Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Mechanical and Industrial Engineering

Madeleine Ruiz Høyer

Developing a Product-Service Business Model for a Semi-Process Manufacturing Company in the Digital Era

Master's thesis in Production Management
Supervisor: Jan Ola Strandhagen, Olumide Oluyisola
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Preface

This master thesis was conducted during the spring 2019 and it is part of the 5-year master's program in Mechanical Engineering at the Norwegian University of Technology and Science (NTNU), Trondheim. The project was carried out in the Department of Mechanical and Industrial Engineering in the specialisation Operations Management.

I would like to specifically thank my supervisor and co-supervisor, Ola Strandhagen and Olumide Oluyisola for their feedback and support throughout the entire project. I am very grateful to Pipelife, the case company, for having given me valuable insight in the company. Alongside, I would like to thank Surnadal municipality who have participated in the research and have offered an essential contribution towards the project. Finally, I would like to thank my fellow students and family that have been a great support and motivation along the way who made this semester enjoyable and provided the extra boost each day.

Madeleine Ruiz Høyer

Trondheim, June 2019

Summary

Purpose. Increasing digitalisation, competition and commoditisation are forcing manufacturers to consider new ways of offering their products such that they can remain competitive and sustainable. Smart product-service systems (PSS) bundle services and manufactured products enhanced with sensors. This thesis suggests different product-service offerings which a pipe manufacturer can offer such that they remain attractive to their customers, regardless of the changing market conditions and customer expectations.

Design/methodology/approach. A systematic literature review has been conducted to explore the existing literature on PSS and semi-structured interviews have complemented the findings. Various PSS solutions tailored towards water pipes are proposed based on the gained insights.

Findings. The literature review supports the increasing popularisation in bundling manufactured products with services. Existing literature confirms that PSS will differentiate a manufacturer from their competitors and allow them to both meet customer requirements more accurately and deliver greater value. Nonetheless, challenges must be considered simultaneously. A PSS scale has been created and tailored towards the water distribution industry. With the input from interviews, the most attractive solution bundle satisfying the current situation has been suggested, and the challenges and the impacts it will have on the current operations have been discussed.

Research limitations/implications. Since the PSS scale has been created based on the input from only a manufacturer and a customer, future research should be extended to several similar cases. The thesis is limited by the two databases accessed, the search criteria, the search method, the inclusion and exclusion criteria, and the time constraint.

Practical implications. Conventional manufacturers must identify new ways of delivering value to their customers and this can be achieved by complementing their products with services.

Originality/value. The thesis explores the literature on the evolution of PSS in manufacturing and suggests a new PSS scale created in collaboration with the case companies. This appears to be the first paper to address utility products like plastic water pipes.

Sammendrag

Hensikt. Økende digitalisering, konkurranse og kommoditisering tvinger produsenter til å vurdere nye måter å tilby produktene sine på slik at de kan forbli konkurransedyktige og bærekraftige. Smart «Product-service systems» (PSS) kombinerer tjenester og konvensjonelle produkter som har blitt forbedret med sensorer. Denne masteroppgaven forslår ulike produkttjenestetilbud som en rørprodusent kan tilby kunder slik at de forblir konkurransedyktige, til tross for de endrede markedsforholdene og kundenes forventninger.

Design / metode / tilnærming. En systematisk litteraturstudie er gjennomført for å utforske den eksisterende litteraturen om PSS og semi-strukturerte intervjuer har komplementert funnene. Ulike PSS-løsninger tilpasset vannrør er foreslått basert på denne litteraturstudien, intervjuene og egne refleksjoner.

Funn. Litteraturstudiet støtter den økende populariseringen av fenomenet som kombinerer produkter med tjenester. Litteraturen bekrefter at PSS vil skille en produsent fra sine konkurrenter, og vil gi dem muligheten til å møte både kundens krav mer nøyaktig og i tillegg gi større verdi. Likevel må utfordringer vurderes. En PSS-skala er laget og skreddersydd for vanndistribusjonsindustrien. Med innspill fra intervjuer har de mest attraktive løsningene blitt foreslått, og utfordringene og konsekvensene for en spesifikk løsning har blitt diskutert.

Forskningsbegrensninger / implikasjoner. Siden PSS-skalaen er opprettet basert på input fra bare en produsent og en kunde, bør fremtidig forskning utvides til flere lignende tilfeller. Masteroppgaven er begrenset av de to tilgjengelige databasene, søkekriteriene, søkemetoden, inkluderings- og ekskluderingskriteriene og tidsbegrensningen.

Praktiske implikasjoner. Konvensjonelle produsenter må identifisere nye måter å levere verdi til sine kunder, og dette kan oppnås ved å komplementere produkter med tjenester.

Originalitet / verdi. Oppgaven undersøker litteraturen om utviklingen av PSS i produksjonen, og foreslår en ny PSS-skala skapt i samarbeid med bedriftene. Det tyder på at dette er den første oppgaven som omhandler forsyningsprodukter som plastrør.

Nomenclature

CPS - Cyber-physical systems

I4.0 - Industry 4.0

IoT - Internet of Things

KPI - Key performance index

OEM - Original equipment manufacturer

PSS - Product-service systems

RFID - Radiofrequency identification

SCP - Smart connected products

TLM - Through life management

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1. Introduction

Market leading manufacturers are facing a critical situation which will determine their success and market domination in the future. Competitive pressures and turbulent business environments have pushed companies toward innovation (Abdelkafi & Pero, 2018). The question is no longer if a company has to change but rather where and how it has to change (Meyer, R.J.H., 2007). Innovation in the 21st century is omnipresent, especially in the digitalisation of products and operations and it is expected to progress. To retain their market position and to continue to satisfy customer expectations, they must keep up with the technological advances and especially focus on digitalisation. The order qualifier winners, cost, time, delivery precision and flexibility (Lin & Tseng, 2016) remain imperative, however with increasing competition companies must consider changing their value offerings and business models to continue to stand out from the competitors.

Companies must think of new ways of making money (Johnson, M.W., 2010) and a suggestion is product-service systems (PSS) (Baines et al., 2009). This involves complementing a service to a product to either create additional value or a new offering to the customer. Combining PSS with digital technologies will become a powerful means to manufacturing competitiveness as it will allow them to acquire new knowledge management capabilities (Smith, D.J., 2013). This will allow the manufacturers to better understand their customers and be fully aware of how their products interact with the environment. Ultimately, their products will be both tailored and better aligned with actual customer needs. This is achieved by embedding Big Data infrastructures and potentially creating digital twins (Siemens, 2019). These are key aspects in the digital future and offering services has sparked the interest of a growing number of manufacturers (Bustinza et al., 2015).

Manufacturers are becoming aware of the digital disruption and the Industry 4.0 technologies and they can quickly embrace these opportunities. Nonetheless, there is less awareness around how it can impact current operations and business models. Many rely on old business models that satisfy another age and are misaligned with the requirements for the transition towards the digital era. Thus, the emergence of business model innovation (Osterwalder & Pigneur, 2010) must be in focus if the digital disruption is to occur successfully.

The water distribution industry has been conservative with digitalisation and adoption of technology. Increased globalisation and urbanisation will stress water management while climate change will magnify the extremes further. Water is a scarce, valuable and vital resource and it is critical to find new solutions for controlling and managing water flow and water quality. Norway can be subject to extreme stormwater and pipe manufacturers are seizing the opportunity and making it their corporate social responsibility to safely transport water. They are proposing smart pipes and smart water management and the suggestion is backed by both The Research Council of Norway and Norsk Vann, a Norwegian non-commercial interest organisation for water.

Water pipes have already featured in the context of Industry 4.0. Klaus Schwab, founder of the World Economic Forum, discusses urban innovation on national and global scale in the dawn of Industry 4.0. He suggests "Waternet", an internet of pipes which would employ sensors every couple of meters, often in valve locations, and which would control flow and manage the complete water cycle for human and ecological needs. The pipes would detect and indicate both when and where leakages were present. Early detection would facilitate quick repairs and limit the ejection of large volumes of water. Rapid and efficient repairs would incur lower costs and make the initial investments in instrumented pipes worthwhile (Martínez, M., 2018).

Although commercial sensors for monitoring flow and quality exist, water pipelines are not commonly equipped with them as a result of cost, inaccessibility of already buried pipes and the lack of suitable systems (Metje et al., 2011). Nonetheless, major developments have occurred in wireless monitoring systems that supervise buried utility systems (e.g. wireless sensor devices, power sources and sensor systems) (Akyildiz & Stuntebeck, 2006). The improvements and the reduction in cost suggest that Schwab's vision of smart pipes and ultimately a "Waternet" may be feasible and closer to the future than initially believed.

2. Problem description

2.1 Motivation

Focusing on the water distribution network

The water industry has been lagging in technology and innovation, but the industry can no longer afford to be slow. Water and wastewater pipes make up a network of approximately 90 000km – a distance equivalent to twice the circumference of the Earth (Norsk Vann, 2019) and on average one third of the water supplied disappears due to leakages. Some regions report having as high as 50% losses. Furthermore, with a third of the pipes being laid in the ground before 1970, it is inevitable that these older pipes are of poorer quality (Norsk Vann, 2019) and can impact human health and safety.

Moreover, tampering large bodies of water that serve as sources for drinking water can become a new act of terrorism which can affect entire cities. Hence, water distributors are becoming increasingly aware of the need for more frequent and accurate surveillance of water.

A pipe manufacturer becoming a service provider

An abundance of examples show that manufacturers are turning to offering additional services because it allows them to both create additional value and it allows them to differentiate themselves. Some couple their manufactured products with services, others take a step further and just offer services. As digitalisation increases, it is predicted that this trend will fortify in the coming years. Some examples will follow which illustrate different methods of combining services and products (Baines et al., 2017).

Rolls-Royce. The aero-engine manufacturer leases engines to the airlines and offer "power by the hour" (Smith, 2013). They monitor data generated by the engines, predict maintenance problems and perform the required work. Downtime is reduced and money is saved (Emerald Publishing, 2019) making this solution better aligned with both their own and the customer's requirements.

Caterpillar. The construction machinery and equipment company offer a portfolio of services. An example is the fleet management, the remote tracking and monitoring of the equipment which provides the customer with updates on both location and information on preventive maintenance. The customer benefits from a tool for decision making which optimises performance, the component's extended life and reduced downtime (Emerald Publishing, 2019).

Philips Lighting. Philips have started to offer lighting as a service (Philips, 2019), where they cover the upfront installation costs and get compensated through a "performance contract". This contract is based on the energy savings the retrofit produces compared to the original solution (Fried, 2014). Through the monitoring of these light fittings, they offer maintenance service.

Deciding for the adequate service varies according to the manufacturer's products and industry. Adding services to water pipes is unusual, hence the challenge will be to develop this successfully.

2.2 Research gap

The emergence of PSS, particularly smart PSS, has been identified as a profitable value creation and is becoming popular amongst manufacturers (Brax & Jonsson, 2009; Westergren, U.H., 2011). Nonetheless, the research on the individual characteristics of smart services is limited (Grubic, T., 2014; Ostrom et al., 2015) and the existing research is only covered with descriptive case studies.

Most descriptive case studies generalise observations and the examples covered in literature tend to address OEMs that manufacture technically complex and advanced products (i.e. turbines and machinery). Nonetheless, there is little research and few examples on how simple utility products, like water pipes, can transition from being tangible products to PSS. Grubic & Peppard (2016) state that studies focusing on the challenges of smart services seem to be particularly scarce. By exploring the existing literature and studying the water distribution industry, the thesis intends to fill these gaps.

3. Research objectives, questions and scope

Production Planning & Control are requesting research on "The Management of Operations towards the next generation of Manufacturing: Implications of Big Data and Digitalisation in the context of Industry 4.0". The objective is to get an understanding of how the technological disruption will influence traditional manufacturing.

Traditional manufacturers are becoming increasingly aware of directing their focus towards services. Till recent, complementing products with services and the concept Industry 4.0 have been two separate fields of study (Liao et al., 2017; Diaz-Garrido et al., 2018). The former basing itself on customer value and the latter on manufacturing process value (Tongur et al., 2014; Coreynen et al., 2017). The two fields are now becoming heavily intertwined, and since both have strategic and competitive implications, the fields are now being studied collectively. For a pipe manufacturer, by installing sensors on their pipes, this could mean extending their customer-manufacturer relationship and provide water as a service instead of delivering a pipe.

Research objective: *Identify new product offerings which a pipe manufacturer can offer to customers when the manufacturer undergoes a digital transformation and shifts towards product-service systems and then evaluate how this will work in practice.*

3.1 Research goals and questions

The research objective will be achieved by answering the following research questions:

Research question 1: AS-IS situation

1.1 Analyse which factors are currently driving a utility manufacturer into investigating the possibilities of complementing their manufactured products with services?

A readiness assessment is a systematic analysis that quantifies an organisation's ability to undergo a transformational process, here an Industry 4.0 implementation project. The assessment identifies a company's available resources, assets and strengths. It will also identify gaps and barriers for realising the project. This readiness evaluation will ensure a seamless and successful transition (Oliva & Kallenberg, 2003; Davies et al., 2006; Rondini et al., 2016; Zancul et al., 2016; Baines et al., 2017).

By considering specific traits, RQ1 will identify an appropriate readiness model to evaluate the case company. The results will indicate the underlying grounds for venturing into this project and will support the decision-making. The assessment will suggest actions which can raise the level of maturity and a specific action will be analysed in detail. This will be the focus of RQ1 and RQ2.

Research question 2: Bundled product-service solutions

2.1 Which are the different combinations of bundling products with services for a pipe manufacturer?

2.2 How can these bundled solutions be illustrated on a product-service scale which ranges from offering a tangible product to strictly offering a service?

Currently, both the pipe manufacturer and their customers have a traditional view on pipes; the customer requires a product which transports water and the manufacturers offers pipes. The purpose of RQ2 is to reflect on how a pipe manufacturer can digitalise their plastic water pipes. By challenging their current views, it will be discovered how a pipe manufacturer will satisfy their customers' actual needs in a digital future and it will be reconsidered how the transformed products will achieve this.

