engineering, etc.

Lastly, many participants mentioned cybersecurity issues, especially amongst the smaller companies that do not have the resources for separate IT and cybersecurity teams. One of the larger companies mentioned cyber security to be their number one priority when it comes to enhancing processes digitally.

5.4 Key success factors

The overall outlook on I4.0 technologies enhancing LM is positive. All participants agree that staying on the verge of technological advancement is crucial for all industries, some even ruling it to be the only way of defending one's competitiveness. Elhart sums up the attitude towards I4.0 technologies enhancing LM: *"The potential [of the combination] is leaps and bounds higher than the risk."*

One of the participants (8) describes the changing environment of the manufacturing environment by quoting the Ancient Greek philosopher Heraclitus of Ephesus, saying, *"The only constant in life is change."*

The introduction of new digital technologies in Lean practices can, however, create more problems than it solves: The third research question examines the key success factors in accomplishing a successful synergy between the two concepts. This section will discuss and analyse the results from the survey regarding these success factors.

Before properly implementing I4.0 technologies into LM, a company must establish a clear framework and understanding of the Lean principles mentioned in section 2.2. Considering the I4.0 technologies, firstly, concluded from the high number of participants bringing up the idea, most importantly, the data illiteracy problem must be considered. Understanding the unrealised potential of the data collected through digital tools is the beginning of the solution. The depth of the data illiteracy problem is explained by Elhart, who describes it as a generational problem, where most people lack a simple understanding of data analyses. He suggests that schools start teaching the basic concepts of structured data, and it be made a requirement for one to graduate high school, for example. “It will take a generation or more for these newly trained people to get to the managerial level”, Elhart states. Sahi supports this and says the success of Lean 4.0 depends on how fast we can build the skillset of the future generation to take advantage of the technologies available. Building competence on both the managerial and factory level is important, but the managerial level should be a priority because this way data-driven decision-making could be increased. Elhart also suggests the idea of educating people with the technical skills on the basics of Lean and bringing them over to the manufacturing environment, stating:

> *“It would be easier to teach someone with technical skills the Lean fundamentals than to take someone well routed in Lean and teach them the technical skills.”*

To keep the control and transparency of Lean manufacturing processes, digital tools should be kept interactive. Teixeira states, “the best digital tools are those that require the team to engage and interact.” He describes interactive touchscreen monitors that can mimic traditional Lean methods and practices as an example. This is supported by Sahi, who emphasises the importance of more traditional and manual Lean practices, restoring the ownership of processes originally created by Lean.

The interconnectivity of digital systems in a manufacturing company should be increased. The friction created by noncompatible digital systems was brought up by multiple participants, demonstrating the need for a more unified digital system. One of the participants (5) introduced the idea of a digital system that did not require open source and was able to read and sort data from multiple sources. This sort of software could then be adapted according to a company's specific digital tools and needs. Bringing a factory’s, currently separated, digital systems together into one unified system would bring us closer to a smart factory of the future.

Transformation should not be forced just to implement Lean or Industry 4.0 but rather to bring increased value to the customer through better quality, faster delivery, and affordability. Companies forcefully implement and combine I4.0 and LM without recognizing the problems they are solving beforehand. The focus should be shifted, bringing value to the end-users, and realising problems before solving them. Concentrating on the smaller, simpler, and lower-risk improvements should be emphasised over larger, costlier enhancement ideas. This reflects the concept of CI discussed in the literature review. It is crucial to have a clear vision and a roadmap a solution to an existing problem before investing in new costly technologies.

6 CONCLUSION

This section presents a summary of the research findings and answers to the research questions, the implication of the study to international business, the limitations of the research and suggestions for further research on the topic.

6.1 Main Findings

For clarity, the main findings of the research will be presented according to the research questions.

R1: *What is the current state of understanding Lean in the manufacturing industry?*
In the last decade, Lean manufacturing has seen a transformation from the automobile industry to all industries, and Lean methodologies have been tailored to the specific needs of these industries. From the answers of the company representatives, it was clear that a unified understanding of the concept was however missing. Only a few interviewees understood Lean as a philosophy, while most only implemented a set of Lean manufacturing tools. This presented a basic understanding of sections of Lean, but a deeper understanding of the Lean philosophy is still missing in the manufacturing

industry. This was also backed by the panel of experienced individuals, who all agreed on the lack of understanding of the true meaning of Lean amongst the manufacturing and other industries.

R2: *What is the current state and future potential of Lean Manufacturing enhanced by Industry 4.0?*
The current state of LM enhanced by I4.0 was researched in three categories; collection, visualisation, and usage of data. The collection of data has increased in quantity, quality and efficiency. Digital sensors have allowed for faster and more accurate data collection than ever before. This collected data can then be visualised and used in real-time, allowing for enhanced data-based decision-making. Digital tools have also allowed for the recognition of interdependencies amongst various occurrences in a factory. The increased data collection has also allowed software to build predictive models, although the reliability of these models is under debate. Additionally, the ability to transfer this data through IoT has greatly enhanced the connection between spread-out factories and offices of individual companies.

