LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY
School of Engineering Science

Benefits of simulation for Finnish manufacturing companies

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Master's Thesis

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ABSTRACT

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Simulation technologies have been around for decades, yet they have not been fully embraced by the Finnish manufacturing sector. The recent advances in the technology sector have made it possible to utilize simulation methods in your business activities in a more comprehensive and cheaper way than before. Generally, it's acknowledged that there are benefits in using simulation methods but identifying the exact benefits as well as the issues that come with the technology is a challenge.

Interviews with the case companies as well as a Delphi analysis were chosen as the research methods of the study. The case companies for the interviews were chosen in such a way that their relative size as well as goals of the DigiPro-project were similar. The Delphi analysis used a wider pool of participants from each of the participant companies of the project. It consisted of four individual rounds and after each round the results were summarized and provided to the participant experts.

The results would indicate that despite there being significant costs and hindrances when it comes to adopting simulation technologies as part of your business activities, the overall benefits outweigh these. Now, most of the benefits seem to focus around product development. The key resource in terms of costs and opportunity would seem to be the person utilizing the simulation models within the company.

TIIVISTELMÄ

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Simulaatiota on käytetty jo vuosikymmeniä, mutta sitä ei ole täysin implementoitu suomalaisessa valmistusteollisuudessa. Viime vuosien edistykset teknologioiden saralla ovat mahdollistaneet simulaatiomallinnuksen käytön yritysprosesseissa kokonaisvaltaisemmin ja halvemmalla kuin aiemmin. Yleisesti ottaen simulaation hyödyllisyys on tunnistettu, mutta sen kautta saatavat konkreettiset hyödyt ja käytön haasteet ovat vaikeasti tunnistettavissa.

Työn empiirinen osio toteutettiin kohdeyritysten teemahaastatteluina ja Delphi analyysillä. Haastatteluihin valitut yritykset valittiin siten että yrityksen koko ja projektin tavoite olisivat mahdollisimman samanlaiset. Teemahaastattelut valittujen tärkeiden osa-alueiden ympäriltä suoritettiin yhdessä yritysten edustajien kanssa. Kaikki haastattelut nauhoitettiin ja litteroitiin. Delphi analyysissä oli mukana laajempi osa projektiin osallistuvista henkilöistä ja yrityksistä. Kyseinen analyysi koostui neljästä kierroksesta ja se edusti muokattua versiota klassisesta Delphi analyysistä.

Vaikka simulaation hyödyntäminen on hyvin resurssi-intensiivistä ja matkalla on paljon hidastavia tekijöitä niin kokonaisuutena hyödyt näyttäisivät olevan haittoja suuremmat. Tällä hetkellä hyödyt painottuvat suuresti tuotekehityksen eri osa-alueisiin. Tärkeimpänä resurssina simulaation maksimaaliseen hyödyntämiseen on henkilö, joka osaa käyttää kyseistä teknologiaa.

PREFACE

This thesis is part of Digital Product Processes through Physics Based Real-Time Simulation project (DigiPro). It's a multi-disciplinary project conducted by Lappeenranta-Lahti University of Technology. The key aim of the project is to provide Finnish manufacturing companies new opportunities through providing them with the needed techniques and toolsets in relation to simulator-driven design and manufacturing. The focus will be on increasing the effectiveness, customer value and business potential of each individual process. The project aims to divert the focus of product and service development from technical aspects towards enhancing the user experience.

In my opinion the overall project was an interesting one. The study had some ups and downs but generally it went exceedingly smoothly. The best part of the study was the chance to interview the company representatives and gain some in-depth knowledge on the subject.

I would like to thank my supervisors, associate professors Lea Hannola and Kalle Elfvengren for the guidance along the project. Also, the cooperation of the case companies who were willing to share their stories and insights was appreciated.

Lappeenranta, 11.06.2019
Ville Kalliola

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LIST OF SYMBOLS AND ABBREVIATIONS

R&D = Research and Development

ICT = Information and Communications Technology

IT = Information Technology

DigiPro = Digital Product Processes through Physics-based Real-time Simulation

1 INTRODUCTION

Following the financial crisis, innovation has become even more crucial in order to produce new opportunities for growth. Through innovation you can create the groundwork for new businesses as well as increase productivity of existing processes thus driving economic growth (OECD 2015, p. 2). As we live in the age of digitalization, concepts such as Digital Twin and simulation are at the forefront of innovation.

As digitalization has become a more and more present trend across all industries, companies have started multiple initiatives to research digital technologies and find ways to take advantage of them (Belian et al. 2015). Despite this, for a long time, manufacturing industry was one of the industries that was slow to adopt a full-scale digital transformation perspective (i-SCOOP 2016). Adaptation to the emergence of these new technologies is imperative as Europe's manufacturing industry has not been that successful recently, but it still has a major role in most aspects of the economy (Berger 2014). The primary issue wasn't the shortage of products or ideas but the inability to be efficient enough in the design and production processes. Nowadays solutions derived from computing such as simulations are one of the cheapest and easily accessible resource within the industry, thanks to the improvements in digital technology (Overton and Brigham 2016). This change from the old manufacturing towards this new manufacturing is called Industry 4.0 and it's about utilizing simulation related technologies to meet the demand, innovating and increasing the overall efficiency of your business processes (Veugelers 2017, p. 13).

The accessibility of simulation related technologies as well as the changing customer needs has also had an impact on the Finnish manufacturing sector. The ability to exploit current technologies has been recognized as the key to success. Not only do companies have to adopt completely new technologies but they also must find a way to use them to develop their business strategies (Schmidt et al. 2015). The nature of how technological innovations affect industries is causing additional pressure when it comes to exploiting these new innovations. Refusing to adapt to a change may result in being left behind by your competitors in any given business sector. (Deloitte 2015) Due to the accessibility of these new technologies the information connectivity within manufacturing processes has

changed drastically from the traditional view of having an operator that acts as the information carrier towards horizontal and vertical connectivity amongst networked equipment. This change has been highlighted in Figure 1. (Kusiak 2018)

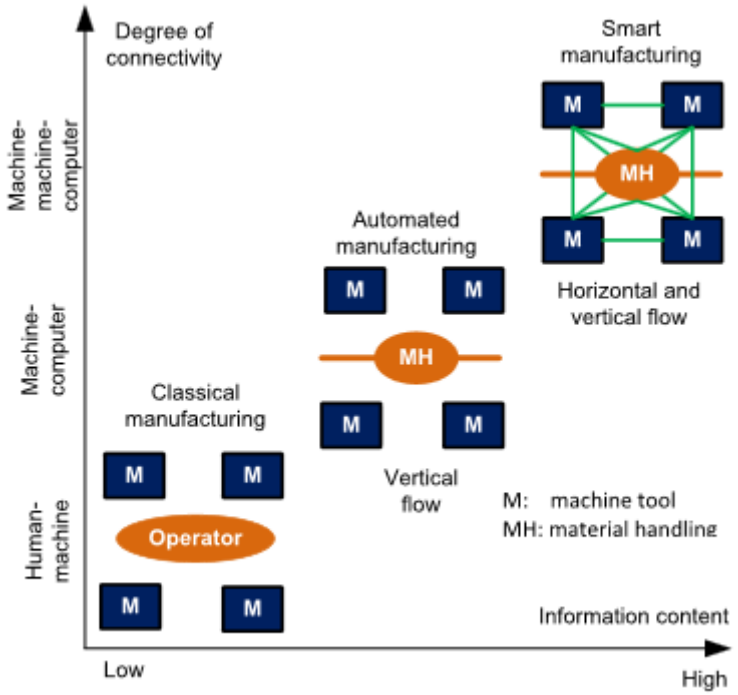

Figure 1. Information Connectivity within manufacturing sector (Kusiak 2018, p. 2)

To further highlight the importance that simulation technologies have, Table 1 showcases projects that are aiming to utilize simulation to achieve benefits that can be transferred to business activities. Each of the projects listed are part of the European Union's Horizon 2020 (H2020) program that aims to secure Europe's global competitiveness. The listed projects are all still on-going, but through European Commission's the Community Research and Development Information Service (CORDIS) database you can find multiple projects that have already finished and researched the use and benefits of simulation technologies. This wide-scale interest to conduct study on the subject matter proves that the importance of simulation related technologies has been recognized and that there is interest in finding new ways to exploit it.

Table 1. On-going H2020 Projects related to utilization of simulation

Project name	Abbreviation	Start	End	Project type	Focus
Simulation in Real Time for Manufacturing with Zero Defects	STREAM-0D	01.10.2016	31.03.2020	Innovation action	Real-time simulation
Digital Reality in Zero Defect Manufacturing	QU4LITY	01.01.2019	31.03.2022	Innovation action	Factory of The Future
Integrated Development 4.0	iDev40	01.05.2018	30.04.2021	Innovation action	Collaborative design and manufacturing

Appendix 1 showcases 14 different projects, both finished and on-going, that are part of the H2020 initiative and are trying to exploit simulation-related technologies. The consortium in charge of these projects usually consists of:

- IT companies
- Academic or private research and technology organizations
- Companies from different industrial sectors

The industrial companies are the ones aiming to utilize simulation technology in their day to day business operations such as design and manufacturing of products. The IT companies are the ones supplying the platform in which the simulations are conducted while simultaneously searching for ways to improve the system. The responsibility of academic organization, such as universities, and private research and technology organizations is to provide both theoretical and technical support regarding the subject matter at hand. This shows that the potential benefits of simulation and all the related technologies span over multiple different industries while requiring the expertise from different fields to be utilized efficiently.

1.1 Research questions

The focus of the study is to research the digital transformation of Finnish manufacturing firms. The goal is to learn what kind of benefits do the manufacturing firms gain by adopting simulation technologies to drive manufacturing process and product innovations. The research will study what are the driving forces pushing for the utilization

these new technologies and what are the economic impacts of using them. The companies involved in the study can also lack a critical resource, be it know-how or finances, needed to get the full benefit from using things like Digital Twin and Simulation. So, one goal is also to identify and explore what kinds of resources are required for firms to be able to exploit these new innovations with maximum effect.

The main research question is:

> *What kind of benefits can Finnish manufacturing firms gain by utilizing simulation-related technologies?*

This question is further explored by the following sub-questions:

> *What kind of resources do firms need to fully exploit these technologies?*
>
> *What are the forces driving and resisting the utilization of new technologies?*

These questions are answered by conducting case studies and a Delphi method survey on the firms within the Finnish manufacturing industry that are part of the DigiPro-project. To get the most current and exact answers to the research questions, only firms that are operating within the manufacturing industry are included in this study. Further introduction to the chosen firms and the methods used for sampling will be done in chapter 3.

1.2 Structure

The thesis is split into four chapters that are theoretical background, research methodology, results and analysis and conclusions. The chapter about theoretical background will focus on concepts that are of high importance in terms of the project: Simulation, Digital Twin and Industry 4.0. A short technical explanation of these terms will be given but the focus will be on finding out what kind of benefits can be achieved

through the utilization of these technologies. On top of this the forces driving and resisting the utilization process will be identified.

The third chapter focuses on the methodology used to conduct the research needed for the empirical part of the study. It will outline the core research strategy and the reasoning behind why that type of strategy was chosen. After this the sample formation is shortly examined and the case companies are briefly discussed. The chapter ends by choosing the methods for data collection and analysis while providing a reasoning behind each chosen method.

The empirical findings of this study as well as their analysis will be showcased in chapter four. The chapter is structured by dividing it into four different subchapters, three of which are the major themes of the multiple case study interviews: Impact of simulation now and in the future, challenges and resources. The results of the conducted interviews will then be analyzed and connected to the existing literature for discussion purposes. The final subchapter is dedicated to the Delphi analysis and the findings gathered through the four rounds of surveys.

The final chapter of the study will present the conclusions. The answers to research questions will be discussed, followed by the potential contributions to academic discussion and managerial implications. Limitations as well as the potential for future research is discussed at the end of the chapter.

2 THEORETICAL BACKGROUND

The literature review part of this study will define the technical aspects of simulation, Digital Twin and Industry 4.0 (Figure 2) but will put more emphasis on the business activity benefits and opportunities they can provide when exploited. The topics will be discussed at a general level but when possible, more focus will be on the manufacturing industry as that is the core of this thesis. The potential problems that exist in the way of utilizing these concepts will be discussed.

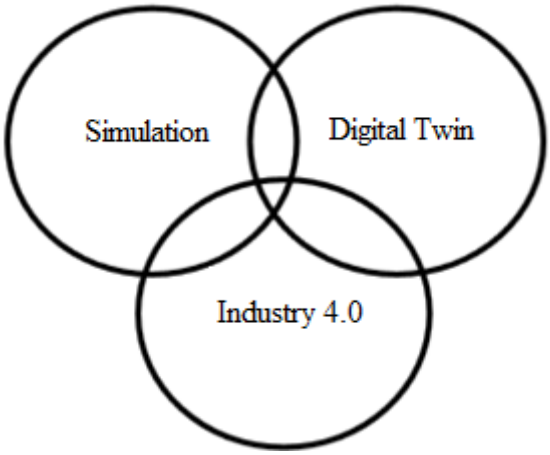

Figure 2. The key concepts of the literature review

2.1 Simulation

Law (2015, p. 5) divided the term simulation into two different concepts: dynamic simulation and static simulation. The difference between these two concepts is how they interact with time. Static simulation focuses on a certain point in time while dynamic simulation is a process that progresses through time. For the purposes of this study, dynamic simulation will be the point of focus. Stewart (2014, p. 5) further defined the meaning of dynamic simulation into: “Experimentation with a simplified imitation of an operations system as it progresses through time, for the purpose of better understanding and/or improving that system”. Dynamic simulation is further divided into continuous and discrete depending on at what point in time changes are occurring in the simulation (Mourtzis et al. 2014).

Utilizing a dynamic simulation is key if you are trying to benefit from using this technology. Static simulation doesn't allow the introduction of changes into it. Thus, if you are aiming at simulating a real physical system, then dynamic simulation is the much more beneficial way to do it. Dynamic simulation provides a much more accurate representation of a real system especially when you examine it over a long period of time. (Seleim et al. 2012) Bako and Bozek (2016) highlighted what kind of relationship and interaction simulation has with the real world (Figure 3).

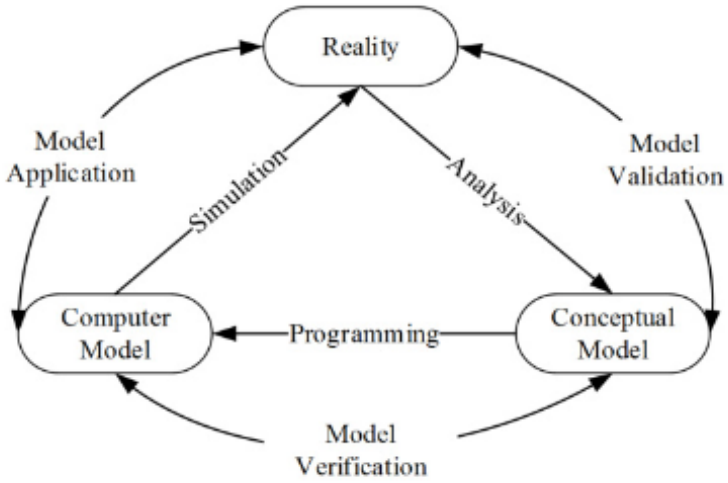

Figure 3. Interaction of simulation and reality (Bako & Bozek 2016, p. 572)

During recent decades the art of simulation has evolved itself from being a purely a tool for experts and mathematicians to be an all-around technique used in in a variety of different areas. This increase in the number of users has contributed to the improvement of simulation technology and today it's the most fundamental tool when decisions are made on design, validation and testing for both components and complete products. (Boschert & Rosen 2016, p. 60)

Some of the fields that utilize simulation are healthcare, marketing, supply chain, military and manufacturing. Especially within the manufacturing industry simulation holds a crucial role since it plays a part in improving the design and performance of entire systems and products (Negahban & Smith 2013). Chryssolouris (2006, p. 2) defined manufacturing as the process of transforming resources into goods needed by the

consumers. Keeping this definition in mind and by examining the real-world applications of simulation within the manufacturing industry (Figure 4) the central role simulation possesses becomes exceedingly clear.

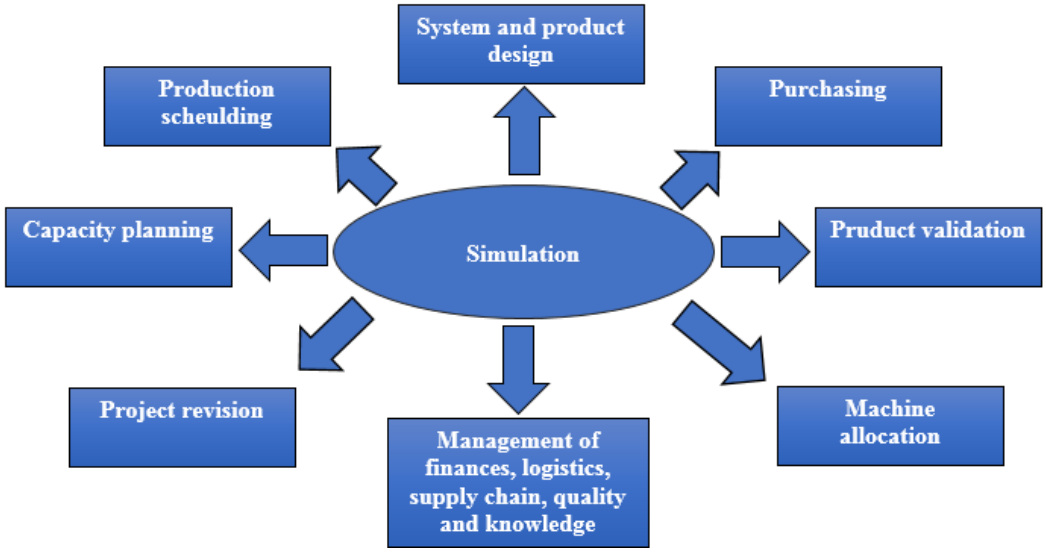

Figure 4. Simulation applications within manufacturing industry (Adaption of Jahangirian et al. 2009; Hosseinpour 2009; Williams 2015)

As pointed out, the uses of simulation cover a fairly wide scope, thus making it and extremely important tool for manufacturing firms to use in order to maximize the potential of their business processes. The manufacturing industry is highly saturated, and companies are aiming at generating new innovative products and push them out to market as fast as possible. As we are moving more towards decentralized production and automation, this tool will become even more crucial. (Mourtzis 2014) A Saturated industry naturally leads to high level of competition in which you need to secure your existence within the industry through being as competitive as possible. The needed competitiveness can be achieved through optimizing the design of systems while keeping these systems up-to-date and efficient through regular improvements (Klingstam & Gullander 1999).