Depending on both the manufacturer's capabilities and the customer's needs there will be different possible levels of digitalising the product. These various levels will be defined and assessed with the support of a structured literature review. A hypothesis is that RQ2 can be summarised in a scale representing the extent of which their product offers a service. The scale would range from entirely product based to fully service oriented. It is essential to define what is meant by product. A manufacturer will always offer a product, but the distinction must be done between a manufacturer who offers a physical product and a service (an intangible product). However, for a manufacturer to deliver a service a physical product must always be produced.

Research question 3: TO-BE solution

3.1 In a TO-BE scenario, which product-service bundle will be the most appropriate to adopt?

3.2 Which challenges will the manufacturer address when changing their offerings and how will they impact Pipelife's operations and business support functions?

After identifying different product-service bundles in RQ2, RQ3 will focus on interviews and assess which solution will be the most adequate for the manufacturer to focus on. After the selection, the challenges which the manufacturer will encounter must be analysed. Furthermore, as a result of adopting a PSS structure there are multiple aspects of their operations and business support functions which must be addressed so several of these essential elements are then raised.

3.2 Research scope

To achieve the research objective, the thesis addresses a broad range of multidisciplinary topics and integrates the findings such that the research questions are answered. The foundation is built on Industrial Engineering, with a specific focus on Production Engineering, Management Science, and Operations Engineering and Management. Operations Management is of great importance and concerns designing, planning and controlling the production processes and redesigning business operations in the smoothest, most reasonable and most economical way. Thus, minimising the use of resources and carefully meeting customer requirements. It describes how the inputs (raw material, labour and energy) are transformed to outputs (goods and services) by coordinating suppliers, customers and technology. This requires the management of both strategic and day to day processes and decisions. The mentioned interdisciplinary studies enable problem solving and decision making in organisations and address management economics and business engineering.

The dichotomy of product and services is becoming outdated and it is being replaced by product-service systems. Products are having a higher service component than ever before, hence calling for the need to address topics such as service economy, extended producer responsibility and life cycle thinking. It is particularly being encouraged by the advances made in technology, IT and connectivity between devices. The differences between products and services are that services are produced and consumed simultaneously, they are perishable, the manufacturer retains the ownership and they are intangible. The major contrasts between the two fundamentally change the bases of business and makes it necessary to analyse how business models must be altered.

The project will focus on defining a PSS scale ranging from a company being entirely manufacturing based to a company being fully service oriented. The intermediary stages between the extremes will also be defined (figure 1). Each of the stages will have certain characteristics which differentiate them, and in the figure, these have been named “factors”. As the digitalisation level progresses in their service orientation, an increasing number of factors will be ticked, and this has been illustrated. The case company Pipelife is currently entirely manufacturing based and through interviews it will be concluded where they envision themselves in five years. This will need to be aligned with the customer’s requirements and needs. As they transition towards a new state, an organisational ambivalence will arise as a result of the coexistence between the product and service orientation (Lenka, S.R. et al., 2018), thus making it necessary to explore the challenges and the pitfalls that Pipelife will need to acknowledge during this transformation.

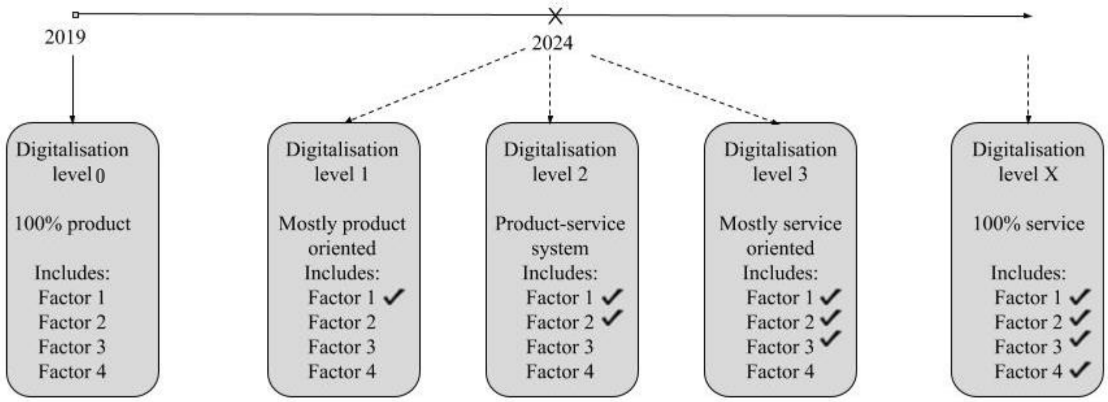

Figure 1. The scale of digitalisation ranges from fully product oriented to fully service oriented. The figure illustrates different levels of digitalisation which Pipelife could adopt the next five years.

4. Research design

4.1 Literature sampling

A systematic literature review technique is a process which “synthesises research in a systematic, transparent, and reproducible manner to inform policy and decision making” (Tranfield et al., 2003, p. 209). Therefore, the following five-step process was selected in order to identify, select and critically evaluate the existing body of literature (Tranfield et al., 2003) on digital transformation of supply chains through the development of PSS. The strength of adopting this technique is that it avoids biases from the literature reviews which are found. Moreover, if executed objectively and critically, the review will accurately summarise the accumulated body of knowledge, investigate the existing knowledge from different perspectives and establish new reliable results from a pool of knowledge dispersed across various fields (Tranfield et al., 2003; Gligor & Holcomb, 2012). A literature review of qualitative nature consists of a literature collection, a descriptive analysis, a category selection and a material evaluation (Mayring,P., 2003).

The entire methodology of the thesis has consisted of 1) Problem formulation: a detailed planning and scoping of search; 2) Literature search: a rigorous execution to identify and select publications; 3) Selection and evaluation of literature: an assessment of the quality, relevance and strength of results; 4) Research analysis and interpretation: a compilation and analysis of the results, and 5) Presentation of results (Denyer & Tranfield, 2009). The first three steps in this technique are of great importance as they will determine the quality and the credibility of the entire thesis.

The design of the structured literature review will now be presented. While the problem formulation and the literature collection will be discussed in this section, the literature sampling, the process of descriptive analysis, the category selection and the material evaluation are discussed in the section “Findings from the literature study”.

Problem formulation. The case company was already selected and through discussions with the manager of digital innovation and transformation, professors in the Department of Mechanical and Industrial Engineering at NTNU and the request from Production Planning & Control to research “The Management of Operations Towards the next generation of Manufacturing: Implications of Big Data and Digitalisation in the context of Industry 4.0” in more depth, the initial problem description took shape. While creating the final problem formulation was an iterative process, the initial formulation evolved based on these inputs.

Literature collection. The first step in this process involved creating a pool of relevant research papers covering the topics of PSS, digitalisation of products and business model innovation caused by PSS. This was achieved by doing a preliminary random search in google scholar. The main objective was to explore the research and the keywords used in existing relevant papers and hence use these in the structured literature search. The structured literature search was done in the online databases: Emerald Insight and Science Direct. The papers were to date from the last 20 years and they could only originate from published journals. Emerald Insight required a combination of keywords categorised into various blocks, whereas Science Direct required one to distribute keywords in either keywords to be found in the main body of the article or in the title, abstract or in the keywords list.

4.2 Interview

Semi-structured interviews serve as exploratory and evaluation research and have contributed with valuable insight (Matthews & Ross, 2010). The theory can be better understood through observing actual practice in the nature and habitat of where the research takes place. It also provides exploratory research while some of the variables and parameters are still unknown. Case studies benefit the quality of the results and strengthen the research (Voss et al., 2002) since research on PSS for utility products is limited. However, great care must be taken when using few cases because a danger is to generalise the observations.

A semi-structured interview has a less rigid interview structure and allows the interviewee to provide additional information and makes it easier to elaborate on the questions and the answers in the interview guide (Appendices A). The interviews may cast light on aspects not discussed in the literature review. In this thesis, the manufacturer’s point of view has not been described in other research papers. The evaluation research analysed the correlations and the discrepancies between the literature study and the interviews. This was valuable because research does not always reflect the reality in industry.

Another advantage with structured interviews is that it will guide and ensure that the questions are covered, and that the conversation does not diverge (Matthews & Ross, 2010).

The quality of the interviews will be dependent on how skilled the interviewer is performing the interview. To achieve the best results, the interviewer must ask good questions, be a good listener and be unbiased by pre-conceived ideas (Yin, R.K., 2013). A disadvantage with these interviews is that the interviewee can steer the conversation based on personal irrelevant interests. The interviewee may be vulnerable to the interviewer's opinion which can be reflected in the answers.

Figure 2 illustrates the thesis' methodology. It can be divided into the different processes which have already been discussed. Although the representation is chronological, completing the thesis has been an iterative process. The problem definition has been continuously renewed as a result of the new impressions and interpretations that have risen as the pool of knowledge has increased. The thesis has been written simultaneously.

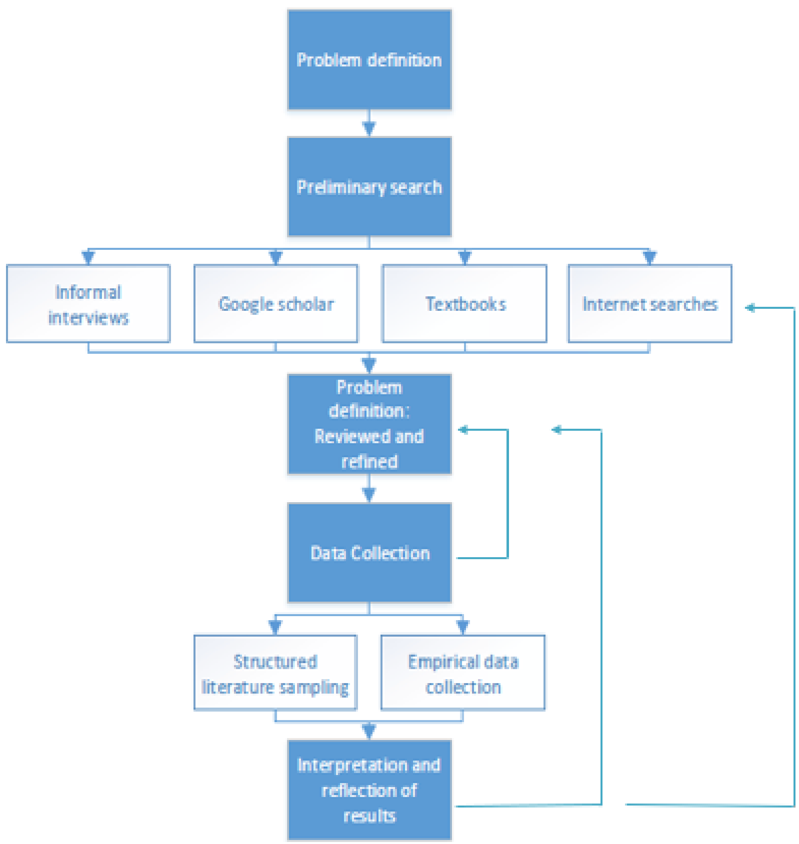

Figure 2. The process for collecting the required information and data. This was achieved by a preliminary search, then a structured literature research, an empirical data (interviews) collection and finally a reflection.

5. Findings and reasonings from literature study

5.1 Findings from literature study

Literature sampling. After several iterative rounds, the final combination of keywords resulted in 68 hits in Emerald Insight (table 1) and 37 hits in Science Direct. In Science Direct, "digital twins" OR "IOT" OR "big data" OR "industry 4.0" were to be found within the article and ("servitisation" OR " smart product service system" OR "digital transformation" OR "disruption") AND ("digitalization" OR "connectivity") AND ("manufacturing" OR "production management" OR "operations management") were to be found in the title, abstract or keywords.

Table 1. The final combination of keywords in Emerald Insight.

Block 1	Block 2	Block 3
Servitisation	Manufacturing	Digitalisation
Smart product service system	Operations management	Digital twins
Digital disruption	Production management	IoT
		Big data
		Industry 4.0

Descriptive analysis. The titles and the abstracts were skimmed for the 105 articles to assess whether they focused on PSS in manufacturing or any synonym related to this concept. Applying the inclusion and the exclusion criteria (table 2) resulted in reducing it to 54 papers. 14 had a questionable relevance, but they were kept ensuring that potentially valuable information was not eliminated. This analysis was a tedious process, but it was considered worthwhile since it would raise the quality, reliability and the accuracy of the knowledge pool used in the thesis.

Table 2. The inclusion and the exclusion criteria for the selection of the research papers.

Inclusion criteria	Reasons
Dating from the past 20 years	PSS is a recent phenomenon. Include papers from 1999-2019.
Research and review articles	To ensure high validity and credibility.
Manufacturing/production industry	To specifically address manufactured and assembled products which can be comparable to pipes.
All geographical locations	Geographical position was not deemed a factor influencing PSS.
All methodologies	To reach both empirical and theoretical research.
PSS and synonyms	The number of papers addressing the topic is increasing but the nomenclature varies (table 5).
Topics addressing the essence of PSS	PSS relates to digital disruption, end to end perspective, value co-creation in manufacturing, business model innovation, IoT and Big data.
Exclusion criteria	
Process industry	Paints and chemicals were irrelevant for PSS.
Other industries	E.g. music, media, textile.

Non-English articles	To eliminate the risk of inaccurate translation.
Abstracts, conference papers, books and chapters	Papers not making scientific contribution to the field. Their validity is not guaranteed, and they summarise existing research presented in journal papers.
Deceiving keyword(s)	Some keywords in the abstracts do not reflect the relevant scope.
General remarks on Industry 4.0	IoT and Big Data not addressing PSS is inaccurate. Additive manufacturing and ICT platforms is irrelevant.
Co-creation mechanisms	Co-creation of services without physical products were irrelevant. Service system entities related to risk sharing, rewards and governance were irrelevant.

Category selection. The selected papers were evaluated based on their relevance to the scope. To achieve this, the quality of the study was considered, and the inclusion and the exclusion criteria were adopted.

Of the 14 questionable papers, five were eliminated. Nine of the remaining papers did not address PSS but did address readiness and maturity models. Although they did not satisfy the criteria of containing research related to PSS they were kept as they appeared relevant for the rigour of RQ1. The same applied for an IFAC conference paper which defined various types of digital twins. Table 3 illustrates the 44 papers used in the thesis.

Table 3. The 44 papers from the literature review used in the project.