As for the future potential of Industry 4.0 enhancing Lean Manufacturing, four main topics were found. First, the increasing overall ability to make use of collected data will lead to more data-based decision-making at a managerial level. Secondly, the amount of human errors will keep reducing through computer aid and replacements. Thirdly, the use of digital twins will increase, as technology gets more accurate and affordable. Predictive models will enhance to be more reliable and will become a more integrated part of manufacturing. Lastly, the overall working conditions of the manufacturing environment will likely keep increasing.

R3: *What are the key success factors in accomplishing a synergy of Lean manufacturing and Industry 4.0?*
Five key factors for a successful implementation of I4.0 and LM were discovered from the interviews. First and foremost, before a proper implementation of I4.0 technologies, a company must have a clear understanding of the basic LM framework and principles. Secondly, a higher level of competence in data literacy needs to be established, in order to identify valuable data and make use of it. Thirdly, digital practices need to be kept interactive to preserve the ownership of processes. Also,

digital systems in a manufacturing establishment should be interconnected and work in a unified system rather than as separate units. Lastly, the use of either LM or I4.0 should not be forced, but rather implemented to solve an identified problem.

6.2 Implications for International Business

Although most of the primary data of this research were collected from Finnish companies and their representatives, all of the companies interviewed operate on an international business level, so the findings can adequately be implemented internationally. Understanding the benefits I4.0 could bring to Lean practices in manufacturing companies, and the key factors contributing to the success of the implementation is highly beneficial for the international manufacturing environment as a whole.

The importance of staying on the cutting edge of technology arouse multiple times throughout the research. As the world's markets are becoming increasingly global in every industry, including the manufacturing industry, for a company to stay competitive, it is crucial to gain an understanding of the transformations happening. The Lean philosophy and the ideology of the Toyota Motor Corporation's managerial approach and production system have taken over the manufacturing industry to where almost all manufacturing companies practice the methods to varying extents. Through the fourth industrial revolution, the use of digital technologies has also become increasingly common, and the benefits and potential of these two concepts intersecting harmoniously, have slowly been realized. Taking advantage of the combination will become progressively important in the international manufacturing environment.

6.3 Limitations of Research

It is important to note that limitations to the research conducted exist and are hereby presented. First, the number of interviewees would optimally have been larger than 11, as more participants would have resulted in more data, resulting in more reliable results. Also, the nationality of most of the participants was Finnish, meaning the results could be more biased and representative of the Finnish manufacturing environment.

The use of Lean consultants as the panel of experienced individuals also creates a risk of bias. The job of a consultant is to sell their expertise, so a business advertising aspect could have been present in the answers of the consultants, creating extra bias.

One limitation is also the broadness of the overall exploratory study. The area of interest of the research was very broad, thus only briefly touching upon general points on the topic. A narrower study could have resulted in more detailed results.

6.4 Suggestions for Further Research

Due to the broad nature of both concepts, LM and I4.0, discussed in this thesis, merely the surface of the opportunities, challenges and risks of the combination has been touched. Future research should aim to reach a deeper level of understanding specific aspects of the combination. Some examples of this could be the change management aspect of implementing digital technologies in a manufacturing environment, the successful implementation process of combining industry 4.0 and Lean Manufacturing, or process improvement by subtraction in manufacturing, using digital tools.

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APPENDICES

Appendix 1: Interview questions for manufacturing company representatives

1. Who are you and what is your position in your company?
2. Does your company practice Lean methods in your manufacturing processes?
   If no, are you familiar with any?
      If no – ok.
      If yes, why has your company not implemented any?

   If yes, how?
3. Have you upgraded these methods since you began practising them?
   If no – why not?
   If yes - how?
4. Did you do this on your own or did you hire a professional to help with the implementation process?
5. To what extent are Industry 4.0 technologies being used to enhance the Lean practices?
   With what success?
6. More specifically, how have industry 4.0 technologies enhanced data collection, visualisation, and usage in your manufacturing processes?
7. Are you able to measure the benefits of Lean practices? How?
8. Has the use of technology brought challenges/risks with it to the lean practices?
9. How do you see the future of Lean manufacturing and Industry 4.0 (potential and risks)?

Appendix 2: Interview questions for experienced individuals

1. Who are you and what is your relationship to Lean?
2. How commonly do you see manufacturing companies practising Lean in their processes?
3. How have you seen Lean manufacturing develop in the past years?
4. Are you able to measure the benefits of Lean practices? How?

5. To what extent are Industry 4.0 technologies being used to enhance the Lean practices?
   With what success?

6. More specifically, how have industry 4.0 technologies enhanced data collection, visualisation, and usage in your manufacturing processes?

7. Has the use of technology brought challenges/risks with it to the lean practices?

8. How do you see the future of Lean manufacturing and Industry 4.0 (potential and risks)?