2.1.1 Methods of simulation

Barbosa and Azevedo (2017) identified three major categories of simulation that have been used. These are:

- System Dynamics (SD)
- Discrete Event Simulation (DES)
- Agent Based Simulation (ABS)

The concept System Dynamics was developed in the 1950s by Jay Forrester. This type of simulation was mostly utilized in supply chains, but it was further expanded into multitude of different fields such as economics, innovation, management, markets and software development. This method performs well in strategic planning within firms. (Barbosa & Azevedo 2017) The downside of System Dynamics is that the method assumes that production is continuous and is unable to take discrete events into account. Trying to utilize this method within industries such as electronics and consumer goods will result in decreased accuracy and model behavior changes. (Jovanoski et al. 2012)

Discrete Event Simulation is a somewhat all-around simulation method. Overall, it's the most used method within the manufacturing industry due to its macroscopic viewpoint and ability to evaluate planning, routing and scheduling. (Barbosa & Azevedo 2017) DES models shine when it comes to modeling production, but it has major issues when it comes to something bigger, such as an entire enterprise. Also, the functionality of DES is questionable when it comes to making decisions at small time increments (Dubiel & Tsimhoni 2006).

Agent Based Simulation is the most modern form of the simulation methods. It can be defined as *"a modern computational simulation method that enables researchers to build, analyze and investigate models consisting of autonomous agents that interact with each other within an environment"*. (Ali et al. 2018, p. 128) The agent that this method is attempting to simulate is defined as an autonomous intelligent entity. The core idea of ABS is to provide a reasonable solution to the issues other methods are unable to resolve

and this is the main driving factor of why the method has gained popularity (Railsback et al. 2006). Common areas of usage for ABS are business areas such as manufacturing and maintenance. This method of simulation requires large amounts of data thus the evolution of computational power as well as increase in available databases has been exceedingly crucial for ABS to work well. (Barbosa & Azevedo 2017) ABS also has its uses when it comes to simulating in real time as it's also able to simulate the interaction of people within an environment at a more accurate level than the other methods (Dubiel & Tsimhoni 2006).

As pointed out different models can complement each other. Whereas SD shines in modeling large scale enterprises the strengths of DES are in focusing to an aspect such as production. Due to this reason some companies use SD for strategic planning and DES for their production planning (Jovanoski et al. 2012). The fact that the different models are complementing each other has led researchers into investigating the potential of hybrid models that are utilizing more than one model to compensate for the individual deficits of each model. Dubiel and Tsimhoni (2005) experimented with combining ABS into DES. They found out that by combining these two methods the resulting hybrid model would be able to simulate aspects that neither model was able to simulate on their own. Jovanoski et al. (2012) had a similar approach but they aimed at making a hybrid model combining SD and DES. They concluded that despite the generation of a hybrid model requiring a lot of work it would be worth it in the end. The need to make quick and accurate decisions within the manufacturing industry was noted and the authors believed that hybrid simulation was a step towards the right direction. Barbosa and Azevedo (2017) noted in their review of hybrid simulation it's a good alternative when you are examining complex environments especially within the manufacturing sector. Figure 5 showcases how they imagined the interaction of two different methods within a hybrid simulation. The authors also came to the same conclusion as Jovanoski et al. (2012) that generating a hybrid model is difficult, but the potential benefits make it worth the effort.

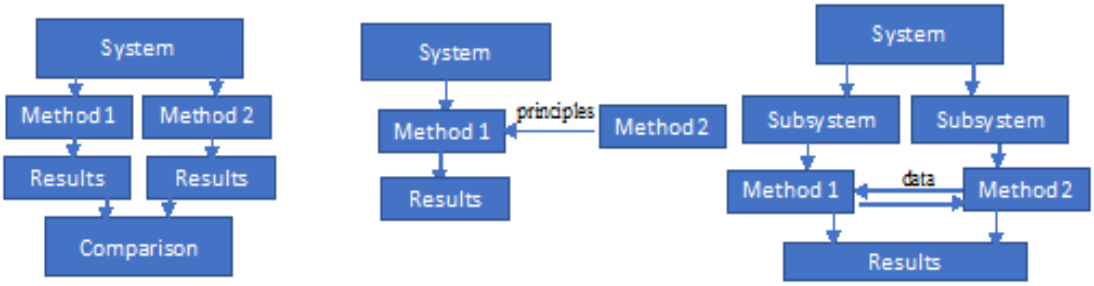

Figure 5. Interaction of simulation methods used in a hybrid simulation (Adaptation of Barbosa & Azevedo 2017, p. 1407)

2.1.2 Real-time simulation

Real-time simulation is form of dynamic simulation that basically means when you input something you can generate an output immediately without a delay. The rudimentary real-time system consists of sensors, machinery and a software that operates between them (Figure 6). Selic and Ward (1996) identified multiple issues that must be solved to be able to use real-time simulation properly. The found issues were:

- Concurrency
- Nondeterministic behavior
- Process dynamics

Concurrency in computer sciences, and in simulation, means the ability to process multiple tasks at the same time which essentially makes the system more efficient. Successfully completing multiple tasks simultaneously without a delay will help in optimizing the use of shared resources. Nondeterministic behavior means that predicting what and how some things in the future are going to happen is extremely hard to do reliably. Building a fully deterministic system is increasingly difficult and even when it's done you must be ready for the unexpected – such as system malfunctions. Process dynamics refers to the environmental burden a system must be able to cope with. The environmental burden can manifest itself as a one-time stress peak. (Selic & Ward 1996)

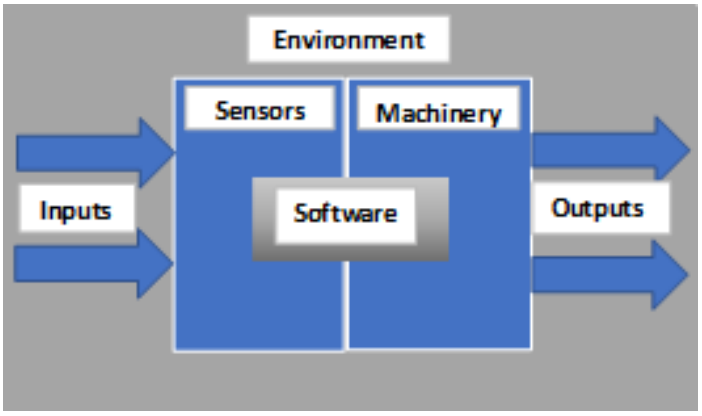

Figure 6. Basic real-time system (Adaptation of Korpipää 1998, p. 10)

Dufour and Bélanger (2002) concluded that due to complexity, budget and time constraints. of modern engineering projects real-time simulation is a crucial tool for both industry as well as researchers. Modern systems will keep getting more complex as time passes, thus there is a need for fast, flexible and scalable real-time simulators. (Bélanger et al. 2010)

2.1.3 Benefits and limitations of simulation

Simulations done by computers is seen as a crucial tool for manufacturing firms especially in terms of optimizing the system design. Yet, so far, the usage of this tool has been somewhat limited due to the complexity of manufacturing systems and the expertise required to utilize it in an efficient manner. (Benedettini & Tjahjono 2008) Most of the benefits of simulation are centered around a product's Beginning-Of-Life (BOL) and Middle-Of-Life (MOL) phases of the product's lifecycle. Despite being an important phase, End-Of-Life phase, has been mostly ignored regardless of it having a major cost-saving potential in terms of decommissioning and providing the earlier phases with crucial information in terms of improving performance and design. (Polenghi et al. 2018)

As we keep getting more technological advancements, we have moved away from experimenting with a physical system in favor of simulating something on a computer. Law (2015, p. 4) points out that in cases where it's cost-efficient to do experiments on a physical product it might be preferable to do it. The reason for this is, that by doing the

experiment on the actual system you know that the results are valid. Quite often simulation models tend need a lot of data which might not be ready when needed and when it is, a significant amount of analysis might be needed to prepare it for the simulation (Stewart 2014). A Study performed by Integrated Manufacturing Technology Initiative (2000) shows that well developed tools have the potential to not only increase the speed of production but cut down the absurdly high amount of resources required for the traditional testing, evaluating and modifying a physical prototype (Figure 7) to move from concept design to product delivery.

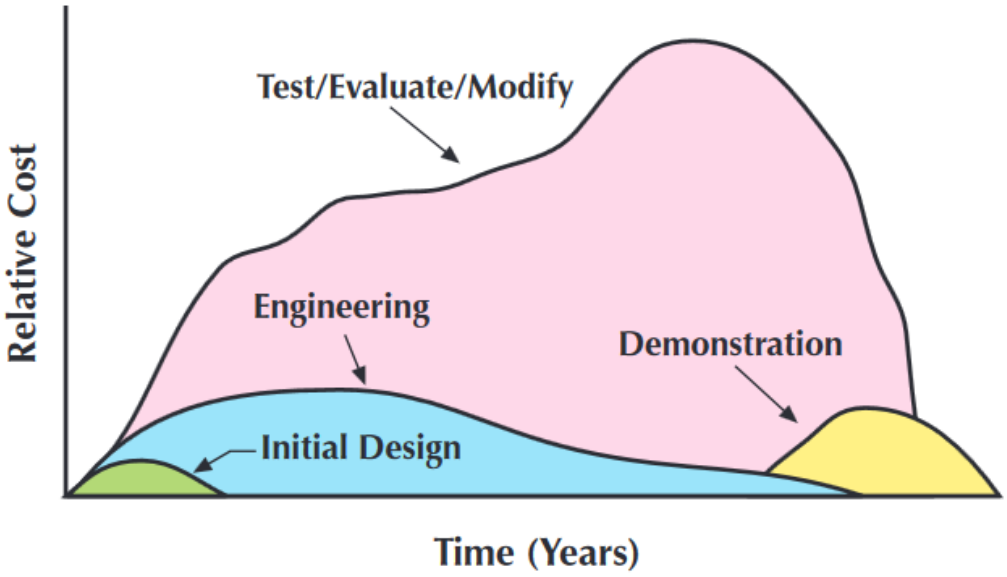

Figure 7. Physical prototyping consumes massive amounts of resources (IMTI 2000, p. 19)

So, simulating a system can be an alternative without the massive resource investment required for machine prototypes, but the required level of detail can be hard to determine (Klingstam & Gullander 1999, p. 175). Stewart (2014) also points out the notion that utilizing a simulation model properly can require different kind of expertise than is required when using a physical prototype. Table 2 shows the potential benefits a simulation can provided when compared to a physical model or a cruder mathematical model while also highlighting the potential managerial benefits. (Heilala 1999)

Table 2. Simulation benefits over physical model or mathematical model (Heilala 1999)

Benefits over a physical prototype	Benefits over a mathematical model
• Costs • Repeatability • Control over time base • Legality • Safety	• Dynamic • Transient effects • Non-Standard distributions • Interaction of random events

Key benefit within the manufacturing industry is time-to-market. The emphasis is on minimizing the time required for a product to move from design concept into a product on the market. Figure 8 highlights how through the utilization of simulation you are able to stack the different development phases in order to save time. Simulation technologies are the key factor in reducing the amount of time needed for a product to enter a market through production simulation and virtual manufacturing tools. Heilala (1999) noted that not only is simulation able to reduce the time-to-market, but it also speeds up the production ramp-up because operators are able to get introduced to the new system before anything physical is installed. Products can be made from multiple different components, all manufactured in different factories and possible even countries. Utilizing simulation technologies can make managing this wide scale system in an efficient manner in order to match the customer's needs more closely. (Heilala 1999)

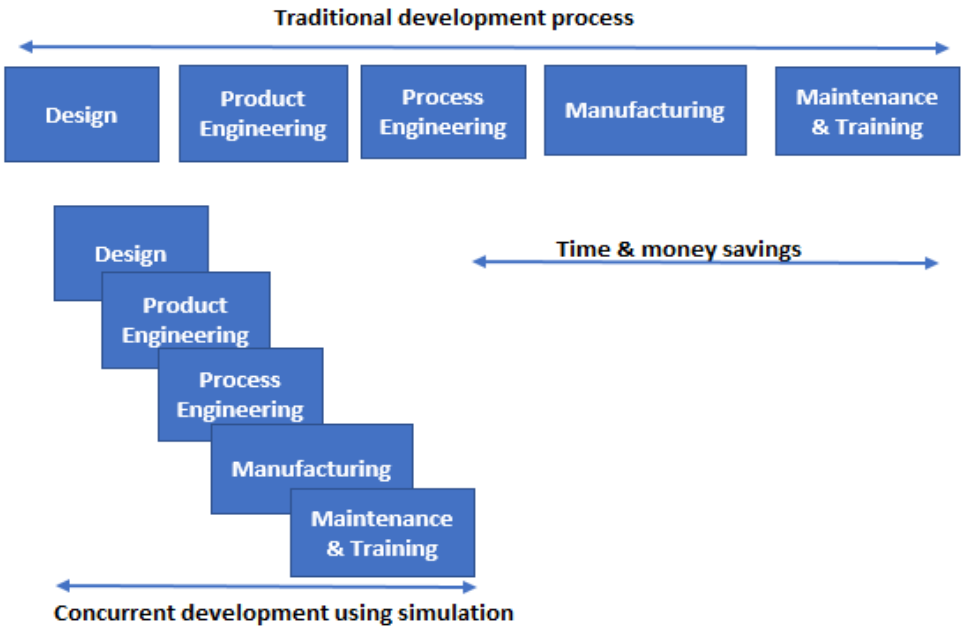

Figure 8. The impact of simulation on product design steps (Adaptation of Heilala 1999, p. 2)

Maintenance is a key aspect of the manufacturing industry as once the product has been made, maintenance makes sure the system keeps operating at agreed upon level in terms of reliability and safety (Mourtzis et al. 2014). Literature often assumes that machines are constantly working which is not the case as they can break down or have maintenance operations that require them to be shut down. These kind of manufacturing issues cause several problems in multiple different areas of business as they tend to lead to issues regarding human safety, the environment, reliability of industrial processes and decision making. Thus, it's no wonder that tackling this issue is of high importance in order to reduce downtimes as well as the overall maintenance-related costs (Bousdekis et al 2017). Jahangirian et al. (2010) recognize the potential of using simulation as a tool to support maintenance operations as it can execute multiple different functions such as maintenance, production and inventory control simultaneously (Negahban & Smith 2013). Bako and Božek (2016) also recognized the potential of using simulation as a support tool for production planning. By using it correctly it's possible to reveal problems that have gone unnoticed giving the production planner ample time to make the necessary fixes before performing any actual actions. They concluded that simulation technologies are crucial when you want to enhance the production operations and reduce the number of apparent bottlenecks within the system. This kind of pre-emptive maintenance and process control through simulation can be further improved on when done in conjunction with a virtual representation of a physical product – a Digital Twin. Feeding the Digital Twin data from the physical product you can analyze and diagnose unforeseen situations and predict how the product will operate. (Kher 2017)

On top of the cost-reduction potential simulation offer, Seleim et al. (2012) also noted that there are immense benefits of utilizing simulation technology as a supportive tool in decision making. The proper use of simulation provides benefits in terms of visualization, understanding and analyzation the functionality of the manufacturing system which in turn benefit the overall decision making. This kind of managerial benefits were also noted by Heilala (1999) as he pointed out how utilization of a simulation model can increase creativity, promote complete solutions and improve the communication.

Nowadays most of the simulation models in use are Visual Interactive Simulations (VIS) in which you are given a visual display that shows the model and you are able to interact with it. (Stewart 2014, p. 49). As such the user-experience of the person who is using the model becomes increasingly important. The term gamification means the use of game like elements in non-game situations. When it comes to generating a more enjoyable and immersive user experience it is an extremely efficient tool. (Baldwin 2015)

2.2 What is a Digital Twin?

The definition for Digital Twin differs depending on which source you are using (Table 3) but the overall idea behind the concept stays mostly the same: Digital Twin is an identical virtual representation of a physical product. These twins should also be connected in a way that allows them to communicate and transfer data. Boschert & Rosen (2016) identify Digital Twin as the next major wave in simulation technology.

Table 3. Digital Twin definitions from existing literature

Author	Definition
Grieves, M. (2014, p. 1)	*"Virtual representation of what has been produced"*
Dongming, Z. et al. (2017, p. 1)	*"Digital twin is an integrated multi-physics, multi-scale, and probabilistic simulation of a complex product and uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding twin"*
Glaessgen & Stargel (2012, p. 13)	*"A Digital Twin is an integrated metaphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin"*
Boschert & Rosel (2016, p. 59)	*"Very realistic model of the current state of the process"*
Tao, F. (2017, p. 4)	*"Digital twin is a real mapping of all components in the product life cycle using physical data, virtual data and interaction data between them"*

The concept of Digital Twin has been around for a while as it was first introduced in 2003 at University of Michigan Executive Course on Product Lifecycle Management. At this time the idea of having a digital model of a physical product was still in its early stages (Grieves 2014). Thanks to the advances in innovation and information technologies the concept of Digital Twin has been on the rise recently (Alaei et al. 2018).