Author	Year	Journal	Number of citations
Bustinza et al.	2013	Supply Chain Management: An International Journal	106
Holmström & Partanen	2014	Supply Chain Management: An International Journal	85
Brennan et al.	2015	International Journal of Operations & Production Mgt	60
Eloranta & Turunen	2015	Journal of Service Management	81
Kohtamäki & Helo	2015	Benchmarking: An International Journal	18
Roos & O'Connor	2015	Journal of Intellectual Capital	13
Wang et al.	2015	Industrial Management & Data Systems	14
Bogner et al.	2016	Procedia CIRP	8
Gerpott & May	2016	Info	18
MacCarthy et al.	2016	International Journal of Operations & Production Mgt	50
Viitamo et al.	2016	Outsourcing: An International Journal	1
Zancul et al.	2016	Business Process Management Journal	36
Altuntas Vural	2017	Journal of Business & Industrial Marketing	4
Baines et al.	2017	International Journal of Operations & Production Mgt	144
Brax et al.	2017	International Journal of Operations & Production Mgt	24
Gebauer et al.	2017	Journal of Service Management	6
Kache & Seuring	2017	International Journal of Operations & Production Mgt	77
Abdelkafi & Pero	2018	Business Process Management Journal	3
Aryal et al.	2018	Supply Chain Management: An International Journal	-
Breidbach et al.	2018	Journal of Service Management	6
Field et al.	2018	Journal of Service Management	7
Frishammer et al.	2018	European Management Journal	8

Hasselblatt et al.	2018	Journal of Business & Industrial Marketing	4
Issa et al.	2018	Procedia CIRP	2
Klein et al.	2018	Journal of Business & Industrial Marketing	-
Kritzinger et al.	2018	IFAC-Papers Online	9
Lim et al.	2018	Journal of Service Theory and Practice	18
Matzler et al.	2018	Journal of Business Strategy	-
Paschou et al.	2018	Procedia CIRP	-
Pezzotta et al.	2018	Journal of Manufacturing Technology Management	1
Turunen et al.	2018	Journal of Business & Industrial Marketing	-
Ünal et al.	2018	Journal of Manufacturing Technology Management	3
Zheng et al.	2018	Journal of Cleaner Production	13
Calatayud et al.	2019	Supply Chain Management: An International Journal	-
ElMaraghy, H.	2019	Procedia Manufacturing	-
Frank et al.	2019	International Journal of Production Economics	4
Frank et al.	2019	Technological Forecasting and Social Change	-
Hendler, S.	2019	European Journal of Innovation Management	-
Kreye, M.E.	2019	International Journal of Operations & Production Mgt	2
Martinelli & Tunisini	2019	Journal of Business & Industrial Marketing	-
Matthyssens, P.	2019	Journal of Business & Industrial Marketing	-
Neirotti & Pesce	2019	European Journal of Innovation Management	-
Sony & Naik	2019	Benchmarking: An International Journal	1
Zheng et al.	2019	Advanced Engineering Informatics	-

The growing body of research covering PSS in the past two decades reflects the increasing interest in researching how manufacturing industries are choosing to bundle products and services. No relevant papers were selected till 2013 and since then, over the span of five years, it has gone from one paper to 16 published papers per year. There are several reasons for this evolution, and they will be discussed later in the thesis. Most of the papers state that these topics must be researched in more detail, and with figure 3, the relevance of the chosen topic for the thesis is evident.

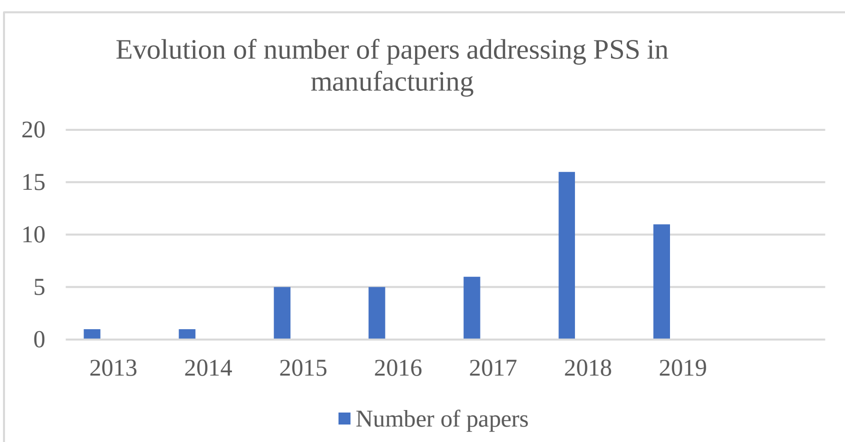

Figure 3. The rising popularity in researching PSS, servitisation and digitalisation for manufacturing industries.

Material evaluation. An excel spreadsheet was created which combined basic bibliographic information (i.e. the title, the number of citations, the year, the authors, the publishing journal, the keywords, the reference) and specific details that were deemed of significant value. Annotations were taken describing the purpose, the methodology, the results and the conclusion of the individual papers. Special attention was focused on whether the papers addressed topics such as PSS and digitalisation, and whether innovation, changes, requirements, benefits, challenges and gaps in supply chains and in business models in the context of PSS were mentioned. The spreadsheet led to table 4, a classification of the papers' contents, and eased the process of retracing relevant information.

The material evaluation resulted in discovering 17 synonyms for the concept of "Product-Service Systems" (table 5). The concept was first introduced as "servitisation" by Vandermerwe & Rada (1988). Nonetheless, it is important to clarify one major difference between the synonyms. For Vandermerwe & Rada, "servitisation" involved bundling products and services together in order to offer greater value for both the manufacturer and the customer. However, in the dawn of Industry 4.0, the concept PSS (MacCarthy et al., 2016; Pezzotta et al., 2018; Zheng et al., 2018; Frank et al., 2019; Matthyssens, 2019; Sony & Naik, 2019 ; Zheng et al., 2019) has gained popularity as manufacturers equip their traditional products with sensors. It enables them to monitor the product's performance throughout its lifetime and can leverage new ways of providing value to their customers. The transition from products to PSS is still of nascent nature, therefore the synonyms are frequently used interchangeably in literature to denote the same concept.

Table 4. A brief classification of the contents of the 44 papers based on the material selection process.

Author	**Methodology**			**Innovation**			**Digital**		**Service and customer orientation**	**PSS, servitisation, value co-creation**	**Benefits and require-ments**	**Chall-enges**
	Empirical study	Explorative study	Systematic literature review	Business model, supply chain and strategy	Technological, digital	Product	Transformation and disruption	Industry 4.0, IoT, Big Data				
Bustinza et al. (2013)	x			x		x			x	x		
Holmström & Partanen (2014)		x			x		x		x	x		x
Brennan et al. (2015)		x		x					x	x		x
Eloranta & Turunen (2015)			x						x	x	x	x
Kohtamäki & Helo (2015)			x						x	x		
Roos & O'Connor (2015)	x			x					x	x	x	x
Wang et al. (2015)					x			x	x		x	x
Bogner et al. (2016)	x			x		x	x	x				
Gerpott & May (2016)			x	x		x		x		x		
MacCarthy et al. (2016)			x	x	x					x		
Viitamo et al. (2016)	x			x						x		
Zancul et al. (2016)			x	x				x		x		
Altuntas Vural (2017)			x						x	x	x	x
Baines et al. (2017)			x	x		x				x	x	x
Brax et al. (2017)			x	x			x		x	x		
Gebauer et al. (2017)		x		x						x		x
Kache & Seuring (2017)	x			x				x		x		x
Abdelkafi & Pero (2018)	x			x	x							x
Aryal al. (2018)			x	x			x	x	x			x
Breidbach et al. (2018)			x		x		x		x	x	x	x
Field et al. (2018)	x			x						x		x
Frishammer et al. (2018)				x	x	x		x		x		x
Hasselblatt et al. (2018)	x			x			x	x		x	x	x
Issa et al. (2018)			x		x			x				
Klein et al. (2018)	x						x	x		x		x

Kritzinger et al. (2018)			x				x	x			
Lim et al. (2018)	x							x	x	x	
Matzler et al. (2018)			x	x	x	x	x	x	x		
Paschou et al. (2018)			x		x			x		x	
Pezzotta et al. (2018)			x	x		x				x	
Turunen et al. (2018)	x			x				x		x	
Ünal et al. (2018)	x			x					x	x	
Zheng et al. (2018)		x					x	x		x	
Calatayud et al. (2019)			x	x			x	x			x
ElMaraghy, H. (2019)			x		x	x	x		x		
Frank et al (2019)	x			x			x	x		x	
Frank et al. (2019)			x	x			x			x	
Hendler, S. (2019)	x			x	x			x		x	
Kreye, M.E. (2019)	x			x					x	x	x
Martinelli & Tunisini (2019)			x	x					x	x	
Matthyssens, P. (2019)			x	x				x		x	x
Neirotti & Pesce (2019)	x			x	x		x			x	
Sony & Naik (2019)			x	x				x		x	
Zheng et al. (2019)			x		x			x	x	x	

Table 5. Synonyms found in the systematic literature review describing manufacturers adopting a service dominant business model.

Synonyms	Authors
Customer solutions	Tuli et al. (2007)
High-value manufacturing	MacBryde et al. (2013)
Hybrid offerings	Ulaga & Reinartz (2011); Brax et al. (2017)
Integrated product and service offering	Wise & Baumgartner (1999); Davies (2004); Brady et al. (2005), Baines et al. (2009) Martinez et al. (2010); Nordin & Kowalkowski, 2010; Windahl & Lakemond (2010); Frishammer et al. (2018)
Product service systems (PSS)	MacCarthy et al. (2016); Pezzotta et al. (2018); Zheng et al. (2018); Frank et al. (2019); Matthyssens (2019); Sony & Naik (2019); Zheng et al. (2019)
Product and service bundling	Zancul al. (2016); Pezzotta et al. (2018); Frank et al. (2019)
Service-dominant logic	Vargo & Lusch (2004)
Service-driven manufacturing	Gebauer et al. (2012)
Servicization	Hsieh et al. (2012); Santamaría et al. (2012)
Servitisation or "servitisation of manufacturing"	Vandermerwe & Rada (1988); Baines et al. (2009); MacCarthy et al.(2016); Paschou et al. (2018); Turunen et al. (2018); Zheng et al. (2018); Frank et al. (2019); Matthyssens (2019); Zheng et al. (2019)
Service addition	Matthyssens & Vandenbempt (2010)
Service infusion	Brax (2005); Eggert et al. (2011); Eloranta & Turunen (2015)
Service orientation	Martin & Horne (1992)
Service package	Matthyssens (2019)
Service transition	Fang et al. (2008)
Solutions or solution providers	Nordin & Kowalkowski (2010), Frishammer et al. (2018)
Total service solution	Lerch & Gotsch (2015)

5.2 Reasonings from literature study

The success or failure of a supply chain is heavily dependent on the design and the management of supply chain flows such as products, information and funds (Chopra & Meindl, 2016, p 17). To remain competitive and sustainable, they must evolve and adapt to changing technology and customer expectations. To successfully manage supply chains, three different levels of decision phases regarding products, information and funds must be addressed:

Supply chain strategy or design. This addresses the supply chain configuration and has a long-term impact that will last for several years.

Supply chain planning. This phase covers a quarter of a year to a year and involves production plans, subcontracting and promotions over the specified period.

Supply chain operation. This phase has the shortest time frame spanning from a couple of minutes to days and involves sequencing production and filling specific orders.

The outcome of the aggregate level will impact and trickle down onto the two other layers. The three phases will be discussed in the thesis, first starting with the most aggregate phase when presenting the PSS scale. Eventually, the other two phases will be discussed when reflecting on a specific PSS level on the scale and when analysing the impact it will have on the operations.

5.2.1 The trends: Digitalisation, Customer centricity, Service orientation

Digitalisation and technology

Technology is being developed at an accelerated rate (Aryal et al, 2018). Companies are experiencing a greater need for digitalising and this can help developed economies maintain their competitiveness. As a result, this will allow the western world to take back the manufacturing which has been outsourced to developing countries in the later years. Bringing manufacturing back to Europe and the USA with the support of digitalisation will enable companies to produce at a higher efficiency while simultaneously reducing costs (Matzler et al., 2018). However, if the transition towards this trend is to occur successfully, changes in existing business models must occur. Hence, the customer benefit will be created in new ways and innovative methods will be required to monetise the created value (Matzler et al., 2018).

Ashton (2009) was the first person to propose the concept “Internet of Things” (IoT). IoT is one of the many technologies which Christensen (1997) once characterised as “disruptive technology”.

IoT is a technological leap within communication technologies where devices become increasingly integrated and cooperate to reach a common goal (Zancul et al., 2016). Instead of having communication devices operating individually they become components in a larger communication network where the virtual and the physical world interact. The entire network is equipped with devices that sense, identify, process and communicate (Ben-Daya et al., 2017; Aryal et al., 2018). The integrated network combines layers of sensors, data transmission and storage, and eventually makes information available to users (Aryal, et al., 2018).

This paradigm shift, where devices communicate with each other and create smart networks, is frequently known as Industry 4.0, and with this, new terms and concepts emerge which have not existed before. Bridging the world between the virtual and the real-world leverages “cyber-physical systems” and as a result of increased communication and data gathering, the amount of generated data propels exponentially. Great masses of generated data, or “Big Data”, also categorised as a disruptive technology, are analysed in depth. Combining advanced statistics with historical data, by systematically collecting, analysing and acting on the data, makes it possible to identify behavioural patterns (Shmueli & Koppius, 2011) and act as a competitive advantage (Davenport, T.H., 2006). Decisions will be more facts-based than assumption-based (Holmström et al., 2010) and decisions can occur real-time (Calatayud, A., 2017), thus allowing supply chains to have predictive capabilities. The real value will no longer lie in the product but in the information generated by the products. The patterns observed will raise new questions and contribute to better business decisions (Bhuptani & Moradpour, 2005). Better decision making is becoming increasingly important where markets are experiencing greater complexities and risks (Christopher & Holweg, 2017) due to growing internationalisation and firm interconnection, higher demand volatility (Calatayud, A., 2017) and faster supply chain speed (Christopher & Holweg, 2017). The improved insight makes supply chains "self-aware" (Christopher & Holweg, 2017) and major benefits are timely planning, control and coordination amongst the processes (Ben-Daya et al., 2017). New opportunities will arise and one of these opportunities accelerated by the digitalisation are product-service offerings - the focus of the thesis.

Bridging technology and customer centricity

IoT enables the identification and the capture of new value for customers (Hasselblatt et al., 2018). The customer is the ultimate driver of business activities and it is highly important to understand their requirements and needs (Vargo & Lusch, 2004). The company who most successfully creates and aligns their solutions with the customer knowledge and criteria will have the most flourishing business compared to competitors who maintain the market transactions at an arm's length (Kohtamäki & et al., 2013). Throughout history, companies have tried to understand their customers. However, a greater customer centricity will be possible as a result of the information exploitation leveraged by Big Data Analytics (Vandenbosch & Dawar, 2002). This will enable solution providers to differentiate their solution offerings (Kohtamäki & et al, 2013), thus making them the winning supply chains (Aryal et al., 2018). Hence, there are many reasons for why manufacturers should consider abandoning a product-centric attitude in favour of a customer-centric one (Baines et al., 2009).

Integrating devices to a greater communication network enables the monitoring of the production and the product's lifecycle (Brax & Jonsson, 2009). Real-time data can be compared to set metrics and any deviations from the expectations can be detected and mitigated, preventing productivity and profit losses. This is an example of "predictive maintenance" (Deloux et al., 2009), one of the many examples of how Big Data Analytics can be applied to enable increased efficiency in operations (Davis et al., 2012).

The concept of digital twins is a step passed equipping products with sensors and analysing the generated data. It consists of three parts: a physical product in real space, a virtual product in virtual space and the data and information connections that tie the virtual and the real parts together (Grieves, M., 2014). Depending on the level of data integration between the physical and the digital counterpart and the direction of the information flow, the copy is defined as a digital model, a digital shadow or a digital twin (Kritzinger et al., 2018). A digital model, such as a simulation or a mathematical model, is the most basic digital representation of a physical object and does not include automated data exchange between the physical and the digital object. It relies solely on manual data flow, and the accuracy and the amount of descriptive information exchange can vary across various models. A digital shadow builds on a digital model, however it has an automated one-way data flow from the physical object to the digital object. Therefore, a change in state in the physical object will lead to a change in the digital model but not vice versa. Finally, a digital twin has a fully integrated and automated bi-directional data exchange. A change experienced in either the physical object or the digital model will result in a change in its counterpart.

Tao et al. (2018) characterise digital models as a real-time reflection that can self-evolve. There are abundant ways of integrating digital twins in manufacturing and products, and the authors have identified nine aspects where digital twins can be used to enable service innovation in manufacturing: 1) real-time state monitoring, 2) energy consumption and analysis, 3) user management and behaviour analysis, 4) user operation guide, 5) intelligent optimisation and update, 6) product failure analysis and prediction, 7) product maintenance strategy, 8) product virtual maintenance, and 9) product virtual operation. Many of these points will be touched upon later in the thesis in the context of PSS, especially aspect 1, 5, 6 and 7.

Business model innovation

Neirotti & Pesce (2019) claim that a company can venture into two types of innovation. The first involves “doing the same with less”. The objective is to reduce operational expenses and to protect a firm’s profit margin from competitive pressures. The second type of innovation consists in “doing new things” and can, if successful, have a far greater impact on a company’s overall performance compared to improving the internal results. An increasing number of firms have started to direct their focus elsewhere than exploiting production capabilities for the internal efficiency gains. Improving production capabilities clearly remains important, nonetheless exploiting opportunities that favour value creation and leverage service operations have been identified as vital (Chase & Apte, 2007). Disruptive technologies, such as IoT and Big Data Analytics, have served as great enablers towards this movement and it has been observed that service solutions can create more overall value than traditional manufacturing (Peters et al., 2016; Antons & Breidbach, 2018). Many consider this the new frontier for innovation (Manyika et al., 2011). Business models based on disruptive technologies are typically more efficient, productive and convenient that the ones based on traditional technology (Christensen, C., 1997). These disruptive innovations shake up industries and, in some cases, create new industries.

Abdelkafi & Pero (2018) define three types of business models innovations: New to the world (NTW), New to the market (NTM) and New to the firm (NTF). They interviewed 24 manufacturing firms and concluded that nearly all the firms adopted NTF business models, a couple adopted NTM, whereas no one performed NTW. The survey indicated that the companies tended to be reactive rather than proactive in their innovations.

Abdelkafi & Pero (2018) also confirm two other types of innovation: supply chain concept innovation and technological innovation (Franks et al., 2000; Bello et al., 2004; Arlbjørn et al., 2011). Supply chain concept innovation can be classified into structural/ configurational, operational and revolutionary. Revolutionary innovations in the supply chain lead to deep structural changes in a supply chain and can have a direct impact on business model innovations. Technological innovations improve the efficiency of the operations by facilitating information and material exchange. Depending on the technological innovation and its overall impact on major operations and processes, it will also be able to have a significant impact on the business model. A prime example is the introduction of RFID and barcode technology which has enabled tracking and tracing objects and components during production and along transportation routes. By capturing real-time data and by supporting operations, it has reduced both inventory levels and costs (Zhou, Z., 2011).

Product offerings that result from digitalising traditional products can be so significant for individual supply chains and create such major impacts on their current operations, that new business models appear. With a greater depth and breadth of information available through Big

Data Analytics, new business models can be fine-tuned towards better meeting and satisfying their customers.

With business model innovation, resources and competences may have to be redistributed and reallocated, and four key strategic business processes must be reviewed in the context of a new value offering. These are value identification, value quantification, value communication and value verification (Töytäri & Rajala, 2015). Once these have been re-evaluated and in place, the new business model will be better equipped to generate value and satisfy both the manufacturers' and the customers' expectations and requirements.

Service orientation

Manufacturers have identified that complementing their products with services will capture new opportunities for creating and delivering value (Oliva & Kallenberg, 2003; Windahl & Lakemond, 2010). In some cases, manufacturers may no longer sell products but value instead. This paradigm shift has been greatly influenced by the technological-push innovation resulting from Industry 4.0 and the demand-pull of service innovation by the customers (Dosi, G., 1982; Wei et al., 2017; Müller et al., 2018). Opresnik & Tasich (2015) explored how the role of Big Data could result in "servitisation" and how this phenomenon would bring new competitive advantages to manufacturing. "Servitisation" is the phenomenon of product and service innovation, which by many is considered a consequence of Big Data (Manyika et al., 2011). It has been suggested that services can generate more stable revenues and profits than products (Gebauer et al., 2012) and that customers that are satisfied with the services are likelier to purchase product replacements from the same manufacturer (Roos & O'Connor, 2015) hence strengthening the brand loyalty. However, to achieve service innovation, manufacturers will need to make great investments in both new technologies and connectivity.

Traditional services versus Smart services

Combining services and products is not a revolutionary concept. However, the concept is being re-invented and is being adapted to other uses. Traditionally, OEMs have produced parts and equipment for other manufacturers, and they have potentially added simple services such as maintenance or installation. However, this concept has evolved and distinguishes itself in two ways. Firstly, the services can in several situations be now considered "smart". Products are equipped with sensors such that through continuous monitoring during its lifetime maintenance can be specifically tailored towards the product based on its already-known history. Monitoring products can lead to predictive maintenance rather than periodic maintenance which is not tailored towards the specific product. Secondly, smart services are no longer reserved for OEMs but for other product types that have earlier not been considered suitable for adding services to.

The advantages of smart services are plentiful for both the manufacturer and the customer: competitive services, new revenues, higher margins and considerable cost savings (Küssel et al., 2000). Laine et al. (2010) add to this the opportunity to learn from their customers and their interactions with the product, thus progressively making manufacturers more service oriented than product oriented (Zheng et al., 2019).

Advances in smart connected products (SCP) have enabled smart services. As a result, a smart PSS becomes a complex system composed of product components (e.g. physical parts, smart components and connectivity components) and service modules (e.g. hardware and software solutions) (Zheng et al., 2019).

5.2.2 Product-service systems

The term was first introduced by Goedkoop et al. (1999) in their book "Product-Service Systems – Ecological and Economics Basics" and defined it as "a system of products, services, networks of "players" and supporting infrastructure that continuously strive to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models". 20 years later, it is still in the research frontier and the existing research remains meagre (Baines et al., 2017). Nonetheless, PSS has become an increasingly popular term amongst researchers in the later years, and it has also started to be adopted in industry. Researches and industry alike have defined and interpreted PSS differently, however the common denominator is that the main purpose is to generate value and to create utility for customers (Zancul et al., 2016). The value creation in PSS is a joint co-creative process between the customer, the provider and their interaction which triggers vertical integration (Prahalad & Ramaswamy, 2004; Payne et al., 2008; Sampson, S.E., 2012).

There are two main gaps which have sparked the growing research. Firstly, when studying value creation and circular economy in business models, it tends to be from the supply side (the firm's side). PSS motivates to study the demand side (the consumer's perspective) (Ünal et al., 2018). Secondly, studies that address the innovation for retaining competitiveness have usually focused on product innovation, while there has been a lack in focusing on supply chain and business model innovation, again something which concerns PSS (Abdelkafi & Pero, 2018)

Motivation and reasons

There are several motives that have sparked the companies' curiosity for investing in PSS. PSS allows them to differentiate themselves from their competitors (Huikkola et al., 2016). This is achieved by offering inimitable sales which consist of bundling (Zancul et al., 2016) and inextricably intertwining (Martinez et al., 2010) products and services. The features that allow them to differentiate themselves can be classified as either defensive or offensive (Baines & Shi, 2015). The former includes cost reductions and setting higher barriers to competition (Oliva & Kallenberg, 2003; Durugbo, C., 2013), while the latter includes revenue and profit growth (Eggert et al., 2014; Baines & Shi, 2015) which is achieved as a result of building new and more stable revenue streams (Baines & Lightfoot, 2013). This occurs since PSS can meet customer needs more accurately (Ostrom et al., 2010) and consequently increase customer loyalty (Gaiardelli et al., 2014; Saccani et al., 2014). Additionally, PSS improves product innovation (Eggert et al., 2011).

Other reasons for PSS are: commoditisation (which has also started to impact advanced engineering products) (Frishammar et al., 2018), the great emergence of competitors (Turunen et al., 2018) and especially low-cost competitors (Matthyssens et al., 2008; Coreynen et al., 2018), and higher customer expectations (Matthyssens et al., 2008; Coreynen et al., 2018).

Characteristics

Frequently, a manufacturer's business model will transition from being ownership-based to becoming performance-based or pay-per-use-based (Stahel, W.R., 2016). Resulting in the firm going from material-intensive manufacturing, known as goods dominant logic (Vargo et al., 2008), to information-intensive services (Apte & Karmakar, 2007) or knowledge-based services (Peneder et al., 2003), a service dominant logic (Vargo et al., 2008). The new critical raw material becomes knowledge (Randall et al., 2014).

PSS emphasises the coordination between goods and services (Mont, O.K., 2002; Baines & Lightfoot, 2013; Kowalkowski & Ulaga, 2017). Compared to traditional practice, the flows and exchanges among supply chain partners shifts from being independent and linear (La Londe & Masters, 1994) to being multidirectional.

Stakeholder management and specifically customer management is enhanced. The relationships between manufacturers (now the service providers), customers and other potential partners become more direct and intensified (Mont, O.K., 2004; Baines et al., 2007; Gao et al., 2011) because individual companies cannot usually perform the entire PSS alone. This arises because of increased operational links, information exchange, legal ties, cooperative rules (Matthyssens & Vandenbempt, 2010) and long-term relationships (Barquet et al., 2013). An engaged and committed management will also ensure that PSS business models are implemented successfully (Reim et al., 2014). The strengthened relationships require contracts that clearly define the responsibilities, the rights and the liabilities of the stakeholders. This must cover the ownership and the responsibility of the product, terms of agreement, level of formalisation and complexity, incentives, and the level of risk which can be tolerated (Reim et al., 2014).

Financial and accounting processes may require modifications and financial incentives may need to be altered (Gebauer et al., 2010). The elimination of the immediate return of capital which occurs when a traditional sale is executed is changed to an extended payment as a function of the usage of the service (Mont, O.K., 2004). Companies will need to create new revenue models based on performance-pricing (Matthysens & Vandenbempt, 2010).

Advantages and benefits

The emergence of IoT technology being installed on the products has made PSS increasingly popular. Zancul et al. (2016) have identified five areas that can be leveraged by PSS and IoT technology: monitoring and information reporting, corrective and predictive maintenance, remote machine setup, product pricing and material supply. The internet connection enables faster and better intervention. Discovering anomalies early can reduce the risk and impact they can have on the overall system. Monitoring the product during its use-phase will not only enable manufacturers to offer services, but they can also learn about the product’s performance and interactions with its surroundings. The product can be improved during R&D and it can be considered a “product Darwinism” (Reeves et al., 2011).

There are numerous benefits on the operational level, as well. The increased connectivity and visibility among devices and supply chain partners will facilitate and greatly improve the chain’s integration and hence overall performance (Fawcett et al., 2007; Nooraie & Parast, 2015; Somapa et al., 2018). Direct implications will be better inventory control (Narasimhan & Kim, 2001;

Fawcett et al., 2007), and it will leverage shorter order fulfilment lead-times and product development cycles (Erhun & Tayur, 2003; Fawcett et al., 2007). The enhanced integration will enable better monitoring of customer behaviour (Fawcett et al., 2007) and risk management (Hiromoto et al., 2017). Operations in logistics will be particularly impacted by improving the abilities to design, monitor and implement logistics plans (Gunasekaran & Ngai, 2004), achieve a greater flexibility and generally improve the delivery performance (Gosain et al., 2004; Closs & Swink, 2005). All these benefits will be particularly advantageous for companies currently characterised as having short lead times and unpredictable demand (Calatayud et al., 2016).

IoT technology, and more specifically remote technology, enables remote maintenance. This increases the value created to the customers because it allows companies to reduce on-site maintenance operations, enables proactive maintenance and reduces downtime (Swanson, L., 2001).