Most of the research done on Digital Twin focuses on the technical aspects of this technology and less on broader scope on how it could be used. When it comes to studying the impact of Digital Twin on the business models and operations of a company we don't know that much (Kindstrom & Kowalkowski 2015). Boschert and Rosen (2016) researched simulation related technologies and noted that there are four significant changes, or "waves" in the utilization of simulation technology of which the Digital Twin is the fourth wave (Figure 9).

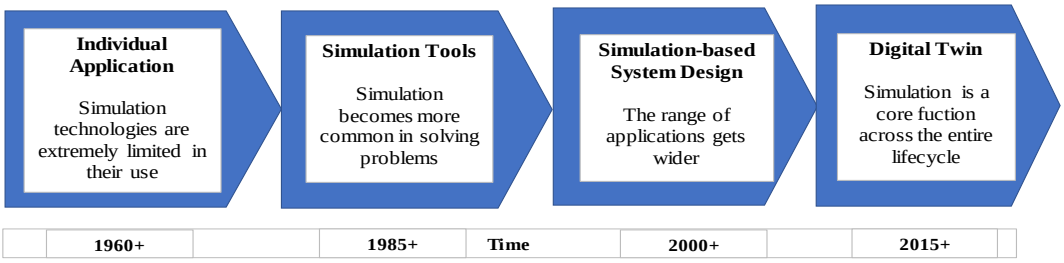

Figure 9. The four waves of simulation technology (Adaptation of Boschert & Rosen 2016, p. 61)

The basic architecture of a Digital Twin in a manufacturing process is highlighted in Figure 10. The figure showcases the loop of information from physical to digital and back to physical again. The figure showcases the five key components that act as enablers: Sensors and actuators, integration, data, analytics and the Digital Twin model. The figure shows just one possible Digital Twin configuration that points out the integrated, holistic and iterative quality of the model.

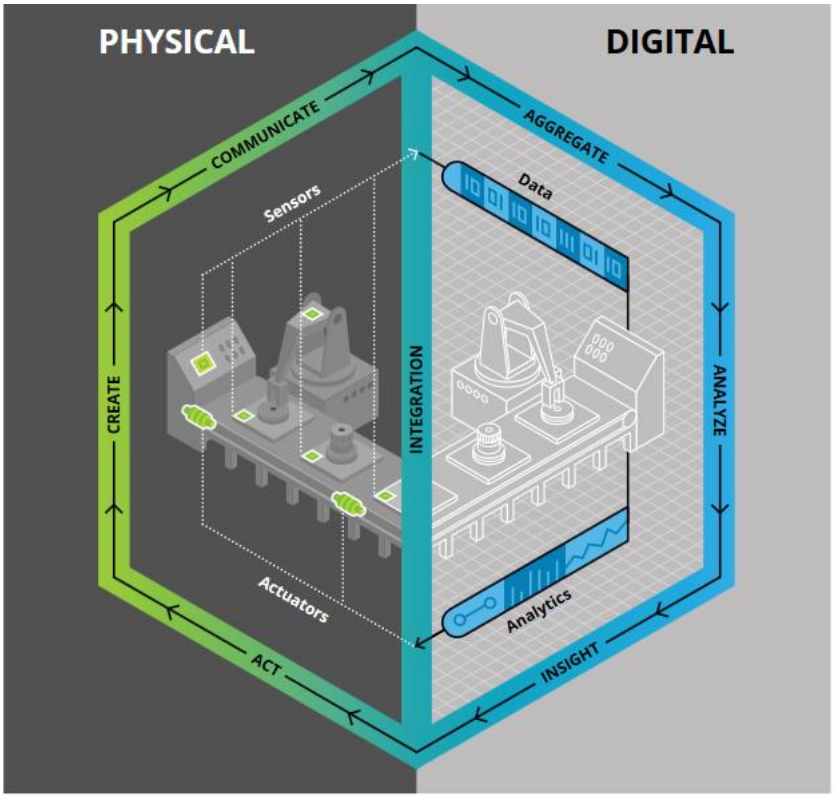

Figure 10. Digital twin model of a manufacturing process (Parrott & Warshaw 2017, p. 5)

2.2.1 Utilizing Digital Twin in product's life cycle

Product lifecycle management (PLM) can be defined as efficient management of all the product processes across the entire lifecycle of each product from cradle to grave (Stark 2005). Utilizing Digital Twin properly provides the business huge potential opportunities but exploiting this technology can be both risky and difficult (Goasduff 2018). Digital transformation in the manufacturing industry can help firms reach new levels of productivity and the catalyst for this change is the Digital Twin. By utilizing the twin it's possible to extend the benefits of simulation across later life cycle phases as a basic functionality on a product or a system. This potential is what makes Digital Twin a core technology when it comes to industrial applications. (Boschert & Rosen 2016) However despite the recognized potential benefits for the exploitation of Digital Twin within the context of PLM there are still noticeable gaps in research in regard to virtual models and their impact on the product lifecycle (Fei 2017, p. 1).

There are three different lifecycle phases: Beginning-of-Life (BOL), Middle-Of-Life (MOL) and End-Of-Life (EOL). Each of these phases has its own set of activities that are showcased in Figure 11 (Hribernik et al. 2011; Stark 2005, p. 2). Through simulation, analytics and machine learning Digital Twins can have an impact across the entire lifecycle by demonstrating the effect of design changes and usage-scenarios, eliminating the dependency on physical prototypes, reducing time-to-market and improving the quality of the final product. (Siemens, 2019)

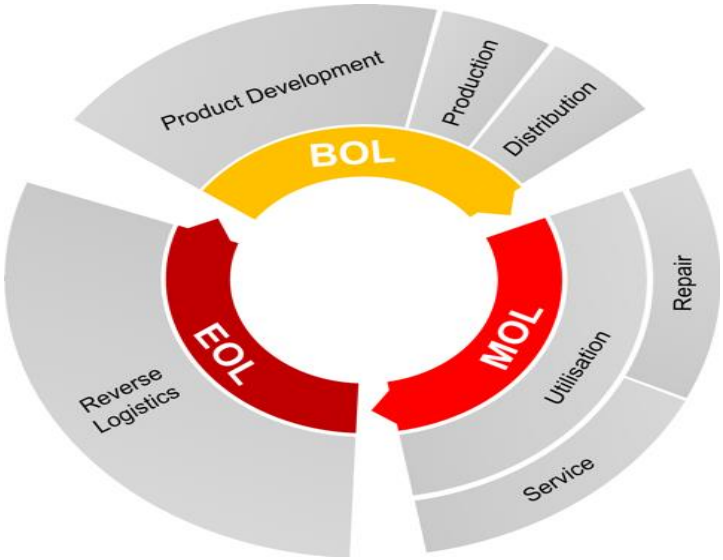

Figure 11. Product Lifecycle Phases (Hribernik et al. 2011, p. 487)

Through Internet-of-Things, the Digital Twin can interact with its physical world counterpart while simultaneously taking advantage of machine learning in order to be as efficient as possible (Donoghue et al. 2018). This interaction between virtual and physical worlds makes it possible to generate and improve data and information through all three lifecycle phases.

The Beginning-of-Life is the first phase of a products lifecycle consists of development, production and distribution. The core function of this phase is to generate the concept of a product and to physically manifest it. (Terzi et al. 2010) Looking at the potential impacts a Digital Twin can have at this phase of a product's lifecycle the first area of interest is the product development. At the start of this phase the physical product doesn't exist yet,

but the system can start taking shape in virtual space. In the past the development cycle would have been centered around a costly physical prototype. (Grieves & Vickers 2017)

Digital Twin also brings benefits when you want to validate the product concept. The functionality of the product has to be validated multiple times during product development in all subsequent phases. Virtual model can mimic the current state of the development and as it progresses, the virtual image grows. (Boschert & Rosen 2016) Traditionally you would also need vast amounts of experience and professional knowledge in order to complete a multitude of different tests to validate the functionality of the product (Tao et al. 2017). By utilizing the digital environment, you are able to pool together knowledge from experts of various fields by having them work on the same digital twin. Using a digital twin at the development phase also makes it possible to start testing the product early in order to find out the potential problems (Aalto n.d.). This type of testing is faster, and the digital aspect also makes it possible to involve the end customer in the designing process in order to reach the best possible outcome right away (Hiljanen 2017). This enables the testing and validation through trial and error, something that would not be viable with a physical prototype but can easily be achieved through the use of a Digital Twin (LNS Research 2018).

Thus, product development through Digital Twin results in improved time-to-market (Boschert & Rosen 2016), better overall efficiency and quality and higher level of customer involvement and commitment (Donoghue et al. 2018). Lappalainen (2018) also identifies the importance of customer involvement at the development phase. He notes that by involving the customer in the development process early on, the end user is able to learn how to use the product before the actual physical asset is finished. This way the implementation process of the new product is much faster as the customer already knows how to use it. The overall uses of Digital Twin in the development or design phase of a product are showcased in Figure 12.

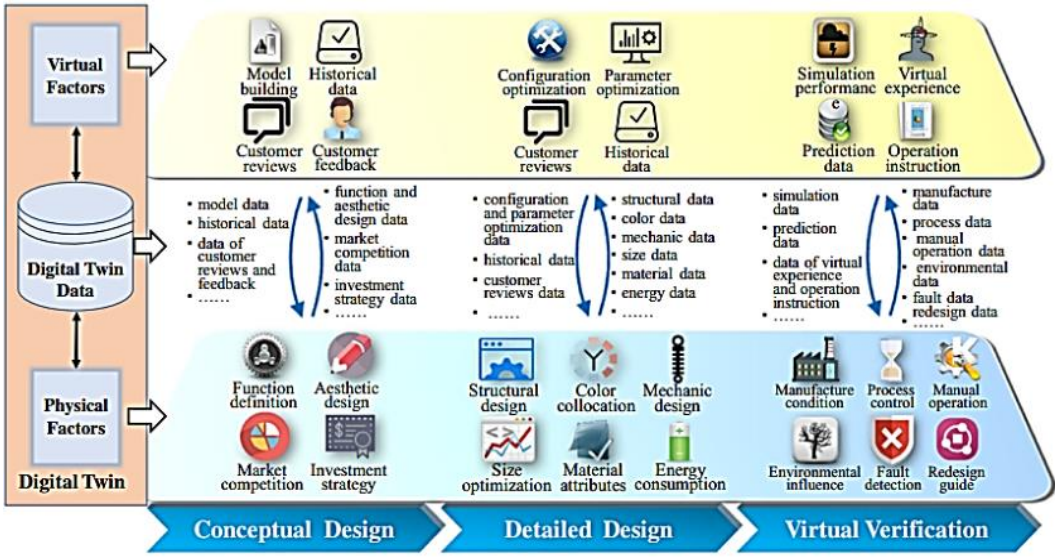

Figure 12. Digital Twin in development phase of a product (Tao et al. 2017 p. 3568)

The feedback loop in which you transfer information from later stages of a products lifecycle towards the earlier stages is of importance throughout the entire lifecycle but especially here, at the beginning. The finished and delivered products are still able to provide information regarding maintenance, usage and decommissioning which are incredibly relevant during the BOL-phase of the product's lifecycle (Rios et al. 2015, p 660). Normally this type of feedback loop isn't possible since it's interrupted after the customer receives the product (Kiritsis 2011, p. 481), but the interaction between Digital Twin and the physical product the reverse information flow can be maintained and benefits such as increased competitiveness and a more sustainable product are able to be realized. Figure 13 summarizes the feedback loop that is enabled through a Digital Twin.

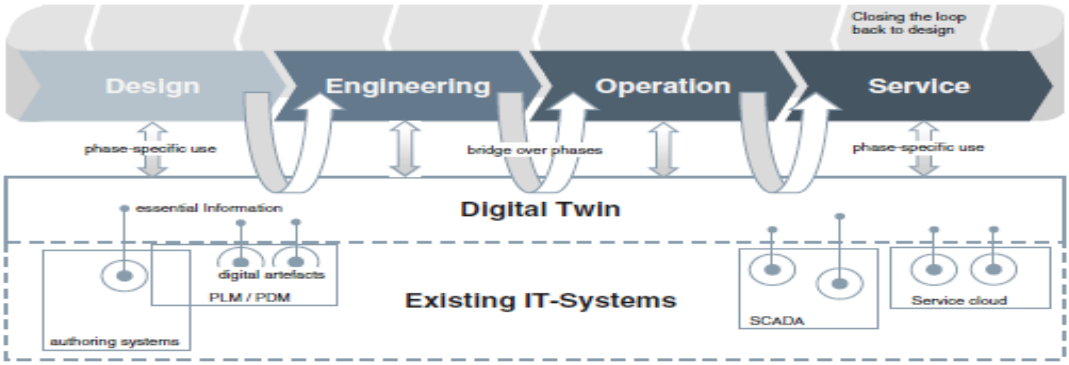

Figure 13. Feedback loop across product's lifecycle (Boschert & Rosen 2016, p. 67)

The Middle-of-Life phase consists of the use, service and repairs of the product (Hribernik et al. 2011). In the past, the idea of providing value during the use of a product might have sounded odd since companies mostly sold only products. Nowadays companies are moving towards service business where they not only provide a physical product but also some sort of service on top of it (Kube 2016).

Parris (2016) also showcases how Digital Twin can not only predict malfunctions but also provide potential solutions to the users in his presentation on Digital Twin technology. In the video Parris interacts with a Digital Twin of a wind turbine. He asks the twin to identify a potential problem, highlight the impact it will have on its functionality and provide potential solutions. The twin then provides solutions it has derived from the data it had access to. This kind of predictive maintenance and product management can be achieved through the use of Digital Twin (i-SCOOP 2017). Not only do Digital Twins have the potential to detect potential threats and provide solutions to them but they also provide maintenance crews the possibility of examining the situation before actually arriving at the site of the physical product. This makes it possible to fix multiple different machines simultaneously and at a faster rate as the problem can be identified remotely. (Standish 2018) During the MOL phase of a products life cycle, a lot of data from different sources is generated and it can be used for the benefit of maintenance, but the gained feedback can be transferred to the BOL phase in order to improve the product design (Tao et al. 2017).

The End-of-Life is the phase at which product has reached the end of its functional life. Depending on the product it could be recycled or disposed. (Terzi et al. 2010) The EOL phase of product life cycle has not been given the same amount of attention the rest of the phases. However, with Digital Twin you are still able to gain certain benefits here. The digital model provides help when you want to safely decommission larger products such as ships for example. A product's lifecycle might be long, but through the use of Digital Twin you are able to simulate potential ways of how to disassemble, recycle and remanufacture a product to create more sustainable business processes (Wilson & Compton 2018). Also, despite the physical product being disposed of, the Digital Twin

can be retained for as a source of information for further projects. (DNV-GL 2017; Danish Maritime Authority 2018)

Table 4 shows the summarization of the benefits Digital Twin can provide at the different stages of the product's lifecycle according to literature. Most of the benefits are focused around the BOL phase, especially in the product development section. The MOL phase benefits are mostly achieved through technological innovation and the potential for servitization that can be achieved through the use of Digital Twin. The EOL phase benefits consist of the closed feedback-loop and the potential to store and analyze past data.

Table 4. Summarization of Digital Twin's impact at different points of Product Lifecycle according to existing literature

<table>
<tr><th></th><th>Beginning-of-Life</th><th>Middle-of-Life</th><th>End-of-Life</th></tr>
<tr><td rowspan="6">Impact of Digital Twin</td><td colspan="3">Closed Feedback-Loop</td></tr>
<tr><td>Faster time-to-market</td><td colspan="2">More sustainable product</td></tr>
<tr><td>Higher Customer involvement</td><td rowspan="3">Services</td><td>Retain the Digital Twin for further use</td></tr>
<tr><td>Cheaper and more efficient testing and validation</td><td rowspan="2">Use the Digital Twin for reutilization</td></tr>
<tr><td>Less reliance on physical prototypes</td></tr>
</table>

2.2.2 Challenges

As stated in the previous chapter, there are multiple different benefits to be gained from implementing a product design process that works around a simulation model or a Digital Twin. This kind of model-centric design process does come with different challenges and issues that must be considered. Issues that you may encounter when trying to utilize the Digital Twin concept can be divided into:

- Organizational siloing
- Technological and computational deficiencies
- Lack of conceptual basis
- Required resources

Grieves and Vickers (2017) are of the mindset that the biggest issue standing in the way of properly utilizing Digital Twin is organizational siloing. Organizations are fragmented entities divided into multiple different areas with each having their own function such as design, engineering, manufacturing and support. Each of these areas has access to information the others might not have but this doesn't mean they are sharing it between themselves. For Digital Twin to function properly it requires information from all sources.

Digital Twin is an exceedingly large-scale concept there can be multiple Digital Twins that differ in terms of nature and the varying integration levels. This sets some technological demands on what is needed for the implementation of this technology. For example, simulation methods such as Discrete Event Simulation are required. Other key enabling technologies include: Internet of Things, Cloud Computing and Big Data. (Kritzinger et al. 2018) The computational deficiency refers to the fact that not only does there need to be a software tool that can execute tasks in parallel and in real-time, but you also need the required computational power to handle the massive number of tasks (West & Blackburn 2017; Grieves & Vickers 2017).

Sleich et al. (2017) recognized the lack of conceptual basis in the approaches used to implement Digital Twin. According to the authors this causes certain applicability issues in the implementation process which in turn leads to problems when trying to construct an integrated Digital Twin of a physical product. They generated a reference model for future uses that included the key aspects Digital Twin needs to have: Synchronization with physical space, scalability, expansibility and fidelity (Tao et al. 2017).