The availability of resources, such as electricity or water, do not tend to be constant and will naturally fluctuate. The pricing strategy offered to the customer can be adapted as a function of the availability of the resources used for the specific product. A better alignment between the price and the availability will be more beneficial for both the service provider and the consumer as it will create a fairer market when capturing the real-time situation.

Digital transformation

Based on a framework created by Fleischer et al. (2014) illustrating the roadmap towards new value capture and creation, Matzler et al. (2018) have identified a six-step process to achieve a digital transformation of a product which can leverage the development of PSS. The steps are the following: 1) A physical product or process must exist; 2) Installing the product or process with sensors or actuators; 3) Connectivity will enable the communication between objects or the exchange of data by equipping the objects with IP-capable sensors; 4) Analytics can be used to gain valuable information from the sensors to be transformed into value-added services; 5) Digital services can now be created on the basis of the analytics from step four; 6) New value capture and creation. Following this flow will lead to the emergence of new business models which presents novel revenue logics. Step one and two are considered analogue, and step four and step five are digital, whereas step three is defined as being the bridge between the two.

The different definitions of PSS

Authors define and interpret the PSS concept differently, nonetheless there is a recurring essence which these definitions and frameworks have in common. All except for one divide their PSS scale into three increasing maturity levels when combining product and services. When comparing the various definitions, it is important to highlight that certain definitions strictly describe PSS as the balance between tangible products and services, whereas for others it is related to the increasing degree of digitalisation of the product. As the products become increasingly digitalised, the offered services become increasingly complex (Lerch & Gotsch, 2015). Since service and digitalisation are very much intertwined, a minority of authors define PSS in terms of a two-dimensional axis, with the degree of service along one axis and the incremental level of digitalisation along the other.

Eight different ways of defining and describing PSS are found and they will now be presented (table 6). In the column "Classification", for each of the authors the terms progress from the most basic to the most advanced value proposition.

Table 6. Summary of the different levels of PSS maturity described by authors found in the literature review.

Author	Classification	Example of offering
Frank et al. (2019)	1. Passive smart products	Connectivity, monitoring, control capabilities
	2. Active smart products	Optimisation capabilities
	3. Autonomous smart products	Autonomous capabilities
Zheng et al. (2018)	1. Conventional PSS	Internet (mobile and data roaming)
	2. IOT enabled PSS	Ubiquitous connections (e.g. RFID)
	3. Smart PSS	CPS, Digital twin
Baines et al. (2017)	1. Base services	Goods, spare parts
	2. Intermediate services	Product repairs, maintenance, overhauls, conditioning monitoring, training, help desk
	3. Advanced services	Customer support agreements, outcome contracts
Cusumano et al. (2015)	1. Smoothing services	-
	2. Adapting services	-
	3. Substituting services	-
Kohtamäki & Helo (2015)	1. Equipment provider	Selling add-on services
	2. Solution provider	Solution sales "product service bundling"
	3. Performance provider	Performance provision "Full horizontal integration"
Tukker, A. (2015)	1. Sale of single products	Basic, mainstream linear mode of consumption
	2. Extended producer responsibility	Financing, maintenance, take-back programs -
	3. Leasing/ renting capabilities	-

	4. Pay-per-use	
Bustinza et al. (2013)	1. Customer support 2. Through life management 3. Availability contracting	- - -
Meier et al. (2011)	1. Product-oriented service 2. User-oriented service 3. Result-oriented service	Installation Customer service “Power by the hour”

The more recent authors, Frank et al. (2019) and Zheng et al. (2018), segmented PSS value propositions as a function of the progression and the maturity of the technology and the extent of the digitalisation which the conventional base product was equipped with.

Frank et al. (2019) created a framework for smart products which illustrated the progression of the level of complexity of the Industry 4.0 technologies implemented to the base products (figure 4). These authors divided smart products into three groups: passive smart products, active smart products and autonomous smart products. Although they did not directly link the smartness of a product to PSS, the smartness can be considered as a leverage for PSS. Their modern definition of PSS involved equipping conventional products with sensors thus making these products smarter. The addition of sensors will enable monitoring which can give opportunities for additional services that would not have been possible without the added surveillance. They indicated that as the smartness increases the base technologies will also become more complex. Passive smart products will initially rely on cloud technology and as the complexity of the base technology increases it will become more common to incorporate IoT, the generation of Big Data and eventually the analytics of Big Data. By this stage, the smart products can be considered autonomous.

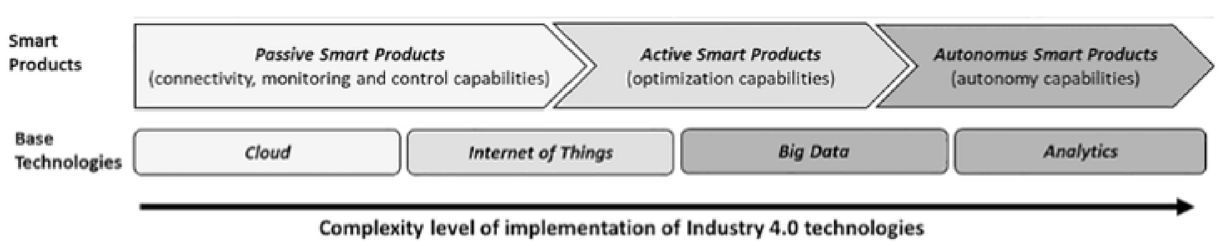

Figure 4. Frank et al.'s framework illustrates how smart products evolve as a result of advancing base technologies which ultimately increase the overall level of complexity.

Zheng et al. (2018) were one of the two authors who defined PSS as a result of two dimensions, connectedness and smartness. They suggested that the evolution from conventional PSS to smart PSS has occurred as a result of the chronological evolution in the development in IT (figure 5).

Conventional PSS dates to 1999-2010 and was considered the most basic PSS solution because it bundled product and services with minimal intelligence. IoT-enabled PSS, common in 2010-2015, was described as an extension of the conventional PSS. Data were collected and interchanged with other networked devices (e.g. sensors, actuators, RFID) so that they collectively could attain an objective. Smart PSS was the most complex and advanced version of PSS. This type of PSS had

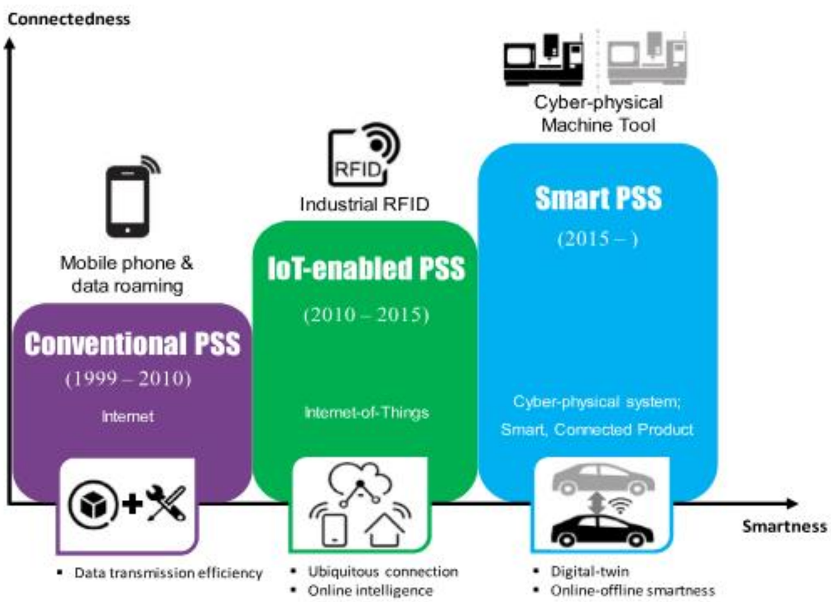

Figure 5. The two-dimensional framework for PSS created by Zheng et al. (2018).

IT embedded in the product itself and leveraged value creation. With the digitalisation of the product, a cyber-physical system (CPS) was created, and this established twin was capable of autonomously interacting with itself and its environment. Smart PSS are still in development since research on CPS, smartness and connectivity remain popular.

Cusumano et al. (2015) present the most complex illustration of their interpretation. They combine a two-dimensional framework, “servitisation dimension” and “digitisation dimension”, which results in a matrix with nine service offering configurations (figure 6). Each of these categories are thereafter evaluated according to their feasibility and complexity of actual business implementation. It is essential to note that this is a generalised matrix which cannot be adopted by all manufacturing firms in different industries.

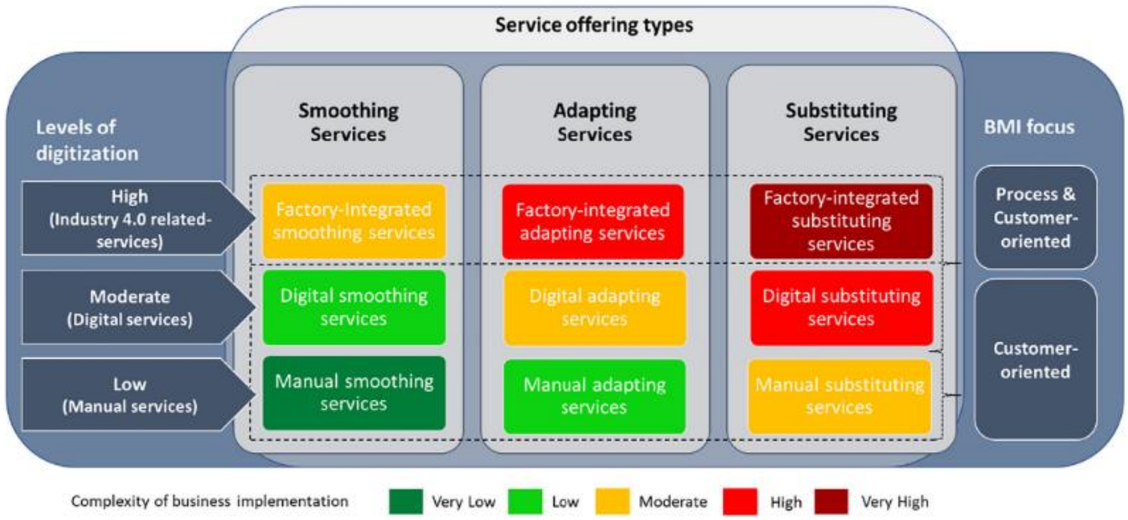

Figure 6. Conceptual framework for Servitisation and Industry 4.0 convergence (Cusumano et al., 2015).

Figure 6 shows that the "servitisation dimension" can be divided into three categories: smoothing services, adapting services and substituting services. Smoothing services facilitate the usage of the product without significantly altering the functionality. The complementing services are only loosely coupled with the product. Adapting services alter the original functionality of the product since they are integrated to the product and a new product functionality is expanded or becomes entirely different. It is achieved if the knowledge exchange between the manufacturer and the customer increases. Finally, substituting services completely shift the ownership of the product from the customer to the manufacturer. The manufacturer retains the responsibility of the product and is instead remunerated through a leasing or performance contract.

The vertical axis of figure 6 depicts the three levels of digitalisation: low, moderate and high. A low digital level includes basic technology as support (e.g. to create databases) but they do not provide the service themselves. A moderate level of digitalisation employs technology which enables the manufacturer to create and offer distinct services. A high level of digitalisation is the only level which is considered to comply with the concept of Industry 4.0. As the levels increase across both axes, so does the complexity of business implementation.

The remaining authors, Baines et al. (2017), Kohtamäki & Helo (2015), Tukker (2015), Bustinza et al. (2013) and Meier et al. (2011), have created similar PSS definitions and frameworks. They mostly base themselves on the extent to which services accompany a product rather than the degree of intelligence of the PSS. Baines et al. (2017) distinguishes between base services, intermediate services and advanced services which manufacturers can offer. Each of these stages are explained with different examples. Kohtamäki & Helo (2015) have created a very similar framework to Baines et al. (2017), where they, too, identify three levels of PSS maturity: equipment providers, solution providers and performance providers. They state that selling performance is a full horizontal integration of a product service organisation (Kohtamäki & Helo, 2015).

Both Bustinza et al. (2013) and Meier et al. (2011) confirm both Baines et al. and Kohtamäki & Helo's observations and reflections, however they name them slightly differently: customer support, TLM and availability contracting, and product-oriented service, user-oriented service and result-oriented services, respectively. Tukker (2015) has four classifications rather than three. The classification is very similar to the other authors, the only difference being that he has separated "leasing/ renting activities" and "pay-per-use" while the previous authors have combined them and called them for example "performance providers" or "result-oriented services".

PSS proposal design

A successful transition from offering conventional products to offering PSS solutions must take into consideration both their customers' requirements and needs, and the manufacturer's own competences, resource portfolio and resource deployment structure (Oliva & Kallenberg, 2003). Before a manufacturer rushes into adopting a PSS model it is necessary for them to follow a structured method which identifies and defines the requirements and the objectives of the PSS. Doing this will ensure the greatest potential of the transition.

Rondini et al. (2016) created a solution concept design which they named a Product Service Concept Tree (PSCT) which analyses the customer's needs, identifies the promising PSS concept solutions and finally evaluates them. The PSCT aims at: 1) Identifying PSS solutions capable of fulfilling the customer's declared and latent needs, 2) Represent the solution in a structured approach and 3) Manage the selection of the "best" PSS concept to implement. This structured analysis will not only determine the customer's needs and wishes, and the possible solutions to satisfy these, but will also indicate which resources will be necessary to implement a solution. The PSCT model considers the possible impact the chosen solution will have on the company's value and the difficulties which a company would encounter when implementing a potential PSS. Clearly, the selected solution should be the one with the least difficulties which offers the highest impact, and which is the most economically sustainable. Throughout the analysis it is necessary to select KPIs that monitor the PSS during its entire lifecycle. They are fundamental to identify possible gaps in a firm's offerings.

Zancul et al. (2016) follow the same logic as Rondini et al. (2016), however they segment the structured methodology into more detailed steps and name it a PSS configurator. The steps are easy to follow so this PSS proposal methodology is selected when analysing the case company.

The PSS configurator consists of eight steps. 1) The manufacturing company must have a deep understanding of their company's business model. This step will give them insight in whether they should maintain their current business model or whether they should venture into a PSS structure. It can be helpful to use a canvas business model, and a readiness model and a maturity model can give a company a more structured and better-informed insight. 2) They must choose the value proposition, hence decide for which product-service mix they want to develop. 3) The manufacturing firm will need to identify their target customer, and this is achieved by gathering market data which can indicate which customers will be interested in which potential PSS proposal. 4) Develop different PSSs which customers can be interested in depending on the different phases of the PSS lifecycle they can relate to. After having completed the first four steps, the company should have now opted for a PSS and from now on the remaining analysis should focus on this selected solution. 5) The company should put together the required processes and partnerships and define the value which the PSS should deliver to the customer. When analysing the business processes, the necessary IoT technologies required to support this process must be identified as well. 6) The firm must identify the existing resources and the necessary future resources. By resources, all assets involving knowledge, technology, competence and human resources are accounted for. 7) It is necessary to determine the cost structure, and 8) The manufacturer must identify and evaluate the various revenue streams.

5.2.3 Readiness and maturity models

The PPS configurator suggests using a readiness model and/ or a maturity model to gain a deeper insight in a manufacturer's current business model and operations. Previous authors (Oliva & Kallenberg, 2003; Davies et al., 2006; Baines et al., 2017) have also stressed the importance of researching the internal conditions of where and when change should occur and creates an understanding for service strategy adoption.

An evaluation of the company's AS-IS situation should be executed before the company decides to embark on a major transformational project (e.g. digitalising, adopting Industry 4.0 technology). Following the structure and the guidelines of a readiness assessment, the systematic analysis addresses aspects such as the manufacturer's strategy and organisation, their factory, their operations and their products. The purpose is to identify the company's available resources, assets and strengths and to discover where the weaknesses and gaps may lie that could become an obstacle to a successful implementation of the project (Benedict et al., 2017). The raised awareness will allow the company to address the gaps and the requirements before starting their transformational journey and will identify opportunities concerning their digital transformation towards Industry 4.0.

A readiness assessment is not a term solely reserved for a digital transformation and it can be used in the general context of when an organisation wishes to restructure or undergo a major change. A Smart Manufacturing assessment is a readiness assessment which focuses on transforming a company in the direction of becoming more digital or "smarter". However, for the purpose of this thesis the term "readiness" will be continued to be used.

After the readiness assessment has been used to identify the opportunities and the potential barriers, a maturity model will assist an organisation to reach a higher level of maturity by suggesting a continuous step-by-step improvement process (Mettler, T., 2011). A maturity model will address aspects such as people and culture, processes, structure, objects and technology.

Several smart manufacturing and Industry 4.0 readiness assessments exist, and several papers dedicate themselves to comparing these. It is important to select the model which is best aligned with the company characteristics. SMEs (Small and Medium-sized Enterprises) and MNEs (Multinational Enterprises) will experience different challenges and barriers (Mittal et al., 2018) which must be taken into consideration, something several models fail to do. Based on the European Commission's definition, table 7 confirms that the case company belongs to the medium sized category.

Table 7. SME classification (European Commission, 2012).

Enterprise	Max. Employees	Max. Annual Turnover	Max. Annual Balance Sheet total
Small	< 50	≤ € 10 million	≤ € 10 million
Medium	< 250	≤ € 50 million	≤ € 45 million

A major aspect when comparing SMEs and MNEs is that the required technical and financial resources are frequently not readily available for SMEs. This limits the research, the development and the degree of advancedness which SMEs can obtain in their new solution offerings. Julien & Ramangalahy (2003) concludes that the financial restrictions of SMEs can result in companies not hiring external consultants to conduct the readiness assessment and to help guide their journey. It makes it therefore even more critical that the assessment tool is complemented and deeply integrated within a maturity model.

Mittal et al. (2018) and Schumacher et al. (2016) focused on analysing five models and they have later been analysed by Sony & Naik (2019). Hence, they were deemed potentially relevant and they were summarised as follows:

IMPULS – Industrie 4.0 Readiness. Assessment in six dimensions and a total of 18 subcategories will indicate the readiness, classify a company in a level ranging from zero to five and finally suggest potential improvements to attain a higher level of maturity.

Empowered and Implementation Strategy for Industry 4.0. Assessment of Industry 4.0 maturity, simply a quick check, and part of a process model for realisation. The assessment addresses gap-analyses and it functions as a toolbox for overcoming maturity-barriers.

Industry 4.0: Digital Operations Self-Assessment. Online self-assessment in six dimensions which classifies a company between level one to level four in digital maturity.

The Connected Enterprise Maturity Model. A maturity model composed of five stages describing how to develop Industry 4.0 measures. Technology is the focal point and is categorised according to four dimensions.

*I4.0 Reifegradmodell***.** A maturity assessment executed according to three dimensions and evaluates 13 items. The company is then classified into one of the ten maturity levels.

To select the most appropriate model for this maser thesis, they are each analysed, and Appendix B.1 summarises their advantages and disadvantages.

Appendix B.1 illustrates that IMPULS – Industrie 4.0 Readiness is the most advantageous and appears both academically correct and detailed. It is easy to adopt by management, especially since the online self-check assessment suggests recommendations upon completion. This is particularly beneficial for management that may be inexperienced with using readiness and maturity models.

IMPULS Industrie 4.0 Readiness model

The model was developed as a result of a research project in collaboration between IW Consulting and Aachen University, Germany. The readiness model classifies companies into six possible levels (Appendix B.2). Level 0 and Level 1, considered as "Outsider" and "Beginner, respectively, are combined and define companies in these two categories as Newcomers. Level 2 is for companies that have come further in implementing projects towards the Industry 4.0 concept and are considered "Intermediate" and can be defined as "Learners". The more developed companies can be classified in Level 3, Level 4 or Level 5 and are known as "Experienced", "Expert" and "Top performer". Collectively, these three classifications are defined as "Leaders". The overall results indicate a company's willingness and capacity to implement these new ideas.

5.2.4 The challenges for the manufacturers and the customers

Challenges exist when implementing disruptive technology in a supply chain or when innovating a business model as a result of changing the value offering offered to customers. Disruptive technology entirely changes the core and the basis of competition (Danneels, E., 2004) since the data used in the organisation or the supply chain is now both timely and relevant. The challenges act as significant barriers which determine the success of the innovation. This section will first develop the challenges generally experienced when implementing disruptive technology and then the challenges oriented towards PSS.

Disruptive changes are associated with uncertainty, cost and complexity (Tellis, G.J., 2006). From a manufacturer's perspective, these risks must be weighed up with the investments and the expected returns. The decision-maker must be aware that the benefits and the positive impacts may not be immediate making companies less inclined to embrace change. Companies and supply chains will only benefit from radical changes if they are strategically built into the supply chain and the business model (Pérez et al., 2017). This includes having well-integrated complementary technologies and possessing the necessary managerial capabilities. This may require drastic changes and adaptations that, although they will secure a successful transition in the long run, may be painful and punishing within an organisation and across the supply chain (Tellis, G.J., 2006) on a short term. Since changes can take long to fully integrate and mature in an organisation or supply chain, they can cause conflicts within an organisation (Pérez et al., 2017).

Challenges that arise when implementing a radical change will be experienced differently by companies of different sizes and situated in different market positions. Christensen (1997) identified that disruptive innovation may appear unattractive to established and incumbent companies. In the beginning, it is likely that disruptive changes will start off in a small market niche that do not offer significant growth nor profit opportunities. Established companies may refrain from embracing change because their main profitable customers in the market are uninterested, the innovation would cannibalise their existing business or because their current business model is incompatible with the business model accompanying the change. All the above-mentioned factors are reasons for why established companies can fail in their disruptive industry when they are not au courant. Concurrently, one can argue that although larger companies may be restrained by their major and dominating customers, they will find themselves in a more advantageous financial position which allows them to venture into greater investments than smaller enterprises. This position can allow a more complete change such that the entire transition can occur more successfully and be more fruitful.

The thesis focuses on PSS and several challenges have been identified by academia and in industry (Auramo & Ala-Risku, 2005). The number of challenges which authors have recognised varies from a handful to up to 25 classified challenges (Klein et al., 2018). It is crucial that a firm which considers transitioning into this new model is fully aware of the barriers which they may encounter, and the challenges dispersed across the literature will now be addressed. They have been categorised into three main groups with their respective subcategories and two additional groups with no subcategories. Challenges and barriers resulting from strategy, skills, economics, products and processes, and uncertainties are now presented.

Strategy: Business strategy. The formulation of the value proposition must be updated when changing the product offering and value generation (Grubic & Peppard, 2016) and the modification can only be successful if it is accepted by the customers and the stakeholders. The change is achieved with new partnerships and stakeholders (Mont, O., 2000; Manzini & Vezzoli, 2003) which together will co-create and co-produce (Vargo & Lusch, 2004; Jacob & Ulaga, 2008) new value. PSS does not simply involve the creation of new products and services but also reconfigures business models (Fang et al., 2008; Gelbmann & Hammerl, 2015; Grubic & Peppard, 2016) and creates new business processes (Baines et al., 2009). A reconfiguration risks having internal issues in the organisation (Jonsson & Westergren, 2004) if the transition is not addressed properly. Zancul et al. (2016) also identify the need for rethinking performance measurement, customer management and stakeholder management as a result of the reconfiguration.

The new interactions and relationships can lead to more complicated communication and valuable information may get lost (Jonsson & Westergren, 2004). Manufacturing firms will need to manage multiple projects rather than following one streamlined and standard focus on production (Frishammar et al., 2018).

Strategy: Service strategy. A firm must deploy a service strategy during its transition towards the service phase (Fang et al., 2008; Grubic & Peppard, 2016). However, several fail to do so (Oliva & Kallenberg, 2003) as they embrace the opportunities the disruptive technologies can offer, while the aim of the service business they wish to develop remains unclear (Klein et al., 2018).

The transition is complex, it is essential that the management commitment is strong (Klein et al., 2018) and that a strong framework to guide the journey exists (Breidbach et al., 2018). The absence of management support intensifies the barriers and influences aspects such as strategy, finance and organisation (Klein et al., 2018). Furthermore, the existing infrastructure must be adapted to support the new processes, capabilities and requirements (Brax & Jonsson, 2009; Porter & Heppelmann, 2014; Klein et al., 2018) and this requires the commitment from the top and middle management to do the necessary investments (Hasselblatt et al., 2018). Their absence is a reason for manufacturers "de-servitising" when the outcome has been dissatisfactory (Hasselblatt et al., 2018).

Skills: Competence. Firms may fall into the trap of offering services unrelated and beyond their core offerings and competences (Oliva & Kallenberg, 2003; Grubic & Peppard, 2016; Klein et al., 2018). Their likelihood of failing increases compared to companies that have integrated and aligned their PSS with their existing frame (Fang et al., 2008). Furthermore, it is essential that they acquire matching competences in both technology and human skills (Viitamo et al., 2016) with the service they develop. They must develop knowledge in understanding the new market, the customers and the processes. Achieving all these skillsets can be demanding with no prior experience within the field and lacking experience complicates recognising the added value they are expecting to provide (Jonsson & Westergren, 2004; Grubic & Peppard, 2016). Inadequate experience and competences make it challenging to develop the ability to flexibly adapt to changing circumstances (Porter & Heppelmann, 2014; Klein et al., 2018), a skill which is necessary in the rapidly shifting environment.

Skills: Recognition of potential. Oliva & Kallenberg (2003) identified that firms are frequently unable to recognise the economic potential of the service component in PSS structures. Their understanding of the true capabilities of PSS are limited (Grubic & Peppard, 2016) as the service culture is minimal (Klein et al., 2018).

Skills: Knowledge management. Far more data and information are generated, available and collected because more devices are installed to monitor products and to communicate amongst themselves (Davenport et al., 2012; McAfee & Brynjolfsson, 2012). This complicates identifying and extracting the relevant data and causes companies to overlook information which could support them to seize opportunities (Westergren, U.H., 2011). To handle the masses of data, the appropriate infrastructure must be in place and the IT capabilities must be developed (Auramo & Ala-Risku, 2005; Brax & Jonsson, 2009; Kuschel, J., 2009).

Companies will need to process and synthesise knowledge coming from multiple knowledge components in a broad external environment (Cassiman & Valentini, 2015; Zancul et al., 2016), such as data from IoT technologies and information from the increasing number of stakeholders. All the information must be combined and deeply understood in order to tap into the greatest potential. There may be a misalignment between the collected data and the required data for the wanted analysis (Grubic & Peppard, 2016). As the data transmission between points increases, a robust security management system (Porter & Heppelmann, 2014) must be implemented to alleviate the customer's concern.

Skills: Customer management. A challenge is the often-poor insight manufacturers have in understanding which PSS solutions are appealing to customers (Küssel et al., 2000; Grubic, T., 2014). Manufacturers may lack knowledge in customer needs (Brax, S., 2005), while they simultaneously have not developed the value propositions satisfactory (Foote et al., 2001). Although the manufacturer may have identified the multiple benefits for adopting PSS solutions compared to conventional products, the customers may not have done so. It is difficult to persuade customers when no historical data can reflect and support these changes (Grubic & Peppard, 2016).

Skills: Service culture and reputation. PSS requires a high level of trust and a customer's doubts about a solution provider's capabilities, like poor service culture (Brax & Jonson, 2009; Klein et al, 2018), can jeopardise the tangible product's reputation (Allmendinger & Lombreglia, 2005; Gebauer et al., 2005).

Economics: Cost. New costs need to be considered when investing in PSS. It is likely that the conventional product will need to be equipped with additional technology, such as sensors. The cost will increase as the number of sensors and hardware installed on the product increases (Zancul et al., 2016) so the company must prioritise and adopt only what is necessary. Greater coordination costs will arise since PSS will require a more complex coordination between a greater number of stakeholders (Cassiman & Valentini, 2015). Due to the risks and the additional costs (e.g. TLM costs), a company can suffer from the service paradox. A phenomenon where the revenues increase while the profits decrease (Gebauer et al., 2005; Frishammar, et al., 2018).