Implementation of Digital Twin also requires multiple different resources. The costs of constructing a functional Digital Twin and implementing it to your business operations varies on the complexity of the model and implementation level. A significant amount of know-how is also required from the part of the employees producing the codes for the simulation and actually running the model. This type of expertise can only be attained through deep learning on the subject (West & Blackburn 2017; Tao et al. 2017)

2.3 Industry 4.0 – Industrial Internet of Things

Industrial Internet of things (IIoT) and Industry 4.0 have slight geographical and representational differences, but the terms are close enough to be considered interchangeable. The key difference is that IIoT mostly describes the technical aspects, but Industry 4.0 takes the economic impact into consideration. (Jeschke et al. 2017, p. 3; Weallans 2018) For the purposes of this thesis the terms are considered as one and the same and will be discussed under the term Industry 4.0

The term Industry 4.0 was first introduced by Kagermann (2015) and he explained it was the next continuation in the series of industrial revolutions (Table 5), following the exploitation of automation through electronics and information technology. He also identified that utilizing Internet of Things (IoT) and Internet of Services (IoS), along with technologies such as cloud computing and simulation act as the enablers that made the concept of Industry 4.0 possible. Vaidya et al. (2018) found that Smart Manufacturing and Cloud based Manufacturing are also key concepts for Industry 4.0. These are the most crucial technologies that are required for Industry 4.0 and there are still multiple others that are required in order to get the most out of it. All of the enabling technologies for Industry 4.0 are highlighted in figure 14 (Petrillo et al. 2018).

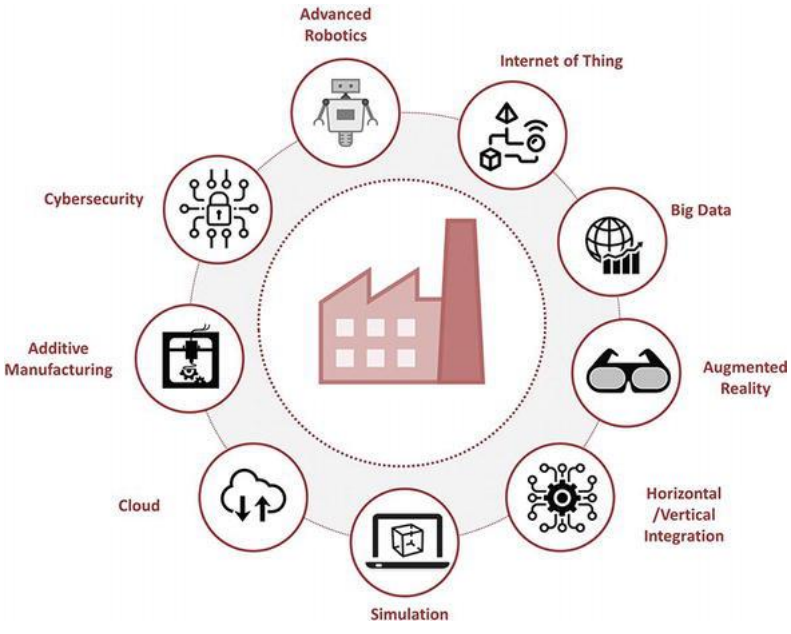

Figure 14. Industry 4.0 enabling technologies (Petrillo et al. 2018, p. 9)

The fourth industrial revolution sparked interest for two different reasons. First, this is the only time we have been able to predict an industrial revolution beforehand instead of realizing it has happened after the fact. Second, as the new revolution promises significantly increased effectiveness across all operations and the potential to form entirely new venues of profit through new and better business models, services and products. (Hermann & Otto 2015)

Table 5. Definitions of industry revolutions (Deloitte 2015)

1st revolution	Utilization of steam and waterpower in production
2nd revolution	Mass production through electrical energy
3rd revolution	Automation through electronics and information technology
4th revolution	Industry 4.0 – merging of real and virtual worlds through cyber physical systems

IoT makes it possible for physical products or components to interact with their virtual, or smart, components in order to reach benefits (Hermann & Otto 2015). As a concept it has vast potential as it can change business processes through multiple different industries when utilized correctly. When used properly IoT can produce benefits even in the most rudimentary industries such as farming (Krotov 2017). Saarikko et al. (2015) estimated that by the year 2020 the number of devices connected to the IoT will reach 50 billion. This amount of devices connected will create a massive market for IoT products and services and the potential value will be immense.

The primary function of the IoS is the ability to use it to interact with consumers through the internet. Basically, it's a combination of people, infrastructure, business models and services (Hermann & Otto 2015). Through the utilization of IoS within the Industry 4.0 manufacturers can examine and rework their business models in order to maximize the profit gained from a product by increasing the length of its revenue stream. A good example of this is the business model of Tesla where the company provides the product, a car, with both software and hardware which are upgradable. As the software is continuously being further developed the consumer can upgrade it and gain additional benefits. The upgrade is then delivered via the internet and thus enabling Tesla to gather extra revenue. (Geldhof 2017)

This combination of technologies is an incremental step towards the concept of smart manufacturing (Fei et al. 2018; Schmidt et al. 2015, p. 16). The main idea behind this new concept is the exploitation of the incorporated technologies in order to produce growth (Kang et al. 2016). In order to fully realize the benefits of this new revolution, a constant interaction between the physical and digital worlds is required (Baur 2015). The technical aspect of Industry 4.0 in manufacturing is called Cyber-Physical System (CPS) and more specifically in terms of manufacturing it's Cyber-Physical Production System (CPPS), or more commonly a smart factory. (Landherr et al. 2016) Petrillo et al. (2018) summarized the functionality of CPS into five key levels:

- Smart connection: The ability to manage and acquire data in real-time
- Data-to-information conversion: Transforming data into value-added information
- Digital Twin: Representing real time in a virtual world
- Cognition: Identify scenarios and support decision making
- Configuration: Gathers feedback on physical world from the virtual reality and applies corrective actions to the previous level

Utilizing the smart factory is a crucial element of Industry 4.0. This factory is a context-aware entity that can interact with workers and machinery and assist them in completing tasks. This kind of contribution and interaction is achieved by receiving data from both the physical and the virtual environments. So basically, a smart factory is a factory that monitors the physical environment, utilizes IoT to communicate with people and machines and can create a digital copy of the examined physical environment in order to make effective decisions. (Hermann & Otto 2015)

Cloud based manufacturing is something that is becoming a mainstream function for organizations. It helps companies to move towards more digital product processes and become more agile, scalable and efficient by replacing the old-fashioned manufacturing business models. The cloud-based manufacturing process offers a natural and simple solution as companies are moving towards a more service-oriented business model. (Xu 2012) One of the main reasons of utilizing cloud-based manufacturing are the IT costs savings it provides. The key difference to the past is that this cloud service operates in a

pay-per-usage way. So, you basically only pay for what you use which makes it a scalable and flexible option for manufacturers. The technology used in cloud-based manufacturing also presents many other benefits such as improved information sharing through which you can achieve better collaboration, compliance and competitiveness. This improved information flow will assist decision-making, product development, customization and quality control. (Serenic 2018)

United Nations Industrial Development Organization (2015) recognized the importance of Industry 4.0's ability to generate value and new business models while highlighting that the key ability required from a company to adopt Industry 4.0 successfully is their adaptability. They also noted that this is a characteristic that can be developed through constant innovation management. Gilchrist (2016) agrees with the statement that adaptability is the key as he notes that in order to adopt a strategy involving Industry 4.0, companies will have to drastically change their business operations in every area. He identified three crucial assets (Table 6) when moving towards a major digital transformation such as Industry 4.0

Table 6. Key assets of digital transformation (Gilchrist 2006)

Customer experience	Operational process	Business model transformation
• Know the customer • Customer contact points	• Process digitization • Worker mobility • Performance management	• Digitally modified business • Automation • Smart technologies • Workforce transformation

2.3.1 Benefits and opportunities of Industry 4.0

The potential of Industry 4.0 is unquestionable but there are some worries that are causing companies to question whether it's wise to adopt it now. As it tends to be with most new trends there is always a certain presence of hype and excitement around an innovation which makes companies worried that if they focus on these new technologies too early, they will end up committing massive mistakes. On the other hand, waiting too long might reduce the potential advantages that could be achieved (Schmidt et al. 2015, p. 17). Despite this lingering uncertainty, Berger (2014) sees the potential impacts as mostly

positive across all aspects. According to Karre et al. (2017) by understanding the different aspects of Industry 4.0, companies are able to adjust their strategies accordingly.

Increased efficiency across both equipment as well as resources is a direct result of utilizing Industry 4.0. The production process and resource utilization will be optimized which will in turn lead to improved productivity and lower amount of manufacturing failures and waste. The increased degree of automation will in turn enable much leaner production processes as well as the potential to eliminate certain manual activities. (Kiel et al. 2017)

Integrating production processes with the technological aspects of Industry 4.0 will lead to lower costs in terms of unit price, operation costs and personnel expenses (Kiel et al. 2017). The implementation process does take a somewhat substantial investment, but this high entry fee is well worth it as the costs will eventually plummet. The ability to handle a complex mix of systems and processes seamlessly also works towards the goal of lowering costs. (Almada-Lobo 2017)

Business models can also be upgraded towards a more service-oriented one. Traditionally the business models within manufacturing industry are focused solely around generating and assembling products that they sell in order to generate profit. The required infrastructure of machines, materials and personnel end up being an extremely high fixed cost. By adding services to their products, they would be able to reduce this cost or at least increase the overall revenue gained from the product. This way the amount of value creating activities can be expanded through different kinds of product/service solutions. Value generated through services would help the manufacturing firms to compete on other areas except solely on manufacturing costs – leading to enhanced competitiveness. The result of this kind of business model approach would lead to the generation of product service system (PSS). The end goal is to connect multiple stakeholder groups into a networked ecosystem. (Ibarra et al. 2018) The more service-oriented business model will of course lead to being able to respond to customer needs in a better way which opens up a way to target bigger markets (Almada-Lobo 2017; Thoben et al. 2016).

Through Industry 4.0 the cooperation between machines and humans will improve. The reduction of manual labor will lead to increased quality of the product. The systems are able to receive and analyze data in real-time which makes spotting errors more efficient. The used data is stored in a cloud which makes it readily available which leads to increased flexibility when you are required to make changes whether they are expected or unexpected. (Rüßmann et al. 2015) Industry 4.0 workers are able to provide real-time feedback about the production processes through a smart handheld device such as a phone or tablet. The person acting as the manager is also able to use these smart devices to better allocate labor resources where they are needed. This simplifies the coordination and management of the employees and helps the management sector to evaluate workers and notice key motivational factors. As the end result, workers are able to realize their full potential and, in a sense, become flexible problem solvers that are able to support the overall production process as well as management decisions. (Sanders et al. 2016)

2.3.2 Implementation challenges

Despite being almost universally coined as a positive influence in terms of providing multiple different benefits within the manufacturing industry there are some problems that need to be overcome in order to implement Industry 4.0. In this chapter these issues are highlighted, and the possible solutions found in the literature are pointed out.

Industry 4.0 leads to further automation in terms of exceedingly repetitive and easy tasks are, more often than not, executed by machines. This automation and connectivity of all functions requires that the systems within Industry 4.0 are becoming extremely complex. These changes lead to a shift in terms of what kind of skills and knowledge are required from the workforce (Karre et al. 2017). The long-term impact of this needs to be examined by the companies so they are able to adapt through recruiting and training. (Rüßmann et al. 2015)

As companies move from management and production systems that are not connected towards Industry 4.0 where most aspects exist in a network the concept of cybersecurity becomes a problem. Through smart manufacturing and cloud-based manufacturing there

will be high amounts of detailed manufacturing data available for analysis purposes. This presents a massive risk as by gaining access to this data, the competition would be able to reverse-engineer your product and thus gain significant advances in the knowledge department. There is a need to protect all the critical systems and activities within a company. More secure and reliable communications can be attained through cooperation with companies that are cybersecurity experts. The availability of data in the cloud also presents the opportunity of sharing it with a company from a different market segment through cooperation. (Rüßmann et al. 2015; Thoben et al. 2016; Petrillo et al. 2018)

The required investment to get started is one of the issues of Industry 4.0 – though only for smaller companies that need to reap the benefits much faster than larger ones. It's extremely hard to accurately calculate the so-called break-even-point, a point in your business processes when your technology investment becomes profitable. The inability to predict the return on investment is a hindrance companies have to overcome. Cooperation is a good way to overcome this challenge surrounding resources. Especially for smaller companies it's wise to divide the costs in order to mitigate the investment issue. (Thoeben et al. 2016, p. 13; Petrillo et al. 2018, p. 10)

3 METHODOLOGY

The methodology of the empirical part of the thesis is explained in this chapter. It starts by introducing and discussing the research strategy chosen for the study, followed by the selection and introduction of the case companies involved. The chapter ends by explaining the process of data collection and analysis.

3.1 Research strategy

This research is exploratory in nature as the goal of the study is to find out the benefits of using ICT-enabled functions in the business activities of the firms operating within the manufacturing industry as well as generating information on the resources needed to exploit these technologies. The subject matter is not entirely new but due to how quickly advances in technology happen, the flexible approach of explorative research is particularly useful as the study focuses on the present as well as seeks future insights. (Saunders et al. 2009, p. 139; Adams & Scvaneveldt 1991)

There are multiple ways to conduct academic research on this study. The first choice is to identify whether the study will be utilizing qualitative or quantitative methods. Identifying the goals of the research is the key factor when it comes to selecting a research strategy. Quantitative focuses on molding the data into a form that can be statistically analyzed and tested in order to reach the wanted conclusions (Hirsijärvi et Al. 2009, p. 140). Ghauri, Grønhaug and Kristianslund (1995, p. 84) describe qualitative research as a process-oriented method with holistic perspective and emphasis on understanding.

Yin (2009, p. 63) and Ghauri (1995, p. 84) identify the potential in mixed method designs that utilize both quantitative and qualitative research methods. Bryman and Bell (2011) noted that this mixed-method way of conducting business research has been increasing in popularity during recent years and further elaborated on its ability to fill the gaps left by either quantitative method or qualitative method when used alone.

Thus, this thesis will utilize the mixed-method design and combine the quantitative and qualitative research methods through:

- Qualitative research: Multiple Case Study
- Quantitative research: Delphi Method

3.2 Multiple case study

The qualitative research part of the study was conducted as a multiple case study as there are many manufacturing companies cooperating in the DigiPro project, of which this thesis is a part of. Also, this was seen as the best way to find solutions to the main research question of the study. Case studies are excellent when you are working with something that is hard to quantify or study outside its natural habitat (Ghauri and Grønhaug 2005, p. 114). In a multiple case study, you use a replication strategy in which you observe the same phenomenon but from multiple different perspectives in order to find patterns and emerging themes (Santos & Eisenhardt 2011). This form of doing research also makes it possible to generalize the results more easily (Saunders et al. 2009, pp. 146-147).

In this study the multiple case variation was chosen over the single one due to the fact that we are able to look at the goal of this study, benefits of simulation technology, from the perspective of multiple companies who all work within the manufacturing industry. It's highly unlikely that every single result would occur by utilizing a single case method.

The multiple case study of this thesis will be performed through interviews with the case companies. A purposive sampling method was used because it enabled the possibility to choose the companies that best fit the aim of this study (Saunders et al 2009, p. 237), thus eliminating firms that are from the wrong industry or don't possess the same characteristics as the selected firms. The companies were chosen through the following requirements: A Finnish manufacturing company that is part of the DigiPro-project and is aiming to make a simulation model or a digital twin of their product that they can utilize in their business activities. Moreover, the companies selected are expected to be reasonably close to each other in terms of revenue and employee amount. Table 7 shows

the Finnish manufacturing companies that are part of the DigiPro-project and highlights the companies accepted for this thesis in green and the rejected companies in red. The revenue amounts are from the year 2017 while the employee count is based on the most recent number provided by the company. The names of the companies have been removed and replaced with an assigned letter between A and H. Companies A and G are way bigger than the rest of the firms in terms of both revenue and employee amount while having a project goal that also differs from the rest by quite a bit – thus, they are excluded from the interview part of this thesis. Rest of the manufacturing firms share an acceptably close revenue and employee amounts while having similar aims. By utilizing the purposive sampling method, we were able to find a homogeneous group amongst all the companies in order to gather the optimal group of case companies that are used for the multiple case study.

Table 7. Companies taking part in the DigiPro-project

Company	Revenue (million €, 2017)	Employees	Project goal
A	8940	57000	Using virtual sensors in development
B	70	500	Simulation model
C	43	260	Parametric model
D	96	918	Simulation model
E	114	700	Digital Twin
F	19	130	Simulation model
G	949	12200	Adjustable rock pile
H	181	772	Simulation model

In the chosen companies, showcased in green on Table 7, the goal was to interview the core individual or individuals related to the company and their aim of utilizing the simulation-related technologies. All the interviews were conducted using Skype. Interviews were conducted within the time period of 19.03.2019 – 01.04.2019.

3.3 Delphi method

The quantitative research part of the empirical section of this study will be conducted through a Delphi method. The Delphi method was first introduced by Dalkey and Helmer (1963) and it was used as a tool to build scenarios through the help of several experts of the subject. It's a variation of a survey that makes group communication processes more effective by allowing the individuals to tackle the issues as a group (Turoff & Linstone 2002; Renzi & Freitas 2015). The key focus of Delphi method is real-world issues, which the technique attempts to solve through the aforementioned cooperation of experts.