Economics: Pricing. With uncertain costs, pricing the PSS offering is difficult (Klein et al., 2018). Additionally, the manufacturer may be uncertain about the added value they are offering their customers. Nonetheless, an appropriate billing is essential for companies to profit financially (Allmendinger & Lombreglia, 2005; Kowalkowski et al., 2015). There are different ways of pricing a PSS model and a company must decide which will be the most profitable. They must determine who will have the ownership of the final product. The conventional solution involves the customer buying the product and the manufacturer providing additional services which are paid for separately. A use-oriented model is where the manufacturer remains the owner. The product is offered as a value-adding service and typically follows a rental or leasing agreement (Beuren et al., 2015). The revenues from the product sales and maintenance fall dramatically while incomes from monthly fees increase. A result-oriented model is where a seller agrees to provide a certain outcome or result and the customer pays for the agreed-upon results (Reim et al., 2015).

A PSS model is likely to be more expensive than a basic product. Customers may only take notice that the products are more expensive than those of the competitors and they may fail to see the cost advantages over the whole product lifecycle (Kowalkowski et al., 2017). Pay per use products are particularly attractive to price sensitive customers that are low product users.

Products and processes. A PSS model poses increased technical and process complexities (Grubic & Peppard, 2016) and the overall performance may be unsatisfactory if the conventional product remains immature (Küssel et al., 2000; Kuschel & Ljunberg, 2004). Inappropriate connectivity, insufficient data and inadequate analytics tools can lead to technical challenges (Klein et al., 2018). Thus, the products and the equipment must be re-engineered with the changing requirements for digital manufacturing (Holmström & Partanen, 2014) and changes to the equipment may need to be coordinated with external suppliers.

Uncertainties. In addition to challenges, a firm will also need to face organisational, relational, environmental and technological uncertainties (Kreye, M.E., 2019) which will increase the risks when venturing into a PSS structure.

6. Facts about the cases

Pipelife: The manufacturer

Customers and Market. The Pipelife Group operates in 29 countries and is a leading plastic pipes and pipe systems manufacturer. The focus will be directed towards Pipelife Norway, Norway's largest producer and supplier of plastic pipe systems. Their customers vary from private users to industrial applications, and a significant proportion of their products are exported. Both their large PE pipes which are unique in the western hemisphere and their innovative drainage systems are popular export products. Other pipes are made of either PVC or PP.

Product. Their products are made of plastic and the portfolio ranges from pipes, pipe systems and pipe fittings. The applications of these pipes vary from telecommunication networks, industrial applications, water cycle usage (e.g. sewage disposal, rainwater drainage, drinking water) and energy and power distribution. Most of their products are standardised, however a separate department can customise products.

Production and logistics. Pipelife Norway has two different production sites that make products to order (MTO), in Surnadal and Stathelle. The production plants perform advanced moulding and extrusion techniques. The Surnadal plant produces smaller pipes with diameters just below one meter which are stocked in their warehouses till they are shipped to either wholesalers or directly to customers. Stathelle produces the largest pipes which are used in marine applications.

Surnadal municipality: The customer

The facts about Surnadal municipality and their requirements for water distribution have been presented by Michal K. Heimlund and Terje Forberg, Operating manager for water and drainage and Head of department for municipal engineering, respectively.

Surnadal municipality provides water for their citizens by collecting water coming from a lake higher up in the valley. The lake water is collected in a dam before it gets treated in a processing facility and is eventually pumped to the civilisation. There is one main pipe channelling the water into the process facility and there is one main pipe from the facility and down to the houses. There is always one main pipe in question which transports the water, while smaller pipes branch off when the water is being distributed to individual consumers. The municipality possesses a total of 240km of water pipes and the majority of these pipes were dug in the ground in the early 1970s.

Pipes are expected to operate for at least 100 years within the current standards, though it is believed that they are unable to reach this predicted time.

Their objective it to deliver enough water at a high quality so their KPIs are to deliver sufficient water within the defined qualities at a low cost with minimal leakages.

They state that they experience leakages corresponding to approximately 30%-40% losses. This is due to cracks, poor fittings, age, weathering and poor construction.

The water distribution follows a strict inspection and maintenance policy. The team needs to check on the dam and the process facility three times per week and they need to take water samples from six different locations once every two weeks. A major problem is that a large segment of the water distribution network is in an area deprived from coverage and electricity. As a result, when the team drives up to inspect the performance, they come completely unprepared and unknowing of the situation which awaits them. They drive up to assess the situation when everything is satisfactory and if they experience that something is wrong, they must drive down to the village to pick up the appropriate equipment and drive back again. The entire process is considered tedious.

For the monitoring of the water flow, the employees need to measure the flow, pressure and speed. For the water quality, it is necessary to control the clarity, the colour, the pH and the bacteria level. All water checks need to go through the laboratory. A disadvantage of the current practice is that the water samples only represent a second of the environment. Ideally, they would like a solution which surveyed the water more continuously.

If leakages are observed, it is the team's responsibility to tackle the problem. It is their job to perform a risk assessment and evaluate how to address the leakages. They perform the general repairs since they possess a lot of the necessary equipment. They need to sometimes contact the power company to see whether they will be operating in proximity of powerlines.

They have a good idea of the performance of the water distribution which occurs above ground. However, the performance and the potential leakages of the entire water network occurring below ground is relatively unknown.

Heimlund and Forberg confirm that the knowledge on the pipes' location is very accurate. When the pipes are dug in the ground, their position is taken by GPS survey equipment which then updates a map with the location of all the water pipes in the municipality. The map can be retrieved on iPads. These iPads are then used when the operators are out in the field and need to dig up the pipes.

The pilot project between Pipelife and Surnadal

The municipality wishes to gain more control over the leakages throughout the entire distribution network, and they specifically wish to gain a better visibility of the section where there currently is no coverage nor power. In alignment with these expectations, Pipelife would like to become water distribution solution providers and offer services which complement their water pipes. They wish to be proactive and create an NTM solution. Their ambitions are to start this project before there is an actual demand for smart pipes as they are predicting that the market will grow.

With this cooperation, the municipality hopes to reduce the number of trips they do up to the valley, have a better surveillance over the valley and hence arrive better prepared to the area with the appropriate equipment. With a better surveillance, they would like to be faster at identifying leakages. With these objectives, the ultimate expectation is to have cleaner water, better visibility and guarantee a greater safety within the water distribution.

7. Discussion of research findings

7.1 Pipelife's readiness assessment

Pipelife's online self-check readiness assessment was carried out by a team of five people, a Pipelife engineer, three PhD candidates and me, a master's student. More detailed results can be found in Appendices C. The readiness of the six dimensions is scattered and the maturity level varies between 0 and 3. With such broad disparity, the overall readiness corresponds to maturity level 1.

Pipelife should raise their overall maturity level. The dimensions "Smart products" and "Data-driven services" are on level 0 so these must be placed in focus and improved. Boge, the manager for digital innovation and transformation, informed that Pipelife are developing various concepts to raise their conventional pipes to becoming "smart" pipes. The readiness assessment justifies the needs for launching such projects. For the dimension of Smart products, there is already a project involving implementing RFID on the pipes. For the dimension of Data-driven services, there is currently a discussion about creating a platform containing pipe specifications and characteristics open to customers. The projects are still in the early phases and the actual implementation, gaps and practicalities of these ideas must be addressed. The purpose of this thesis is to suggest one opportunity and analyse how this suggested project will impact their operations.

Smart products and data-driven services are dimensions which have been treated separately during the readiness assessment, however they should be treated in parallel. Supplementing their pipes with add-on functionalities would lead to opportunities involving data collection and would provide information on the pipe's performance during its usage phase. Add-on functionalities and data collection could also lead to developing new services that Pipelife could offer their customers. There are numerous benefits for the customers if they were offered more advanced pipes. Simultaneously, Pipelife would also experience benefits at their manufacturing plant if they decided to adopt add-on functionalities advantageous to them.

7.2 The PSS scale

Based on the PSS definitions in table 6 found in the section "The different definitions of PSS", table 8 combines these definitions. The terminology "Equipment provider", "Solution provider" and "Performance provider" defined by Kohtamäki & Helo (2015) were considered the most appropriate as they appeared the most self-explanatory and could also satisfy the definitions created by other authors. Throughout the rest of the thesis these will be the definitions used to describe the various PSS offerings. The words below the main terms in bold are the other words used by the other authors.

Table 8. The various levels of PSS based on a compilation of all the various definitions found during the literature review.

Level	Product-service dimension	"Smartness"	Examples
0	**No service**		Traditional products
1	**Equipment provider** Base services Product-oriented services Smoothing services		· Goods · Spare parts · Selling add-ons services · Installation
2	**Solution provider** Intermediate Through life management User-oriented services Adaptive services	Passive smart products	· Solution sales "product-service bundling" · Maintenance · Product repairs · Customer service · Overhauls · Help desk · Conditioning monitoring
3	**Performance provider** Result-oriented services Availability contracting Advanced services Use-oriented PSS Substituting services	· Active smart products · Autonomous smart products	· Customer support agreements · Outcome contracts · Full integration · "Power by the hour"

PSS can be divided into four increasing levels of service orientation. The scale spans from offering just tangible products, to offering some combination of product and additional services, to only offering a service. This spanning can be illustrated as a function of a linear scale and this will be addressed in the following chapter in the context of the cases.

Each level comes with benefits and disadvantages. For a manufacturer, the easiest transition is to become an equipment provider. This can still lie close to their core competence and therefore the risks are smaller. It is also an easier step to start with as the manufacturer would not need to create too many new partnerships and their products would probably not change much in design. Thus, their current production facilities would not have to alter drastically. The manufacturer could consider installing sensors as an extra add-on functionality. This could lay the necessary groundwork if they in the future wanted to become solution providers who offered maintenance, potentially based on the monitoring of the product's performance. Becoming equipment providers can be a safe start if they wish to adopt a PSS structure and then, after some experience, considered adopting a more complex form for PSS structure.

Once a manufacturer considers becoming a solution provider, they must start to gain expertise in areas which they do not currently possess (e.g. on-site maintenance, help-desk functions and help lines, data storage and monitoring, the analysis of extracted data). Furthermore, it is likely that they would have to invest in equipment to perform the services they are wishing to offer, such as maintenance. The major benefit for the customer is that they no longer would need to buy and maintain the equipment. Equipment is often idle and is not frequently used by individual customers throughout its entire lifetime. A manufacturer could gain more value from these investments if they could use them more frequently while managing the products of many customers. As solution providers, manufacturers would have to consider a new pricing strategy now that they are offering different forms of maintenance, repairs, condition monitoring and help desk functions.

A performance provider would have a better visibility of the product life cycle costs. The customer would no longer be responsible for costs related to breakdowns and spare parts. Thus, with this added responsibility, manufacturers would gain greater incentives to develop better products with minimal breakdowns and maintenance costs (Kim et al., 2007). Furthermore, an integrated solution would offer greater value to the customer and fulfil their needs for accurately allowing the customer to focus on creating and offering new and more competitive solutions (Windahl & Lakemond, 2010). The performance provider's product offering may be better aligned with the customer's requirements and business model if the manufactured products they have been buying till now have been used as supporting products to their main product. For them, the possibility of leasing and having less responsibility over the supporting products may be exactly what they need. Rolls-Royce and their notion of "power by the hour" was introduced earlier in the thesis. Rolls-Royce discovered that airlines didn't need to buy turbines, what airlines actually needed was some form of propulsion to take their passengers to the final destination. Therefore, simply leasing the Rolls-Royce turbines fitted the airline's strategy better as it allowed them to execute their main function while avoiding the responsibility of monitoring and executing maintenance. Whether this model can work will depend on whether the customer is willing to transfer their ownership over to the manufacturer. Some customers may fear locking themselves to only one provider who could potentially gain full monopoly in the future.

The generalised table 8 has been created so that it can be used for several products belonging to different industries. When adapting the table to a specific product, in this case pipes, it is possible to segment level one to three further and this is illustrated later.

The column “Product-service dimension” has collected and classified the different definitions found in the literature study. As mentioned, the words in bold have been selected as the words encompassing the synonyms.

Column three describes the product’s degree of smartness. The services a company can offer as “Equipment providers” are very basic and they do not rely on equipping the original base product with technologically advanced sensors. Level of service 1 can be considered the traditional and simplest form of PSS products (e.g. periodic maintenance services). However, these repairs are not generated based on the product’s individual performance and interactions with the environment. Level of service 2 includes products possessing a passive smartness. It is defined passive because data is collected and eventually measured, however it does not contribute to real-time monitoring. The data can indicate the product’s past performance and can then be used to control and suggest necessary maintenance or repairs. There are two types of smartness in Level of service 3, “active smart products” and “autonomous smart products”. Active smart products have optimisation capabilities, whereas autonomous smart products have autonomous capabilities. Products with this level of smartness can suggest optimal solutions based on sensing and monitoring. The difference is that autonomous smart products are capable of functioning independently of human interaction and can act and perform the necessary intervention based on the calculated optimisation. As the smartness and the digitalisation of the product increases, so does the digital complexity and required data processing and data storage. The data is either static or dynamic. Static data describes the product in detail (e.g. information about the components), and dynamic data is the accumulated information during the product’s usage (Allmendinger & Lombreglia, 2005; Yang et al., 2009).

The last column indicates different types of services which can be provided by the manufacturer. A manufacturer offering just one of the services it its level would find themselves on the lower tier of the level, while if they offered all of the suggested services they would find themselves in the higher tier of the level.

Table 9 correlates to table 8, however it focusses on the digital dimension of PSS and consolidates figure 5 and figure 6. It summarises how the level of digitalisation has increased over the years and illustrates how this has impacted the services which have been provided to the customers. It shows the technology used to achieve this rising complexity in services. The table also indicates that the PSS concept is not new, nonetheless with the rise of Industry 4.0 technology the introduction of smartness to the PSS concept is. Furthermore, the difference between level 2 and level 3 is that the communication between the real world and the virtual world is bidirectional. Level 2 simply monitors a product's performance, whereas level 3 can process the generated data and can react autonomously to the data.

Table 9. The levels of digitalisation a PSS can adopt. Based on the finding from the literature study.

Digitalisation level	Connectedness	Digital dimension	Description	Date
0	No service	-	-	-
1	Conventional PSS	Manual services	Internet, roaming	1999-2010
2	IoT enabled PSS	Digital services	Ubiquitous connections, RFID	2010-2015
3	Smart PSS	Industry 4.0 services	Digital twin, CPS	2015-

Table 9 will always modify according to the maturity of the current technology and can therefore not be set. The level of digitalisation follows a chronological order. With the growing advances made in digitalisation, the more complete will table 9 become. Extending the table from level 2 to level 3 has been a recent development resulting from the growing popularity of digital twins and cyber-physical systems. There is also a correlation between connectedness and smartness. Simultaneously, it is challenging to predict whether the table will grow with further research. Although much research and advances have been made on Smart PSS and Industry 4.0 services, it is not representative of the reality in industry. Different industries and product types are lagging in innovation and advances may still linger somewhere between digitalisation level 0 and 2.