The Delphi method revolves around the idea that when a group of informed individuals come together and pool their ideas and expertise together, they can provide a more accurate prediction of the future than could be achieved through theoretical methods (Gupta 1996, p. 186). In this method there are multiple rounds of questionnaires used in a row while providing the participants a summary of their collective opinions in between each round. These questionnaires are replied to anonymously and this kind of repetitive process with the absence of peer pressure is believed to direct the group towards the best possible response. (Grobbelaar 2007, p.1)

The method suits situations where there is a limited amount or no existing literature on the subject matter (Gupta 1996, p. 187). The Delphi method can be further divided into two subcategories of classical and modified. The classical Delphi method attempts to gather ideas from a group of experts and then find a consensus amongst them. Human judgement is seen as a working input to forecasts and the analysis of a group is seen as more valid than that of a single individual (Börjeson et al. 2006). The modified Delphi process has similarities to the classical one in terms of having multiple rounds of questionnaires and the goal is still the same – to arrive at a concensus. The key difference is that in a modified Delphi you may begin the process with a more carefully selected set of items. The reason for this is to increase the response rate for the first Delphi questionnaire round and tie the study into existing literature. (Custer et al. 1999) As part of a modified Delphi you can also combine the classical Delphi with another method such as scenaria writing or interviews. There is also the potential of utilizing a real-time

function in Delphi, where the expert responses are analyzed in real-time and provided to the participants instantly. (Strasser 2017)

The benefits of the Delphi method are that it doesn't require absurd amount of data, time or resources in order to make a valid contribution to scientific research. Thus, the primary use of Delphi is when the study can't be completed without a certain amount of the aforementioned resources or when the scale of the research is too wide for any ordinary methods of forecasting (Börjeson et al. 2006).

3.4 Data collection

For the multiple case study, semi-structured form of interview was chosen as the most fitting method of data-collection. This type of structure lends itself well for exploratory study because it allows an in-depth discussion of the matter at hand while allowing the interviewer to ask additional questions about key facts that came up during the interview (Harrel & Bradley 2009, p. 27; Saunders et al. 2009, pp. 321-322; Holstein et al. 1995, p. 41). This type of qualitative method is exceedingly suitable when your aim is to understand the attitudes, opinions and reasons of the research participants (Saunders et al 2009, p. 321). According to Yin (2014, p. 106) case study interviews have the strength of simple and insightful which shows the method has a direct impact on the topic at hand while providing personal views and reasons such as opinions and attitudes. Hirsjärvi (2007, p. 200) also notes that in cases where the results can be diverse, this type of interview proves valuable.

As part of the semi-structured interview, the researcher has a list of questions set around the central themes that will be discussed (Saunders et al, p. 320). These themes and the interview questions will be decided in a way to get the most current and exact answers to the research questions. There were three key themes selected for this study. First of them was the importance of simulation technologies within the companies at the present and in the future. The second theme was opportunities and challenges and its purpose were to identify what has driven the companies towards utilizing simulation technologies and what kinds of opportunities have simulation models provided them with. The last theme

was resources, where the interviewees explained what kinds of costs the direct result of using simulation technologies as well as what kinds of resources are needed in order to use simulation beneficially.

These central themes will be discussed broadly while having a few questions prepared around them beforehand. The questions themselves are not set in stone and may change depending on how the interview progresses (Saunders et al, p. 320). Table 8 shows the basic information of the interviews.

Table 8. Interview summary

Companies		Interviewee roles			Average Time (minutes)
Interviews	Interviewees	Head of R&D	R&D Engineer	R&D Manager/Director	
6	6	2	1	3	33

For the Delphi study an expert panel of 20 participants from the business sector was selected. Their commitment to the study was ensured before starting the first round of questionnaires in order to make sure they would participate through the entire research process. The instructions and summaries of previous Delphi-rounds were provided to the experts via email. The selected expert panelist responded to the questionnaires electronically through Meetingsphere internet portal. Meetinsphere is a software which allows the people participating to announce their opinions through the simple usage of internet browser.

Table 9 shows the overall structure of the Delphi study utilized in this thesis. Between each round of questionnaires, the results of the previous rounds were evaluated and summary of them was created. The Delphi expert panel were provided an opportunity to comment on the summary of the previous round. This part of the study utilized a rough time limit of three weeks to respond to each round of questionnaires. After each of the rounds were completed the results are presented to the expert panelist and company representatives at a live meeting concluding the results of the entire DigiPro project.

Table 9. The Delphi process

Stage of the process	Content
Decide the scope and goal of the study	• Plan the research with academic and firm representatives
Plan the content of the Delphi rounds	• Four rounds of questionnaires • Identify the key issue areas of the research • Form the questionnaires
Selection of the expert panel	• List of the potential participants • Evaluate the willingness of the participants to engage in the research
1st round	• What the companies are hoping to gain from simulation? • What benefits have emerged or are expected? • What are the forces resisting or driving the change?
2nd round	• Rating the driving and resisting forces • What are the business-related effects of simulation in the long term? • What benefits are there for stakeholders in the long term? • How to identify customers who want to cooperate and commit?
3rd round	• Prioritizing business-related effects based on 2nd round results by using two criteria (cost-benefit and attainability)
4th round	• Summary of the 3rd round responses • Possibility to comment on the 3rd round responses
Evaluating the results	• Summary of the whole Delphi process • Presenting the results to the panelists • Discussion of the results and their utilization • Consensus; argumentation o the most controversial issues

3.5 Interpreting data

The approach a research can take is a line segment where at one end there is inductive research and at the other end there is deductive research. The deductive approach assumes that there is a strong theoretical pillar set up before the actual collection of data happens. Inductive approach is aiming at collecting data and generating theory that is based on that data afterwards. (Saunders et al. 2009, p. 41; Gabriel 2013) This research is leaning more on the deductive approach side of things as we have a solid theoretical framework on the benefits of simulation related technologies. By using the data gathered from interviews and the Delphi survey we can see how well the identified benefits of this technology match up with the experiences of the selected Finnish manufacturing companies.

The process of data analysis is described as something that brings order, structure and meaning for the collected data. It can be complex, multifaceted and time consuming but also as a creative and interesting action. (Marshall & Rossman 1999, s. 150) Kreuger and

Neuman (2006, p. 434) identified some commonalities that are present in both analyzing qualitative as well as quantitative data:

- Deducing, utilizing verified data to justify conclusions
- Public method or process – researcher explains the structure of the study
- Comparing as a central process – recognize what is repeating, what is different or what is similar
- Avoid mistakes, wrong conclusions and misleading deductions

4 ANALYSIS RESULTS

In this section we'll be reviewing the information gained through the Delphi-style surveys as well as the multiple case study conducted through interviews. Table 10 is an adaptation of the tables used in the chapter 3. The companies disqualified from the interviewee process have been removed from the table and the remaining companies are assigned a number between #1 and #6. The companies will be referred by their number in this section of the study. Moreover, each company's interviewed representative's role has been pointed out and an overall description of the company's product has been given.

Table 10. Key information on interviewed companies

	#1	#2	#3	#4	#5	#6
Interviewee role	R&D Director	Head of R&D	R&D Director	Head of R&D	R&D Engineer	R&D Manager
Firm's product description	Hydraulic cranes	Forest and material handling technology	Tractors and farming machinery	Industrial forklifts	Hydraulic cylinders	Entire production systems

4.1 Present and future of simulation technologies

In the interviews conducted as part of the multiple case study the current state of simulation technologies within the manufacturing industry and the chosen firms was discussed. The purpose of this theme was to identify the current state of simulation technologies within the company and see what kind of vision the company has moving forward in terms of utilization of simulation. The interviewees were asked for example what kinds of changes have they noticed regarding simulation related technologies during their work experience.

The interviewed experts with the most experience (#1, #3, #4) within the company had noticed significant advances in hardware, software as well as the emergence of new forms of simulation.

> *"Largest individual change was gaining access to [Simulation technology supplier's] simulator and the ability to utilize it within our product development phases" - #1*

> *"Most significant change was the fact that we are now able to use simulation technologies from multiple different viewpoints. New simulation tools and areas of application have emerged. Nowadays it is possible to do increasingly specific simulations for example when examining the mileage, cooling systems and air conditioning of both the motor and control room. Also, there have been great improvements in terms of software and the ability of using real-time simulation within software testing" - #3*

> *"The biggest notable change maybe the ability to do simulations in real-time. This has yet to have an impact on the firm's operations, but in the future, it makes certain things possible that we have been unable to do until now." -#4*

When examining the answers of the interviewees with 5 years or less of experience (#2, #5, #6) within their respective companies we notice more significant differences in the changes they have experienced when it came to simulation technologies. Some had noticed no changes (#2) where a few (#5, #6) noted the potential of advanced simulation related concepts such as real-time simulation and Digital Twin.

> *"During my time in the company, there have been no significant technology related leaps" - #2*

> *"The simulation tools haven't changed, but we are now able to use the simulation program to generate code automatically that can be utilized by the control unit. This has made working easier and faster" - #5*

> *"The overall scale of [simulation technology's] utilization has increased, and their impact is going to increase in the future. We have focused on*

developing mechanical models of Digital Twins for the past 3 or 4 years. This is also the area where real-time simulation is utilized." - #6

The interviewee's time within the company has an impact in highlighting the recent changes in terms of simulation technologies and their utilization. As show in Table 11 the most notable changes have been witnessed by people who have been around the industry and the company the longest while the newer employees have noticed little to no major changes in terms of utilization of simulation technologies, in most cases that is.

Table 11. Notable changes in terms of simulation technology

Company	Interviewee's time at the company (years)	Notable simulation related changes
#1	19	Access to a simulator and the ability to use it in product development.
#2	2	No notable changes in terms of simulation technology.
#3	12	Overall wider scale of use. Massive strives in terms of software and the ability to use real-time simulation.
#4	12	The ability to perform real-time simulation.
#5	5	The simulation software automatically generates code that can be directly executed with the control device.
#6	4	Overall wider scale of use. The ability to generate Digital Twins and use real-time simulation in their development.

After this we moved to inspect the scale on which simulation technologies were exploited in each of the companies' in terms of business processes. One of the companies (#4) was a clear anomaly in terms of this section as they used to utilize simulation in their activities but at the moment they did not. Currently they are just planning for the future.

"At the moment it's not part of the company's processes, however it used to be. For the moment we are just waiting for the "second coming"." - #4

Two of the companies (#1, #2) utilize simulation technology at extremely wide scale within their business activities from development up to providing training or utilizing the simulation model as a presentation tool.

"Product development utilizes the simulator daily and it's the biggest area of use. The after-marketing division uses it a lot for training purposes. It's useful for malfunction analysis, for example when someone calls from abroad it's much easier that the helper can work through the issue in a simulator" - #1

"In product development phase it's used for modeling and malfunction repetition. On top of this it's utilized in training and concept presentation. I believe in the future the uses of simulation will increase" - #2

Table 12 summarizes the opinions of the companies in regard to where they feel simulation technology is mostly utilized in their day-to-day business activities. We can clearly identify that there is a certain degree of variation, in terms of how widely simulation technologies are used within the companies at present – one company has yet to even start the use of simulation in their processes.

Table 12. Simulation technology utilization

	Product development	**Training/Presentation**	**Malfunction analysis/Maintenance**
#1	X	X	X
#2	X	X	X
#3	X		X
#4			
#5	X		X
#6	X		

As we have identified the areas of use for simulation technologies, we asked the interviewees about what kinds of benefits have they achieved within these areas and what are their goals for the future in terms of exploiting simulation technologies. Most of the companies (#1, #2, #3, #5, #6) mentioned the benefit of relying less on physical products in one way or another. One of the companies (#3) pointed out a potential issue when it came to using simulation technology to prove a concept.

> *"[Simulation] speeds up software testing as you don't need a machine to test it in, but instead do it in a simulator. This is a big deal as we don't produce hundreds or thousands of machines a year – they are not always available for testing." – #1*

> *"Operating without simulation tools would not be possible for us or it would require more workforce in product development. Much of the system development is automated, thus making it hard to be done without simulation. This means less required labor in the development cycle." - #5*

> *"Proof-of-concept is still something you need to validate through a physical model. The validity of simulation technology is only perceived by those who understand it" - #3*

For most of the companies mentioned this was something that they had already achieved but for one (#4) it was something they were aiming for. As we noted in table 11, this company doesn't have simulation technology incorporated within their processes yet, thus it's extremely logical they are aiming for something other companies from the same industry have deemed important.

> *"Our goal is to make dynamic things before making the physical prototypes. What we are interested in is the product development simulation world. On the long-term our operations will become more efficient and better which leads to faster time-to-market" - #4*

Being able to cut unnecessary physical prototypes has its own benefits in terms of reducing costs and improving the product development speed. However, a few companies (#2, #3, #5) mentioned the lowered costs business operations as well as the overall decrease in product development time as a separate benefit. One of the mentioned companies (#5) also brought up that simulations can decrease amount of workforce needed. Company #3 also noted that despite already having achieved benefits on this area they feel that there is much potential to be achieved in the future.

> *"Most of the benefits are in the product development phase in terms of speed and cost savings" - #2*

> *"[Business operations] require less labor resources. The overall decreased costs as well as production time lead to better productivity. –" - #5*

> *"There is much to be achieved from performing early stage concept design when the methods become more commonly understood" - #3*

The potential to increase the overall efficiency of your operations was also one of the major areas of interest as four companies (#2, #5, #6, #1) pointed it out. This increase in efficiency was achieved through multiple different avenues such as: Identifying and fixing malfunctions (#2, #5), increased perception (#6) and improving the software (#1).

> *"Solving malfunction situations becomes easier through simulation" - #5*

> *"Certain situations are extremely hard to perceive without [the use of simulation technologies]" - #6*

Most of the companies except company #6 see efficiency as something that is a key in terms of potential benefits on the long-term. Mostly their focus is in increasing the overall utilization of their simulation technologies in order to gain further benefits on areas such as:

- Further decreasing the time required for product development (#1, #4)
- Maximizing and measuring the benefit gained from a simulator (#2)
- Utilization of virtual techniques and simulation tools to make product development more front heavy (#3)
- Bringing the whole system into simulation and the possibility of wide-scale testing and development (#5)

Increasing customer value is something that can be achieved using simulation in multiple ways. Two companies (#1, #2) pointed out that they have been doing training and presentations by utilizing this technology. Though, one of them (#2) made a point that the potential benefits from this are not easily measured while the other (#1) noted that you can even sell a simulator to the customer to further increase the potential benefits.

> *"Many customers value the fact that their users can be trained even before the final product arrives, which makes it possible that you can properly start working from the moment you receive your machine. You are also able to sell the simulator to the customer through which you gain further benefits." - #1*

> *"The benefits of using [simulation technology] for training and presentation are hard to quantify, but it's something we have been doing" - #2*

One of the companies (#6) already utilized simulation technologies in order to provide their customers with unique service and were also looking into how they could further increase perceived customer value through simulation. Their product encompasses an entire production system and as such the actual customer is not the same thing as the persons operating it. Company #5 had already managed the integration of their customers into product development.

> *"We provide our customers with the option of testing the products in a virtual environment. This way they can run test scenarios based on real-world data gathered by analysators" - #6*

> *"We want to incorporate the end-user in the development process, but we are not yet ready for this. The things the end-users are operating are extremely hard to simulate in our products" - #6*

> *"We have plenty of customers as a part of the product development. This brings multiple benefits as our products are implemented to different machine types. The end-users and machine builders have the best comprehension on how the machine is used - - it's valuable information to know how and towards what goal a machine is being used." - #5*

The concept of tailoring your product towards the customer's needs was also something that was identified as a key benefit that simulation technologies can provide in the future. Companies #3 and #4 identified the user-experience as a key competitive advantage in the future and an area where simulation technology should be utilized. Company #5 was planning to further increase their customer-centric approach by utilizing a Digital Twin in their marketing and customer interactions.

> *"The user-interface and other user environment becomes a more important factor [in the future] and it's a way of differentiating from your competition. This is one of the new areas [for simulation] in the future." - #3*

> *"Developing user-experience further by integrating end-users in the product development. This way we can utilize the feedback of the end-user in the development process" - #4*

> *"[Our goal] in the long-term is utilizing Digital Twin in marketing and demonstrations for the customers. As our product is a hydraulic system instead of a complete machine, we don't need a Digital Twin of the whole machine - - this makes the concept realistic." - #5*

Table 13 summarizes the perceived benefits, both achieved and ones the companies are aiming for. Both sections of the table highlight what the companies perceive as the biggest benefits currently and what they see are the areas in which most new benefits will be achieved. So, not mentioning a certain benefit doesn't mean there are none, but that the most notable benefits exist elsewhere. In a similar fashion, aiming for something you

have already achieved just means it's an area where they see potential for further improvements.

Table 13. The most impactful benefits of simulation as perceived by the companies

	Achieved Benefits							Goals for the future					
	# 1	# 2	# 3	# 4	# 5	# 6		# 1	# 2	# 3	# 4	# 5	# 6
Less reliance on physical prototypes	X	X	X		X	X				X	X		
Increased development speed and cost savings		X	X		X					X	X		
Efficiency increase	X	X			X	X		X	X	X		X	
Increased customer value	X	X			X	X				X	X	X	X

As Table 12 showcased the interest in simulation technologies is not decreasing in the future. This increasing interest as well as the fact that technology is constantly evolving would mean that the companies have to keep a constant flow of resources going towards simulation technologies in terms of training, salaries and hardware. The company representatives were asked if this constant development of technology was a threat or an opportunity. The general consensus was that despite having its downsides the overall outcome of technological development is still positive. One of the companies (#6) did point out that the further the development goes; the less competitive advantage is available as everyone has access to the technology. This company felt that despite the fact that the potential advantages in comparison to competition are decreasing you should still try to remain as the innovator in your sector.

> *"[Technological development] is an opportunity. When the development process goes forward exponentially, the achievable competitive advantages will decrease. In ten years, the differences [between competitors] have most likely shrunk but by staying as the innovator you are still able to outrun your competition" - #6*

4.2 Opportunities and challenges

As part of identifying the driving factor behind why firms within the Finnish manufacturing industry have decided to utilize simulation technologies the interviewees were asked what drove the firm towards exploiting simulation technologies in their business activities.

Two of the interviewees found the driving factor behind their simulation technology utilization to be a recognized opportunity (#1 and #2). The other company recognized that the competition did not possess the required technology for their type of product and seized the position of innovator. The second company noticed the potential for improved efficiency and decided to test out the potential of the technology. Another company (#3) noted that when it comes to driving competitive advantage, the factors that utilize simulation are not a factor as most of the competitiveness revolves around user experience which as of now doesn't exploit simulation technologies. Instead they noted that the driving factor was the recognized potential to work with less and still gain more.

> *"The competition did not possess the required simulators for this type of machines, and I am not even sure if they still do. We started utilizing this type of technology 5 years ago and we kind of were the innovators. So, the push towards exploitation of simulation was more about a recognized opportunity" - #1*

> *"We recognized the potential for a more resource efficient operation. We tested the potential last spring by developing and testing a product simultaneously during the design process. The result was less mistakes and a faster overall process" - #2*

> *"The factors that are simulated these days aren't that obvious to the customers. What differentiates companies from competition is the user interface and this is something we are unable to utilize simulation in. Instead the driving force is the ability to improve the development process*

> *and do better products with less resources - - also we are talking about engineers so it's fun to do things just because they are new and cool" - #3*

In one case (#5) the driving factor was the internal need of the company combined with the recognized opportunity simulation technology held in terms of reducing the amount of labor-resources needed for the design process.

> *"At this moment the operations would not be possible or would require a much larger crew to work around the design phase - - The complexity of the system demands the use of simulation. This is a recognized opportunity" - #5*

In the other three cases (#3 and #4) the interviewees pointed out that the competition was at least partly responsible for their decision of delving into the world of simulation. However, on top of this they did note that there were other secondary reasons as well.

> *"The pressure for faster product development phase is immense, so in that way the competition was a factor. Also, the environmental factors that cause problems for [physical prototype] testing played a part" - #4*

> *"Of course, competition drives us forward, but every machine manufacturer needs to have the internal drive to improve otherwise nothing changes" - #6*

The overall driving forces that pushed companies towards adopting simulation technologies into their business processes can be summarized into three categories: External pressure, internal pressure and recognized opportunity (Table 14). As shown in the table below, there can be a multiple different driving forces affecting a single company that have acted as the catalyst to push the company into utilizing simulation technologies.

Table 14. Summarization of the forces that drive companies towards simulation technologies

What drove the companies towards utilizing simulation technologies?		
External pressure	Internal pressure	Recognized opportunity
#4 #6	#5 #6 #3	#1 #2 #3 #5

The benefits of simulation technologies have been highlighted by previous sections thus making it obvious why companies are trying to utilize them as well as possible. Now the companies were asked how hard it's to implement these new technologies into their business operations. All but one of the companies (#5) saw the implementation process as something that does have its issues and problems. For company #5 it was such a necessity that the implementation had to work.

> *"Simulation technology has always been used in the company. I believe that when there is a real need to use a certain technology then [the implementation] will be relatively successful" - #5*

In the case of company #2 they pointed out that their end goal was a Digital Twin. They highlighted that the implementation process is not just a mechanical problem but something that requires the attention of the whole organization. Despite the challenges they still felt that moving towards their goal was necessary.

> *"Yes, the implementation is difficult. Our goal is a Digital Twin - - this requires maturity and quality from every section of the firm. So, it's not just a technical challenge but an exceedingly wholesome one. Despite this we are going towards a direction where we are aiming for a perfect Digital Twin." - #2*

Companies #4 and #6 pointed out that the utilization and implementation of new technologies does require a new resource. Company #6 gave a basic formula of a product development process (Figure 15) and pointed out if they were to add for example a Digital Twin into it, that would require the addition of entirely new resource and would require

them to think one production line at a time about how the Digital Twin will be implemented – a massive endeavor. Despite this they felt that in a product development mindset, the concept of Digital Twin is crucial and despite the difficulties they want to examine it further. They did note that in terms of utilizing Digital Twin the product of the company makes a massive difference on how beneficial and difficult the implementation process is.

> *"It's completely different to manufacture an excavator and deliver 1000 similar machines. In this scenario a single developed Digital Twin can service most of the products. We are making whole product lines and each customer has different needs - - forming a Digital Twin is not simple and you need multiple different versions of them – we need to think to what extent it's beneficial to offer these" - #6*

> *"In a way it's difficult. A new [simulation technology] requires loads of resources in order to function. On top of this the actual implementation process is difficult" - #4*

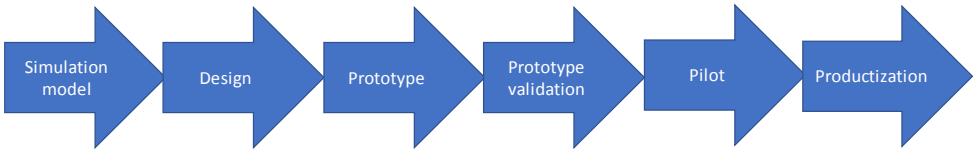

Figure 15. Product development process example (Company #6)

Company #1 noted that the implementation process could be made easier and faster and that the platform developers should strive towards this kind of development. They noted that an easy to use model, with options to select different operating environments could be easily used by personnel who don't possess in-depth knowledge of the modeling platform. The interviewee also noted that if it would be possible to have interoperability across multiple models, certain benefits could be acquired.

> *"Component manufacturer could provide us with measurement data from their systems that could be directly inputted into our simulation model – thus saving us the time of doing the measurements" - #1*

In the case of company #1 the biggest issue was the required labor resource. They had noted that the utilization and implementation of the simulation models requires more people to work on them. Because the company is investing more money into something, they are of course expecting some concrete benefits, so the amount of resources spent would be offset by resources gained. Despite the noted implementation issues the company recognized that the potential future benefits still drive them forward.

> *"We are striving to be industry leaders in terms of technology. It would be difficult to continue without [simulation technologies] in the future if you are manufacturing a product that is even a bit complex. Product development, training phase and lifecycle management become easier with the use of simulator and a Digital Twin" -#1*

One company (#3) noted that as the driving force for utilizing simulation technologies comes from the market and their customer-oriented approach. Due to this you need to look at your product roadmaps and identify the best possible opportunity for implementation – if there are none, then you shouldn't implement it. They also noted that the implementation should be done at an early stage when examining your product roadmaps.

Table 15 summarizes the issues the companies have been facing when trying to implement simulation technologies into their business activities. Despite the fact that each of the companies are part of the manufacturing industry they were facing surprisingly different types of issues and in some cases, no issues at all. The differences can be accounted by the fact that despite being part of the same industry their products are still vastly different. If your product is extremely large size-wise or is otherwise complex you are in all likelihood facing more problems in your implementation processes.

Table 15. Summarized results on what are the perceived implementation issues of simulation technologies

	Implementation issue
#1	• Requires a lot of labor resource • The models have a lack of interoperability
#2	• Requires maturity and quality from all areas of the firm
#3	• Finding the right time for implementation
#4	• Resource requirements
#5	• No real issues
#6	• Requires an entirely new resource • Every product needs its own Digital Twin

The company representatives were also asked about the ways the successful implementation process of a simulation technology changes their operations and if they have any way of measuring the success and profitability of the implemented technology. In terms of having ways to measure the concrete benefit from a successful implementation of simulation technology the responses varied heavily. Three companies (#2, #4, #6) pointed out that at the moment they have no way of truly measuring the achieved benefit.

> *"We have not reached that kind of level in our operations just yet. We are unable to draw any systematic conclusions" - #6*

Company #1 pointed out that they don't have a concrete model to monitor this as they felt that the benefits are quite hard to examine. However, they did point out that one way of doing this is by monitoring the amount of profit gained from selling or renting a simulator or by offering training.

> *"In software development you can examine how much costs would pile up without a simulator. After this you add up the expenses and see if you have gained revenue through selling or renting a simulator or its training services. This is somewhat based on gut feeling." - #1*

Two companies (#3, #5) were much further ahead in terms of how they evaluated the success of the implementation process.

> *"As you are doing a new product development project, it's based on a business case where we define the cost-accounting. As you are developing a new technology this is a much lighter process - - we are looking at what are the observable benefits of the technology from a business viewpoint" - #3*

> *"We examine the product development project from the standpoint of how many resources and how much time was spent. Then we compare the results of projects where the utilization of simulator is possible to those where testing was done on a physical prototype" - #5*

Table 16 shows to what degree are the companies able to quantify the success and benefits derived from a successful implementation of simulation technologies. The scale is set from low to medium to high and the placement of each company is decided by comparing them to each other as there is no objective way to universally rank companies by their ability on this. So, having a 'high' ability to measure the success of implementation only mean that in the context of these 6 companies they are superior in comparison to the rest.

Table 16. Comparison of companies' abilities to evaluate the benefits of simulation technology

Low	Medium	High
#2 *#4* *#6*	*#1*	*#3* *#5*

Identifying the concrete changes that happen in a firm's operations through the successful implementation of a simulation technology turned out to be a difficult question. Most of the companies (#2, #4, #5, #6) noted that of course changes happen but were unable to identify the exact ones. Company #1 pointed out that the biggest changes happen in the areas of software testing and training.

> *"Software testing changes in a concrete way as you can do it in a program instead of a physical machine. So that's a completely new way of doing things. Same development happens in training. The drivers can now use simulators and you don't need a machine" - #1*

In the case of company #3 it was identified that due to their approach towards the implementation process, no noticeable changes happen – or to be clearer, they happen at an extremely slow pace.

> *"I don't think the implementation changes the way we operate. The practical implementation happens slowly, you are finding the right place to do it. In our organization you are unable to validate a new method to such an extent that it could be taken into use immediately. You must carefully integrate it into your product processes" - #3*

4.3 Resources

Each of the interviewed companies act within the manufacturing industry and are in the business of making physical products. Thus, they were asked how the perceive the benefits of both physical prototypes as well as simulation models what kinds of advantages and disadvantages these have.

All but one company (#1) had the mentality that simulation models and physical prototypes complement each other and that it would be highly unlikely that they would stop using physical prototypes in the near future. In the case of company #1 they had identified that due to the price of their product as well as its complexity, using a physical prototype would not be viable – at least not in the traditional sense.

> *"Our product's price is in the millions [of euros] and there are multiple different variations that can be made. Due to this, using a physical prototype is almost impossible" - #1*

What makes this company interesting is that they aren't modeling the entirety of the machine and are mostly only using simulations in designing the control systems. In a way they are using the first machine as a prototype but despite this the product is sold in the same way as the rest of them. They have identified that problems do arise but the costs of

having to do product maintenance after delivering the product are still lower than the costs of using a high price machine as a complete prototype instead of selling it.

> *"The first machine acts as a prototype but it's still sold the same as the 50th one. Of course, this brings the pressure to get it right on the first try so you can run the product development through in a way the end result is a working machine. The benefits are so great that we simply must forget the actual prototyping. Doing field maintenance has never procured costs over few tens of thousands" - #1*

By cutting out what is considered a normal prototype phase in most manufacturing companies they are able to gain the added benefit of selling every product they make. Simulation modeling is utilized in this case to increase the overall validity of doing business in this way as well as decreasing the chances of having to do field maintenance after the product has been delivered.

As the benefits of simulation technologies have been discussed the company representatives were asked what kinds of costs do the utilization of simulation technologies cause for the company itself. The idea was to identify the areas in which most of the costs appear and what are the most significant ones for the company. As a result of the answers there were three key categories of expenses that are the direct result of using simulation technologies:

- Training, employee salaries and overall knowhow
- Simulator and other hardware
- Software and license fees

Every company agreed that the user of the simulation platform plays a crucial role when it came to gaining benefits from simulation technologies – thus it's also one of the major expenses for these firms. One of the companies (#1) noted that despite having two proclaimed simulation experts working for them they still require more expertise in order to maximize the benefits of their simulation processes.

> *"Training your own employee or hiring a new one is major expense. The salaries of these employees are also a constant expense. We have two simulation experts in-house, but they have yet to be fully immersed in the technology. We have a plan to hire a new employee whose sole focus is the utilization of our simulator in a more wide-scale fashion – this has happened few years later than we had hoped." - #1*

Company #3 agreed that the user aspect is a significant expense and that you need to assign him in the correct position. In order to maximize the benefits derived from your utilization of simulation technologies, the user not only has to be trained well but has to be placed at the right position within a company's production processes.

> *"One significant expense is the user, if it's an in-house project you need a fulltime user, and this is often a problem. You need to assign the new user to the correct position, whether it is computation or design, in order to maximize the benefits." - #3*

Two of the companies (#2, #6) noted that despite being the biggest expense the user aspect of simulation technology isn't something a firm needs to have internally but it can be gained through external means such as partnerships. One company (#5) didn't specifically highlight the cost aspect of the user in so many words, but they pointed out that the biggest overall costs are time related.

> *"Software and its users both cost money. We have the internal know-how, but we are also utilizing outside knowledge" - #6*

> *"Training and the resource that executes maintenance and development is crucial. You can utilize your own know-how or gain it externally through partnerships – it's significant" - #2*

Four of the companies (#1, #2, #3, #5) pointed out that on top of the employee-centric costs there are also significant hardware related expenses that are directly connected to the acquisition of simulators or other key technologies. For one company (#1) the acquisition of their first simulator and the development that goes with it was the single largest expense. Company #2 was of similar mindset and noted that this is a major sink of finances – but still a mandatory one for their business activities.

> *"Simulation platform and its development. The acquisition of our first simulator was the single largest expense for us." - #1*

> *"The acquisition of the simulator as well as its upkeep and development. The product has to be modelled and that is where most of the expenses are coming from." - #2*

Two of the companies (#3, #5) shared the view that simulators are expensive but had a more wide-scale view of the hardware expenditures within their businesses. Instead of focusing solely on the simulator they noted that there are other hardware related expenses that come from acquiring the necessary technologies to make the overall simulation process to work. Company #3 also noted that if you don't own the necessary equipment yourself, you can always outsource the functions that you can't perform within your own company.

> *"Infrastructure and calculation capacity are important [cost wise] when you are talking about wide-scale projects. We are talking about calculation clusters. Another option is to outsource this, but in our case, we possess the required hardware in-house." - #3*

> *"Hardware that is included within a simulator is a big expense. The total workload of the implementation is dependent on the type of solution you are aiming for" - #5*

Most of the companies (#1, #3, #4, #5, #6) pointed out that aside from the hardware and employee requirements you still require the right software which comes with its own license fees. Most of these companies just made a quick note that there are some extensive costs that are related to utilizing the required software but didn't go much more in-depth. One company (#3) shared their viewpoint on why they feel that despite being a massive expenditure, the overall impact of the software still results in a net profit.

> *"Licenses are extremely expensive; we are talking about hundreds of thousands [euros] per year. However, the overall costs decrease when you compare to simulation with a physical prototype. Even one prototype costs around a hundred thousand [euros] and you are making multiple ones each year. If you are able to reduce the number of physical prototypes produced per year even by one or two, the cost of the licenses will be covered." - #3*

Table 17 summarizes what each of the companies felt were the most important costs that are caused by their utilization of simulation technologies. We can clearly see that the companies are mostly in agreement on what the key areas of costs are and thus there are only slight differences of opinion on the matter. Though the companies are mostly in agreement there are some differences in terms of how much thought they have given to the simulation-related costs of their business activities. Some of the companies had understood that certain areas can be outsourced. One company had even made the necessary observations and calculations to realize that despite being expensive, the overall result is still a positive one in terms of finances.

Table 17. Expenses that are directly related to the utilization of simulation technologies

Expenses caused by the utilization of simulation technologies		
Employees, training and know-how	Simulators and other hardware	License fees
#1	#1	#1
#2	#2	#3
#3	#3	#4
#4	#5	#5
#5		#6

The companies were asked to recognize the most important resources that are needed in order to be able to implement simulation technology into the company's business

activities successfully. Clearly the most crucial resource was a person who can not only make but also utilize the simulation model properly. This importance of know-how was emphasized by every single company that was interviewed and was clearly the most critical resource.

> *"Things don't work just because you purchase a simulator. Especially if you are utilizing it in product development it requires continuous improvement of models and experimenting besides the rest of the product design phase – this is a special kind of expertise. That's the most important resource." - #1*

> *"You need the right people in the right places, and you must allocate enough working hours into it in order to maximize profit" - #3*

Two companies (#1 and #2) pointed out the company doesn't necessarily need to have internal know-how but can and should utilize partnerships and subcontractors to gain similar benefits. In one of these cases (#2) it was noted that they did not want to allocate resources to gain this specialized expertise in-house, but instead were able to use their partners to get the needed know-how.

> *"A person who can utilize the model is the most important thing - - in our case this expertise comes from the outside, at this moment we do not want to tie our resources into gaining our own internal simulation expert" - #2*

Three of the companies highlighted the importance of financial resources in some way. The software and licenses cost money (#1), budget can be a limiting factor (#4) and that finances decide which direction you are going towards (#6). In two cases (#4 and #6) the interviewees also pointed out that simulation can be used to get the finances required through being able to showcase the benefit of the project visually.

> *"Budget can be a limiting factor towards doing something. Simulation model can be used to get the finances required because it can be used to concretize the potential of the project" - #4*

> *"Finances are important, you must internally decide which way we are going. Simulation model can be used to showcase the function of the project in order to secure the required funding" - #6*

One of the companies had the mindset than in order to maximize what you are getting when the implementation of simulation is complete you must think of the bigger picture. The interviewee in question (#3) pointed out that a long-term strategy is needed if you are going to invest into simulation. They pointed out that you must not only have the right people in right places, but also commit enough working hours into product development to maximize the benefits.

> *"First and foremost, it requires a long-term strategy - - you need to allocate enough working hours in order to gain the real benefits. Also allocating time to develop the required tools up to par. Resources, working hours and know-how." - #3*

As we have an incredibly homogeneous group of companies that are around the same size and interact within the same industry it was no wonder the companies had such similar views on what the most important resource is to possess when you are implementing a simulation technology into your business processes – an expert using the tools is absolutely crucial. Figure 16 shows the key resources that the companies identified as crucial. The size of the letters is indicative of how important a specific resource is – the bigger the better.

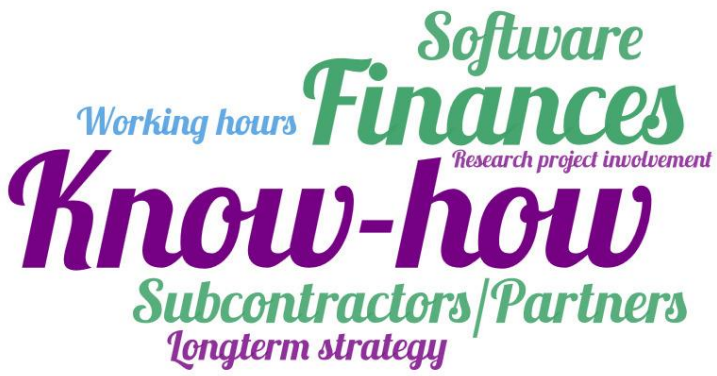

Figure 16. Word cloud showcasing the key resources in implementing simulation technology

Few of the companies (#3, #4 and #6) pointed out that different academic institutes play a key part in nurturing these key talents and one company (#6) even highlighted the importance of collaborating with universities.

> "*Interaction with universities is important, and that's why we are part of the DigiPro-project. This way we can research the potential [of simulation technologies] and more specifically what are the potentials for us" - #6*

4.4 Delphi method

The Delphi analysis has four rounds of questionnaires and the expert panel consists of 19 experts across all the companies that are taking part in the DigiPro-project. However, this analysis doesn't follow the structure of a classical Delphi analysis as there was a recognized threat that keeping up a high enough participance would be near impossible due to the other responsibilities of the expert panelists. Still, for each round every expert is provided with the same questions across the board, but the questions change or are further inspected as we go forward in the Delphi analysis rounds. After each round the panelists had the opportunity to see the summary of the round as well as edit and rationalize their own responses while also commenting on the responses of other experts. The aim of such directed Delphi process was to create a more innovative, open and trustworthy environment in comparison to standard questionnaires.

The purpose of the Delphi analysis within this context was to identify and rate the potential of digitalization and simulation technologies as part of the product processes of Finnish manufacturing companies. The goal was to recognize the impact of simulation technologies for the overall business activities of the participant companies as well as take note of the forces driving and resisting the utilization of said technologies.

First round

The goal of the first round was to get the experts to share what types of benefits are they aiming for within their companies when it comes to simulation technology. The answers were further compiled under the following larger themes:

- Product development
- Testing and validation
- Digital Twin and IoT
- Other functions

Product development was the area where the experts saw the most benefits or areas of potential use for simulation technologies. The basis of the product development goals was centered around gaining more in-depth understanding of the model and its uses in order to utilize it in the best possible way when an opportunity arose. Moreover, the simulation technology was seen as a way to directly improve the quality of the entire product or as a way to enhance the functionality of one area such as the control system – all the while decreasing the time requirement of the development phase. The fact that in the past manufacturing companies were relying heavily on physical prototypes was noted. Due to this it was noted that examining what type of simulation model or hardware was needed to provide the same degree of product validation as the physical prototype.

The expert panelists saw customer integration as something that could bring extra value directly into the product development. They understood that the customer experience was a key aspect of their business and thus developing a user interface by utilizing the

feedback gained from the end-users of their products was crucial. Developing new ways to further integrate customers into product development was one of the goals for the future.

The potential simulation technologies possessed in terms of improving the testing and validation of products was recognized. One identified benefit of utilizing simulation models for testing was the fact that you can reduce the overall testing time and execute scenarios that aren't viable to be tested through traditional means. Being able to start the testing process before any physical prototypes were made, was seen as a major benefit. Additionally, through this type of testing you are able to take advantage of the knowledge of different departments or even the customers during the testing process.

The goals the experts were striving for weren't strictly limited to manufacturing processes. The technology's potential to be used in variety of purposes such as sales and marketing was brought up. Simulation technology could be used as a way to demonstrate different scenarios. As far as education purposes go, the aim is to make the process of transferring different models and interfaces into simulator more efficient. Being able to provide more customer value by simulating specific customer cases was also mentioned as a goal.

The potential of Digital Twin was also something the experts touched upon. Mainly it was seen as something to be utilized in pre-emptive maintenance. However, the potential it possesses in terms of service business was also noted. The panelists were tasked to identify what kinds of benefits they have already witnessed or are expecting to receive from the utilization of simulation technologies. Also, they were asked to point out what they felt are the factors resisting the utilization process. The answers provided by the panelists were summarized and added into the 2nd round prioritization task.

Second round

The main task of the second Delphi analysis round was to have the panelist to analyze the importance of the forces driving and resisting the utilization of the simulation

technologies within their companies. Each of the driving and resisting forces were rated on a scale from 1 to 5, where 1 means that the force has minor significance and 5 means that the force is extremely significant. Tables 18 and 19 showcase the force field analysis highlighting twelve of the most impactful forces driving and resisting the use of simulation technologies in Finnish manufacturing companies. Force field analysis emphasizes the driving and resisting forces that are part of any change and identifies that in order to be successful the driving forces need to be more significant than the resisting forces (Baulcomb 2003). In the case of this study the force field analysis is used as a tool to identify the most important factors that need to be focused on in order to successfully utilize simulation modelling. In order for change to be successful the driving forces must be enhanced, or the resisting forces weakened.

Table 6. Forces driving the simulation technology utilization

F	Forces driving the change
4.8	Shorter implementation and testing times
4.7	Possibility of cutting a physical prototype round thanks to simulator testing
4.2	Benefits for product development through virtual testing
4.1	The test situation in the simulator is not too predetermined and it's possible to find out things that could not be noticed in advance
4.0	Faster failure in testing phase leads to learning in product development
4.0	Testing different product variations more systematically and fully
4.0	A better understanding of the machine's dynamics, especially in the initial dimensioning phase
3.9	Enabling hardware and control solutions that would be too expensive or time consuming
3.8	Utilizing simulation shortens the overall time of product development from idea to market
3.6	Customer's test driver's feedback can be considered before the machine is built
3.4	Speeds up operator's skills development by enabling training without a physical machine
3.3	Enhances application dimensioning and proactive maintenance

Table 7. Forces resisting the utilization of simulation technologies

F	Forces resisting the change
4.1	Resource requirements such as financing, skilled workforce, time requirements and the right target of application
3.9	Building models is laborious and they need to be quickly operational and meet your needs
3.8	Workload required by simulator development
3.8	The development and maintenance of models in product development should not be more cumbersome than the current practices
3.8	Finding the characteristics and data of the devices so that the model has the right accuracy
3.6	Technical challenges slow down the use of simulation
3.6	Multiple parallel simulation and modelling tools in use lead to issues
3.5	Multiple machine types are simulated so that you can't easily combine subassemblies
3.5	Selling simulation practices to people in different fields/departments is difficult
3.3	References and examples are required when engaging colleagues or decision makers
3.3	Amount of work required. The costs are too heavy to allow large-scale utilization
3.1	Lack of knowledge

As part of the second round the experts were tasked to identify the long-term business activity impacts that simulation could have. The participants identified that multiple benefits could be achieved through a well-developed simulation platform such as:

- Methods of pre-emptive maintenance
- Optimizing customer's traffic
- Improved understanding of the product and its functionality
- Fulfilling customer needs more efficiently

One of the key goals of the companies was the overall improvement of their products and transforming that quality towards increased production and sales volume. To achieve this the quickening of the product development process and faster testing of new products was also seen as crucial aspect of simulation. The overall supportive function of simulation in terms of product development was also noted, as it has the ability to connect multiple different functions within the company. One of the key aspects of the future in terms of product development would be the creation of a Digital Twin that could enable the ability to control a real machine through a simulator.

The concept of servitization and customer involvement was also one of the long-term aspects that the companies were eager to investigate. According to the experts' simulation enables the ability to incorporate customers in the development process as well as provide the manufacturers the benefit of being able to educate their customers about their products in a better way. This kind of interaction with customer results in gaining more information about their needs. Understanding the needs of the customer at an early stage was something that the experts saw as crucial for the overall success of their projects. Improved ability to simulate products would also enable the possibility of adding more service business related activities to product.

The expert group were also asked to comment on what kinds of benefits do simulation technologies provide for the customer and other stakeholders in the long term. It was pointed out that simulation modelling provides a unique opportunity to bring customers and product developers closer together and provide both with benefits. Simulation was

seen as something that can noticeably decrease the amount of service interruptions and improve the overall maintenance process which benefits the customer. Providing well developed and maintained system solutions increases the overall customer value. By utilizing simulation technologies, you are able to incorporate customers and stakeholders in the product development process by allowing them to share their ideas and comments with the product development teams of the company. This type of interaction would increase the overall understanding of the customer and stakeholder needs. The experts generally agreed by using simulation technologies you can increase the overall productivity of the company. The experts noted that the importance of this kind of customer-oriented approach through simulation would increase in the future.

The experts were also asked to comment on ways you can measure and evaluate the long-term impacts of simulation for their business. They identified multiple of different ways you can achieve this. Monitoring product development and maintenance was seen as a way to evaluate the impact of simulation. You can analyze the data gained through automated malfunction notifications as well as assess the amount of maintenance calls you get from customers – these work as excellent measurements of success, the lower the amount the higher the success. By examining the product development phase, you can clearly see if the number of physical prototypes required has been reduced through the utilization of simulation technologies. Taking note of how simulation modeling affects the time required for product development was also seen as a simple way to monitor the impact. As stated previously, simulation was seen as a way to incorporate customers in the product development process and thus this is also one way to evaluate the impact of the technology. You can conduct questionnaires to gather customer feedback and monitor the overall customer satisfaction levels. By monitoring how certain business activity figures such as sales numbers, production volumes, market share and number of new products, you can see how the utilization of simulation affects these key figures to assess its impact. Further examination could be done by comparing the results to projects where simulation technologies were not used and draw conclusions from that. Table 20 summarizes the ways to measure the impact of simulation in the company's business activities into three main categories of customer, product development processes and overall business figures.

Table 20. Ways to gather data and measure the impact of simulation to business

Measuring the long-term impact of simulation in business activities		
Customer	**Product development processes**	**Overall business figures**
• Feedback • Satisfaction • Amount of new customers • Number of lost customers	• Time requirements • Number of physical prototypes required • Amount of maintenance calls	• Sales • Production volumes

As it has been identified, customer and stakeholder cooperation are a significant aspect of utilizing simulation technologies within the manufacturing industry. To conclude the second round of questionnaires the experts were asked on how are they able to identify the customers that are willing to cooperate and with whom it's beneficial to cooperate with.

The experts valued customers that are willing to commit to the project on a wider scale. Customers who share the required information for modelling purposes as well as take part in the expenses that are caused by forming, maintaining and developing the models are wanted. The companies felt that just by contacting the customers directly you would be able to find out if they are willing to have an influence in the development process or not. It was also noted that by inviting the customer to join the development process and by pointing out the potential to influence it you are more likely to get them to commit to the project. The companies also pointed out that simulators should be developed further to provide information such as meters that can measure productivity and this way the simulator could be used to convince the customer about its benefits.

Third round

The third Delphi round consisted of the experts examining the long-term business activity related effects of simulation even further. They were tasked to evaluate the long-term business activity effects via two criteria: costs-efficiency and achievability. First the experts were tasked to evaluate the statements of the previous round about the effects of simulation on business activities in terms what are their cost and efficiency related impacts. In order to achieve the benefits, the companies must be willing to invest resources such as time and money.

So, the panelist graded the costs-efficiency aspect by essentially determining how much are they getting out of something in comparison to the amount of resources they are putting in. The costs-efficiency grading was done on scale of 0-6 (0= very small, 3=decent, 6=very big). After this the experts had to evaluate how easily the goals can be achieved. The grading for achievability was done on scale of 0-6 (0=difficult to achieve, 6=easy to achieve). Table 21 showcases the results of this grading process. Mean is the statistical average that is used to show the central tendency of the data that is being analyzed. It is calculated by adding all the gathered values together and dividing the total by the number of people who have responded. SD means the standard deviation and it is used to quantify the variation in a set of data values.

Table 21. Evaluation of the cost-efficiency and achievability

Business-related achievement	**Costs-efficiency**		**Achievability**	
	Mean	*SD*	*Mean*	*SD*
Efficient use of simulators in software testing and development	4.8	0.26	4.4	0.25
Agreed upon/Understood specs at an early stage	4.6	0.16	4.3	0.14
Stronger support of product design and new product development through simulation	4.6	0.16	4.3	0.18
Involving customers, customer support and other stakeholder groups in the design project through concept simulation → gaining information about customer needs through their involvement in the design process	4.4	0.18	3.7	0.22
Speeding up product development and testing by utilizing simulation	4.4	0.18	4.6	0.14
Advanced simulation platform provides product development a more in-depth understanding of the product and its uses	4.4	0.22	4.1	0.17
Customer can be involved in the product development and testing at an earlier stage → more versatile information transfer and the overall improvement of understanding	4.4	0.22	3.8	0.27
Unrestricted testing and validation of new ideas for further development	4.3	0.16	4.4	0.14
Presenting product properties is easier	4.3	0.18	4.1	0.23
Improved products increase sales and production	4.3	0.19	3.6	0.16
Better risk management in product design	4.2	0.20	3.2	0.17
Simulation connects functions within the company in a better way	4.0	0.18	3.2	0.19
Supporting sales and marketing activities through simulation	3.9	0.24	4.3	0.22
You can simulate how the product functions in customer's processes	3.3	0.19	3.1	0.17
Managing real-world systems through simulators (digital twin)	3.3	0.29	2.2	0.25
Simulation can find new potential business opportunities while managing the solutions of current endeavors	3.1	0.27	3.0	0.21
The product customization in project deliveries can be controlled more efficiently	2.7	0.28	2.3	0.30
Advanced simulation platform can improve the methods of preemptive maintenance	2.6	0.18	1.9	0.09
Forming and maintaining customer relationships through the simulation platform. Bringing value through services.	2.2	0.19	2.3	0.24

The results of this round would seem to suggest that the most crucial benefits that can be derived from the utilization of simulation seem to be centered around product development. Despite being one of the costliest areas of business processes that most amount of benefits can be gained by improving the overall quality and speed of the product development process. The benefits of product development are also something that the experts generally agreed as being easily achievable. Improved testing capabilities was also one area of product development that was highlighted as cost-efficient and generally easily achievable through simulation. The experts also identified the benefits of risk management but were unsure on how this improvement could be achieved.

On top of the benefits circling around product development another key area of interest was the customer aspect. In this area there were some mixed results as one of the most cost-efficient and easily achievable areas of simulation technology was the ability to use it as a presenting tool to showcase the product's properties. Also, the ability to use simulation as a supporting tool for marketing and sales activities was noted. However, the experts felt that using simulation modeling to form new customer relationships and selling new services to provide more value is neither efficient nor achievable. Despite these two contradictory results the overall potential of customer involvement was seen as crucial. By utilizing simulation methods, the experts felt that the customers could be involved in the product development process in a fashion that is easy and cost-efficient. One of the more unsure aspects of customer interaction through simulation technology was the ability to simulate how a product functions at customer's processes. It would seem there is potential in utilizing simulation in such a fashion, but achievability and cost-efficiency seem moderate. Funnily enough, despite highlighting the potential of involving customers in the product development process the experts also felt that product customization through simulation is neither cost-efficient nor achievable.

Fourth round

The fourth round of the Delphi analysis acted as a way to summarize the overall results gained through the previous questionnaire rounds. The experts were provided with the highlights of the study and were given an opportunity to comment on this summary report.

The process was finalized by presenting the overall results to the panelists at a live conference meeting. During this presentation the final discussions on the results were had and the panelists generally agreed with the outcome. During the discussion on the results of the Delphi analysis, the potential for furthermore in-depth research on the subject matter at hand was also brought up.

5 DISCUSSION

In this section the different themes that arose from the interviews as well as the Delphi questionnaires will be discussed. The similarities and differences surrounding the central themes will be analyzed. Also, the results from these research methods will be connected to the existing literature where possible by comparing how the opinions of the interviewees as well as those of the Delphi panelists match with the existing ideas within the literature. The biggest focus will be put on sections that are the most crucial in terms of providing answers and insight to the research questions of the study.

The literature review part of this study identified that utilizing simulation methods was in no way a new thing within companies – they have been around for a long time. However, the complexity of the simulation models as well as the way they are used have changed in the past years. This was something that could be identified from the interview results as well. The more senior interviewed parties noted that the overall scale of the functions where simulation could be incorporated has widened. The literature also highlighted that the recent technological improvements bring out new possibilities in terms of simulation. The interviewed parties agreed to this as well while bringing up the potential of concepts such as real-time simulation and Digital Twin.

The overall benefits that were identified through this study seem to be centered around product development as well as customer interaction. Through the interviews it was generally agreed that companies invest into simulation technologies in order to optimize their product development processes. After this task has been started or even achieved, they start looking into other areas of interest where simulation could be utilized. This type of thought-process could be identified through the Delphi analysis as well. Despite the focus being on areas of product development, the experts were able to point out multiple benefits in other areas of business where the utilization of simulation could be useful. One common theme arose from both the interviews and the Delphi analysis in terms of how product development changes in the future in terms of using simulation. It would seem there is great interest in utilizing this new technology to incorporate customers into the product development process.

As we identified in the literature review sector of this study, simulation can be utilized in many different areas of a company's processes. Table 22 showcases the key areas of use for simulation in manufacturing that were identified through existing literature. The right column showcases what was the impact of certain area of interest in terms of responses from the interviews as well as the Delphi questionnaires. As we can see, the key areas of use are truly centered around the product. The fact that certain key areas identified in the literature weren't mentioned through the research methods of this study could just mean that simulation isn't yet used in such a fashion or that the impact of being used in such a way was seen as insignificant. Most companies generally agreed that the benefits that could be derived from the use of simulation can only be achieved on the long-term. As simulation technology and its use is exceedingly resource intensive it was noted that this type of long-term mindset and patience are needed – benefits are not seen immediately but instead after a period of time.

Table 22. Key areas of utilization for simulation identified in literature and their importance in this study

Simulation uses in literature	Impact in this study
System and product design	High
Product validation and testing	High
Machine allocation	Not mentioned
Management of finances, logistics, supply chain, quality and knowledge	Medium
Project revision	Medium
Capacity planning	Not mentioned
Production scheduling	Not mentioned

As product development was the area in which companies were mostly utilizing simulation technologies one interesting fact arose. The companies had a very similar opinions on how simulation models and physical prototypes are used and this was seen in both the Delphi analysis as well as the interviews. The general consensus was that simulation models were indeed faster and easier to use but the significance of physical prototypes within the manufacturing industry is still quite immense. The literature provided a somewhat black and white vision, pointing towards the direction of

abandoning physical prototypes in favor of simulation models altogether – the case companies didn't feel the same way. Only one of the companies had removed the idea of having a physical prototype phase in their product development and even in that case, the first sold product sort of acted as the prototype. Most of the companies saw that even if they are using simulation models, physical prototypes still have a certain place within product development. The general idea was that through simulation models you are able to better divide the tasks of product development between the virtual and physical models as per their strengths. Certain aspects such as the overall user experience were much easier to test through physical prototype and the results were more valid. As such the companies saw that the best results are achieved by using simulation models and physical prototypes together. Also, it was noted that it's highly unlikely that they would be able to move away from physical prototypes in the near future even if they tried.

When the interviewees were asked about how are they evaluating the success of the use of simulation in their companies, hardly any of them had ways to measure to quantify the success of a simulation-driven project. However, when the experts of the Delphi panel were asked a similar question to identify ways to measure the long-term impacts of simulation to the business activities the results were drastically different. Table 23 showcases the results of the two selected research methods when it came to identifying ways to assess the benefits of simulation technologies in your business operations. The Delphi method clearly provided more answers from a wider scale. The result could be due to the anonymity of the Delphi process as well as the fact that there was no rush to answer and you could take your time and think. However, result like this clearly speaks in favor of choosing two different research methods. The existing literature didn't provide that many examples on how to monitor the success of utilizing simulation in your business activities. However, the importance of being able to analyze and quantify the usefulness of simulation was noted. For example, Thoeben et al. (2016, p. 13) pointed out that it's crucial, especially for smaller companies, to be able to define and quantify the benefits of the new technology in order to understand how long it will take for your investment to bore fruit. To that extent it's a positive sign that the companies that are a part of this study have different ways of monitoring the success of utilizing simulation instead of just blindly investing resources into it.

Table 23. How can you monitor the success of utilizing simulation technologies?

Multiple case study	Delphi method
• Monitoring profit gained from selling or renting a simulator or by offering training • Cost-accounting • Observing how many resources were spent and where during product development • Comparing to projects where simulation was used to those where physical prototypes were used.	• Truthfulness of automated malfunction notifications. • Amount of maintenance calls • Monitoring product development and testing time • Customer feedback and questionnaires • Customer satisfaction, number of new products and change in market share • Monitoring changes in sales and volumes • Comparing to projects without simulations • The number of physical prototypes required • Measuring the number of new customers and loss of old customers

Identifying the key driving and resisting forces that are affecting the utilization of simulation in companies' business activities was one of the key areas of this research. The multiple case study interviews had a more general approach as it identified some larger themes on what are pushing companies towards utilizing simulation. In most cases it was seen that the company's internal drive to better themselves as well as recognizing the opportunities outweigh the threat of the competition. The interviews also revealed that there might be a certain lack of understanding within the management sector that is slowing down the process of utilizing simulation technologies on a larger scale. The Delphi questionnaires and especially the force field analysis done during the second round of the Delphi analysis gave a more in-depth look into the forces that are driving and resisting the change towards exploiting simulation technologies.

Table 24 showcases a four forces diagram that is showing the combined results from the interviews as well as the force field analysis of the Delphi method. In this diagram the forces resisting the change are further divided into two forces, one of which emphasizes the habit of the present and another that highlights the anxiety surrounding the new technology. The forces that are driving a company towards new behavior are divided into situational factors and the potential of the new technology. The general opinion gained through the Delphi analysis as well as the interviews was that the benefits of simulation far outweigh the issues and that in the future the importance of simulation technology will only grow. In both research methods the aspect of increasing the overall understanding of simulation was brought up. Especially in the interviews it was brought up that through

improved understanding some of the forces resisting the utilization of simulation could be overcome – such as the management sectors lack of knowledge.

Table 8. Four forces diagram on the utilization of simulation

EXISTING BEHAVIOR			NEW BEHAVIOR
	Habit of the present	**Push of the situation**	
	• "Good enough" attitude • Not having to invest more time and money • Lack of understanding by the management	• Fear of being left behind by the competition • Internal drive of being a technological leader • Recognized opportunities	
	Anxiety of the new technology	**Pull of the new technology**	
	• Resource requirements • Workload required by simulator development • Labour requirements • Technical challenges slow down simulation • A hard sell for different departments and fields • Lead time can be a problem	• Improved product development process • Less reliance on physical prototypes • More customer-centric approach • Enabling new solutions • Virtual testing and proactive maintenance • Enables training without physical machine	

The company representatives were asked to identify what the biggest expenses of using simulation technology in their business operations are. On top of this they were asked what the key resources are a company needs to possess in order to gain the most from using simulation. Table 25 shows the comparison of what the companies felt were the biggest expenses and what they saw as the key resources to possess in order to make the utilization of simulation successful. By comparing the two columns you can draw the conclusion that the most crucial resource to have is finances as you can utilize it to gain access to most of the other key resources such as know-how and software. The fact that the most significant expenses are also the key resources is a good thing as it would make no sense to have something immensely expensive that is not considered crucial for the process. As simulation technologies are financially intensive, there are situations where companies are not willing to invest their own finances into gaining access to the required technologies, know-how or other resources. In these cases, you can try to circumvent the issue by the right partnerships, and this is something the case companies are utilizing to a certain degree. By utilizing long-term strategy and involving simulation in the research projects properly you can maximize the return on your financial investment.

Table 9. Expenses and key resources of utilizing simulation

Biggest expenses	Key resources
• Employees, training and know-how • Simulators and other hardware • Software and license fees	• Know-how • Finances • Software • Partners • Working hours • Long-term strategy • Research project involvement

6 CONCLUSIONS

The main research question of this study was the following:

> *What kind of benefits can Finnish manufacturing firms gain by utilizing simulation-related technologies?*

This question can be further explored by the following sub-questions:

> *What kind of resources do firms need to fully exploit these technologies?*
>
> *What are the forces driving and resisting the utilization of new technologies?*

The answers to these questions were gathered through conducting semi-structured interviews in the Finnish manufacturing industry companies. The interviews (n=6) were conducted with the goal of gaining knowledge and insight on the benefits and issues of utilizing simulation technologies in business operations. On top of the interviews a modified version of the Delphi method was used to gather information through survey-like questionnaires. This method provided anonymously shared opinions on each firm's opinions about utilizing simulation technologies. The connections between the interview and Delphi method results were also analyzed and discussed.

This research found multiple different types of benefits that can be acquired by using simulation technologies. Mostly these benefits were centered around product development. Generally, both the Delphi experts as well as the interviewees agreed that by utilizing simulation methods you are able to improve your product development, testing and maintenance. The result would make the process of development both cheaper and faster while also being able to meet customer needs more accurately. The biggest financial benefit for manufacturing firms was the ability to cut on down on the required number of physical prototypes. It was also highlighted that despite having a reducing impact on the amount of physical prototypes required, the simulation models are in no

way going to entirely replace the utilization of a real physical machine. Instead, these two modeling types were seen as complementary and that the best results would be achieved through using both in symphony.

The most important resource the companies felt they needed in their current situation in order to benefit from simulation the most, was a competent employee who was able to use and develop the simulation models. This was also a significant financial expense as the person would have to commit working hours from which they would be paid a salary. The importance of finances was highlighted outside the salary aspect as the cost of simulators as well as the license fees of the required software are quite high. If you lack finances or knowhow you can try to form the right partnerships in order to still be able to benefit from simulation. As attaining the required resources was seen as a financial strain on the company, having a long-term strategy for the utilization of simulation as well as involving it in as many research projects as possible was seen as a crucial aspect as well.

From the interviews the forces driving the utilization of simulation were: Recognized opportunity, internal drive to be an innovator and the threat of competition. The Delphi analysis took a more in-depth approach into figuring out the driving and resisting forces. As a result, we found out that the core of the driving forces is centered around improving all aspects of product development and the functions incorporated in it. The resisting forces are mostly resource-based as you have to invest loads of finances as well as working hours into the simulation model in order to gain benefits from it. The technical complexity as well as the overall lack of knowledge of the management sector was also seen a hindering force.

6.1 Practical implications

The results of this study do have some potential practical implications. It has the potential to help new companies to identify the potential issues they might face when trying to utilize simulation in their business activities. Furthermore, knowing what kinds of benefits can reasonably be expected they can make the decision whether it’s worth to start using simulation technologies in their business operations. This is extremely important

for smaller companies with limited resources who are in a position where they must choose if they want to spend those resources on a new technology.

While in most cases the utilization of simulation technology was done due to a recognized opportunity and the company's internal drive the impact of competition within the industry should not be ignored. In order to seize market opportunities, you need to be aware of the competition as internal drive doesn't always create opportunities alone. The study did note that the case companies had some difficulty in assessing the success and profitability of their simulation-related projects. When you are dealing with a somewhat new technology it's important to think what kinds of implications it has on the markets and on your business operations. You need to be able to quantify the impact simulation has in your business processes in order to truly understand whether it's beneficial or not.

The study identified that the companies had somewhat narrow grasp on the uses of simulation. The existing literature had identified multiple different areas in which it can be used to achieve benefits, but the case companies used it mostly for product development and the surrounding processes.

By identifying that the crucial resource in the utilization of simulation methods is the user this study provides certain implications for education. As we are moving towards more digitalized business models it's crucial that the workforce can keep up with the development. This is something that could be communicated to academic institutes in order to prepare the future students for what they will be facing in their work environment.

6.2 Limitations

There exist certain limitations for this particular research. The focus of the research used research methods and the researchers are factors that are able to have an influence on the study. The industry area this research focused on was Finnish manufacturing industry. In terms of generalizability of the research this has multiple implications. As this study focuses in a single country, there are several cultural factors in Finland that can have a potential impact on how firms act in comparisons to firms from another countries. Also,

the legal system and public policies do differ from country to country. This means that utilizing the results of this study might not be possible outside Finland.

The research questions were examined in the context of manufacturing industry. This generates the second limitation on generalizing the results. Utilizing simulation technology isn't limited to this single industry, which rules out other sectors. Conducting a similar research in a different industry might result in completely different findings.

The used research methods also caused certain limitations. The explorative semi-structured interviews were used as a data collection method and the amount of cases uses was extremely limited. Small sample size in qualitative case study often leads to the inability to generalize the results. The potential number of firms that could be interviewed was also limited by the companies taking part in the DigiPro-project. To compensate for this the Delphi method was used as an additional method of data collection to form a mixed method study. Delphi is a survey like method, thus requiring a high attendance in order to produce the best results. However, this was hard to upkeep as the experts taking part in it had other responsibilities and perhaps a lack of interest to take part in this survey method.

Purposive sampling method was used to further shrink the company pool for the interview part of the thesis. This was done so that the companies chosen would be somewhat similar size with similar goals. What companies were eventually chosen for the research was up to the researcher's subjective judgement based on the selected criteria. This bias was reduced by discussing the chosen case companies with the instructors of this study before deciding on the final group of companies.

For the semi-structured interviews, a certain set of themes was chosen, and the interviews were built around these. There is a chance that some important theme was left out and potential interesting insights were not obtained for the research agenda. The chance of this happening was reduced by selecting themes that were visibly present in the existing literature. The interviews were somewhat flexible which allowed both the interviewee and the interviewer to bring up topics and issues that felt needed, even if they were outside

of the original interview-structure. The goal was to interview a person from the company that was highly involved in the utilization of simulation technologies, so that the interviewed person would have deep knowledge about the subject and the required expertise to know what to focus on.

As Sanders et al. (2009, p. 326) pointed out, in a semi-structured interview there can be bias on both sides of the interview. The person interviewed might want to only discuss certain things about their firms and leave something out. Not all of the interviewees were high ranking management, thus they might not want to bring up negative issues or problems as much. The lack of information around a certain theme might mean that the participants didn't wish to discuss those subjects. On the contrary, the interviewee might want to heavily focus on what is being done well or bring up issues that can benefit them. You also have to note that the interviewees might understand a question differently or they can interpret a definition in a unique way. The risk of this happening was reduced by having multiple questions under different themes that had the chance to overlap, so that a follow-up question might actually give a clearer answer to something that was already asked.

The companies were at different stages in terms of the utilization of simulation technology and this could also be a potential source of bias. Some were not utilizing the technology while others had it implemented into their business processes in a comprehensive way. Due to this, certain companies may have faced different challenges and attained different benefits, which can introduce a bias within the sample.

The gathered data is subject to being analyzed by the researcher which brings a certain amount of subjectivity into the research when it comes to interpreting the results. This stems from the personal views and experiences the researcher has about the study's topic. The impact of this subjectivity was reduced by examining existing literature beforehand. Recording and transcribing the interviews also has a bias reducing impact on the study.

6.3 Future research

This research focused heavily on ‘what’ type of questions. There is a potential research gap where someone could focus by answering ‘why’ and ‘how’ questions which would deepen the knowledge on the reasoning behind a firm’s actions. Why don’t firms collaborate with other firms? Why do they have problems especially in the implementation of a new technology? How do they attain the required resources to utilize simulation technologies? This type of research could shed light to the reasons behind the decisions the companies have taken and provide further information on what types of choices firms have to make when utilizing a new simulation related technology.

Moving the research into another context could also be a way of furthering the study on the benefits of simulation technology. Similar research could be conducted in industries other than manufacturing. Through this type of cross-industry comparison you could find out the similarities and differences of firms that utilize simulation technology. In similar fashion you could conduct the research in different country which in turn would provide insights into cultural and political differences and what kind of impact these have.

Furthermore, you could combine the results with numerical data. This way you could evaluate the effect of simulation technology to company performance. You could examine if utilizing simulation technology has had significant impact on the company’s growth in terms of personnel count, net worth or even foreign and domestic sales numbers. Albeit doing research like this would be difficult and ideally you would need companies that are just about starting to utilize simulation technologies and then wait a few years to make the results more apparent.

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APPENDIX 1: H2020 PROJECTS INVOLVING SIMULATION

Project name	Start	End	Project type	Focus
A Novel, Comprehensible, Ultra-Fast, Security-Aware CPS Simulator	1.2.2015	31.1.2018	Research and Innovation	Simulation
Twin-model based virtual manufacturing for machine tool-process simulation and control	1.10.2015	30.9.2018	Research and Innovation action	Simulation
Integrated Toll chain for model-based design of CPS	1.1.2015	31.12.2017	Research and Innovation action	Collaborative design and modelling
Product Service Design and Manufacturing Intelligence Engineering Platform	1.2.2015	31.1.2018	Research and Innovation action	PLM/SLM Collaborative design
Innovative Modeling Approaches for Production Systems to raise validation efficiency	1.9.2015	31.8.2018	Research and innovation action	Factory of The Future
Multi-disciplinary integrated simulation and forecasting tools empowered by digital continuity and continuous real-world synchronization, towards reduced time to production and optimization	1.10.2015	30.9.2018	Research and Innovation action	Factory of the Future
Factories of the Future Resources, Technology, Infrastructure and Services for Simulation and Modelling 2	1.11.2015	31.10.2018	Innovation action	Simulation models, tools and data-analytics
Trans-Atlantic Modelling and Simulation for Cyber-Physical Systems	1.2.2015	31.1.2018	Research and Innovation action	Modelling and Simulation
Cloud Manufacturing and Social Software Based Context Sensitive Product-Service Engineering Environment for Globally Distributed Enterprise	1.2.2015	31.1.2018	Research and Innovation action	Collaborative design and manufacturing
And Integrated Collaborative Platform for Managing the Product-Service Engineering Lifecycle	1.1.2015	31.12.2018	Research and Innovation action	Collaborative design and manufacturing
Customer-driven design of product-services and production networks to adapt to regional market requirements	1.1.2015	31.12.2017	Research and Innovation action	PLM
Simulation in Real Time for Manufacturing with Zero Defects	01.10.2016	31.03.2020	Innovation action	Real-time simulation
Digital Reality in Zero Defect Manufacturing	01.01.2019	31.03.2022	Innovation action	Factory of The Future
Integrated Development 4.0	01.05.2018	30.04.2021	Innovation action	Collaborative design

APPENDIX 2: INTERVIEW OUTLINE

1. Interviewee's name and position at the company
2. Interviewee's time as part of the company
3. Experience (in years) from working with simulation methods or similar technologies

Importance of simulation technologies now and in the future

1. What kinds of changes in terms of simulation technologies have you witnessed during your career?
2. To what degree is simulation a part of the company's processes at the moment?
3. What kinds of benefits have you achieved through the utilization of simulation technologies? What are you aiming for in the future?
4. What are your company's key goals, and can simulation methods be used to achieve these?

Opportunities and challenges

1. What has driven your company towards utilizing simulation technologies?
2. What long- and short-term benefits can be achieved through simulation?
3. Is the implementation process of a new simulation method difficult in your company?
4. How do you evaluate the success and cost-effectivity of utilizing simulation technologies?
5. If the implementation process is successful, what kinds of changes will happen in the company's processes?

Resources

1. Is it cheaper to utilize simulation rather than physical prototypes?
2. What are the costs that are the direct result of utilizing simulation technologies?
3. Is the fast improvement of technology a threat or an opportunity for your company?
4. What are the key resources a company must have in order to utilize simulation technology to its fullest potential?