A PSS scale adapted for Pipelife

The purpose of the PSS scale is to identify all the different combinations of product-service bundles Pipelife can offer their customers. Establishing these can then be used to map the alternatives customers would prefer (Oliva & Kallenberg, 2003; Davies et al., 2006; Baines et al., 2017). Simultaneously, a visual representation makes it easier to understand how the pipe manufacturer can evolve and it can allow them to understand which aspects must be in place before a more advanced solution can be offered to the customer (Oliva & Kallenberg, 2003; Davies et al., 2006; Baines et al., 2017).

The scale suggests that the manufacturer will undergo an incremental service development rather than a radical transformation (Kohtamäki & Helo, 2015). This thesis is the first paper to illustrate different PSS offerings as a framework along a linear axis depicting how an offering can range from being just product-based to entirely service-oriented. The interpretation emphasises the incremental transformation. When a company wishes to transform from a product- to service-dominant business model it cannot occur through large leaps at a time. Several obstacles need to be addressed adequately such that the business opportunities that arise with the new strategies are exploited. Emergent strategic transformations (Mintzberg & Lampel, 1999), known as company-level transformations, will be developed and implemented more successfully if the process is incremental. This is because companies can benefit from learning from the business environment, experience strategic learning and reflect on previous strategic decisions (Sirén et al., 2012).

The PSS scale developed for the water pipe industry is by no means measuring the maturity of the value offering to the customer and it does not imply that higher levels are always better in all aspects. Thus, it does not suggest that Pipelife's final objective is to strive towards becoming performance providers. Both Pipelife and Surnadal municipality may have the common understanding that settling for a lower level may be the ideal solution that satisfies both their strategic fits.

A PSS scale (figure 7) has been created based on the findings from the literature search and the input from both the manufacturer and the municipality. As mentioned in the limitations, the time constraint has only allowed for interviewing two case companies. Nonetheless, the requirements for the water distribution network are generalisable suggesting that it is likely that the scale can be adopted to both other water distribution networks within the country and could potentially be extended to other countries who experience similar environments, processes and routines. The scale is strongly tailored towards the water industry so Pipelife cannot use the same scale for other business units (e.g. telecommunication network, energy and power distribution). Nevertheless, the concept of the PSS scale can easily be adopted by other units and sectors provided it is adapted to the necessary processes, expectations and requirements.

The scale is segmented into "Equipment provider", "Solution provider" and "Performance provider". Each of these categories have then been divided further into appropriate subcategories. Since the scale has been adapted for the water pipe industry the three PSS categories involve the three offerings: pipes equipped with sensors, pipes equipped with sensors and includes maintenance and finally, the leasing and the long-term maintenance contracts of pipes. The water distribution requires the monitoring of both the water flow and the quality. The monitoring of the water flow involves measuring pressure, volume and velocity, while the quality monitoring involves taking water samples at distinct points throughout the distribution network. The water flow can be monitored as a result of equipping the pipes with the appropriate sensors. Hence, this does not diverge too far from Pipelife's possible competence which they can adopt when providing a service. The offering of monitoring water flow is covered when they act as equipment providers and solution providers. The monitoring of the water quality is more complex and is only offered given that Pipelife becomes performance providers or "water providers". To achieve this, they would have to develop skills, expertise and collaborations which they do not currently possess.

Figure 7 suggests eight different PSS bundles of varying degrees of product and service. On one extreme of the scale, Pipelife manufactures pipes and deliver these directly to the customers or to the wholesalers. The other extreme is where Pipelife still manufactures pipes, however they become water providers and are responsible for delivering water to customers. Since the scale represents a smart PSS, the increasing degree of service orientation will also increase the level of digitalisation of the product. The intermediary stages of the scale will now be discussed.

As equipment providers, Pipelife would offer a conventional PSS which involves equipping the pipes with location sensors. John Øye, product manager at Pipelife, suggests RFID technology. The cheapest RFID tags resemble a sticker and can function the 100 years which are required of the pipes. Due to the humid environment, the RFID technology may need to be laminated and this would increase the price. The tags could be on either end of the pipes or across a set interval distance, but it would depend on the length of the pipe. The offering could be extended to location and information on water flow. Additional sensors would need to be added. In this scenario the municipality would own the pipes and they would be responsible for installing the sensors in the pipes, for monitoring the water and for maintaining the pipes. This scenario is like the situation they experience today. The municipality already possesses the required skills and equipment for laying and maintaining the pipes.

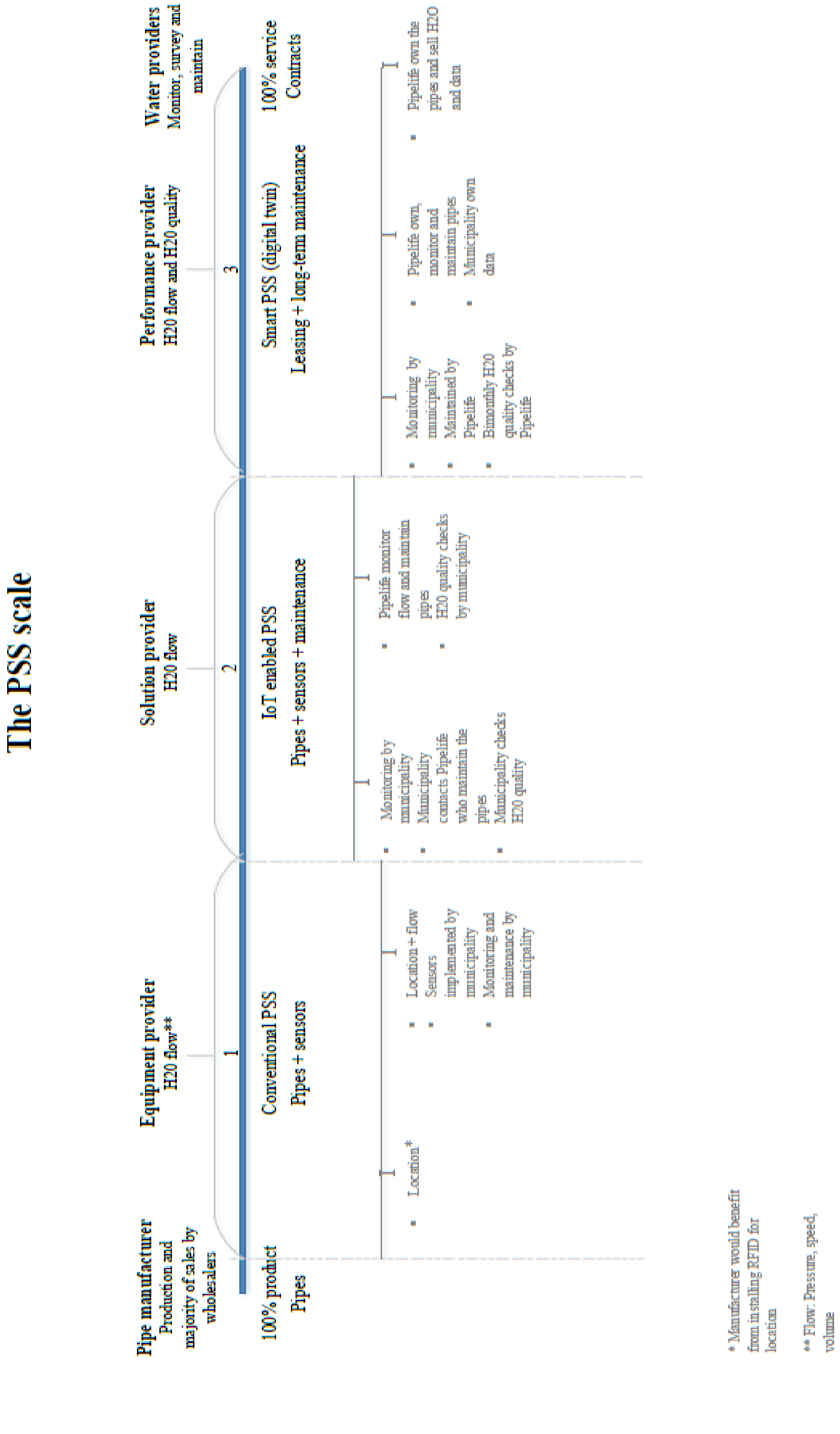

Figure 7. The PSS scale developed specifically for a water distributor based on the feedback from Pipelife and Surnadal municipality. Framework created by author.

Pipelife can increase their service orientation and provide a solution - an IoT enabled PSS. This scenario would entail Pipelife to provide pipes, sensors and maintenance. Like the first level, the second level can be divided into two subcategories, and the services still only address the surveillance of the water flow. The first subcategory would involve Surnadal monitoring the water and Pipelife investing in the necessary equipment and maintaining the pipes. Surnadal would contact Pipelife when necessary. The municipality would continue to perform the two checks they do now (i.e. fortnightly quality controls, triweekly checks on the distribution network), however this would occur more efficiently as they would be more informed on the real-time situation of the network. They would be prepared and bring both the necessary equipment and people the first time around and this would save them time and effort.

An extended offering of solution providers involves Pipelife taking over the surveillance and the water flow. Nonetheless, the municipality would continue with the fortnightly quality controls.

As performance providers, Pipelife would own the pipes and they would offer smart pipe services. These are the most advanced pipes and require a complex sensor network. In literature this is referred to as “digital twins”. Pipelife would offer the distribution of water and would therefore have to monitor both flow and quality. Thus, this product-service bundle involves them taking over the fortnightly quality checks. As a result, they would have to drive to the various check points, collect the samples and deliver them to the laboratory. Existing technology on the market which is installed in pipes would not be able to automatically indicate the quality of the water since the bacteria need to be grown for two days and then be analysed. Furthermore, clarity and the colour must also be measured, and this cannot occur inside the pipes with flowing water. The extension of this service would involve Surnadal owning the data generated in the pipes, while Pipelife would be responsible for producing, monitoring and maintaining the water flow and the quality. Pipelife would become a complete service provider when they would own the generated data and they executed all the necessary tasks. The payment method would become unique because they could generate a value stream based on the contracts with the municipalities. Geng et al. (2005) proposed that the use of bundling strategies could generate “excess” information goods with little value to the company but could hold high value for others. The changes in the financial stream resulting from the superfluous information being sold and exploited by others would lead to the modification of business models. Pipelife could sell data to private companies or research institutions (e.g. SINTEF) that study the impacts of global warming on the water in the valleys.

7.3 Feedback from the stakeholders

Feedback from the municipality

Both the operating manager for water and drainage and the head of department for municipal engineering were present during the interview and there were at times some disagreements. While the operating manager focused on the practicalities of the operations, the head of department was considered by his peer as the "businessman" and was more welcoming to new business opportunities. Regardless, they were both thrilled to be part of the journey.

Surnadal's willingness to participate in Pipelife's project would be governed by politics. Although, the municipality and their board would be willing to stretch themselves far to secure the collaboration and the success of the project. Firstly, Pipelife is the major cornerstone company in the municipality and offers many workplaces. Secondly, this project could make Surnadal become the leading pilot municipality and make them a centre of expertise for the new water providing solution. Thirdly, a valley in Surnadal is used as Europe's point of reference for air and water quality. This is a great pride, making it essential to them to have control over the water quality.

The opinions of the three levels on the PSS scale are systematically presented. They stated that their current KPIs would remain the same when assessing the performance of a PSS bundle; water quality and quantity would prevail, closely followed by cost. Cost is essential since simply reducing leakages from 50% to 0% would automatically half their costs. They affirmed that other KPIs could arise with increasing experience with PSS bundling.

Equipment providers. The operating manager would not be interested in pipes equipped with the adequate technology to indicate location (e.g. RFID technology). They are already using GPS signals to know the location of the pipes in the ground so they would be paying for something they already do themselves. In fact, knowing the exact location is imposed by the law. Nonetheless, the head of the department showed interest in investing in pipes that did provide location.

The municipality have set requirements for the extended services resulting from equipping pipes with extra sensors. Firstly, they would expect that the pipes would at least provide information on flow, if not also quality. Though the latter would be far from Pipelife's core competence. To minimise costs, the monitoring would only be focused on the main pipe which starts higher up in the valley and continues down to the centre.

The operating manager proposes two ideas for monitoring the water flow: incremental monitoring and continuous monitoring. By incremental he suggests that sensors could be placed at set strategic points along the pipes. Adding sensors at the fittings where they extract the water samples would be a natural solution as there is a direct access. The operating manager adds that it would not be too expensive nor difficult to dig up pipes already in the ground and install sensors at critical points that require monitoring.

Continuous monitoring is described as a serial battery, a sensor equal to the length of the pipe, which monitors the entire flow. The measurements would be more accurate because they would create a real-time image of the situation rather than individual snapshots taken every arbitrary distance between two sensors. It was concluded this would be expensive and that incremental monitoring covered the needs just as well.

Solution providers. Although the product manager hypothesised that Pipelife would either have to provide pipes which offered location or become complete water distributors, the municipality expressed that solution providers could offer interesting benefits. Being a compromise between the two extremes, the two participants offered few objections towards this level. Pipelife could become performance providers sometime in the future after having gained experience and developed new skills and competence as solution providers.

Performance providers. This would involve Pipelife taking over the ownership of the pipes and leasing the pipes or sell water to the municipality. The interviewees suggested it could become a new form of outsourcing where the citizens paid directly to Pipelife for their water usage. The operating manager is critical to performance providers because it would privatise the distribution. The danger would be locking themselves to an individual water provider. In this monopoly, the water provider could double the prices while the municipality would be unable to come with a counteroffer. He believes that all the competing water providers should follow the same standard such that the municipality could choose their preferred supplier. Ideally, three to four companies should compete to become potential water providers at Surnadal. He would feel less vulnerable if they owned their data generated by the pipes and Pipelife owned the infrastructure.

Regardless of this possibility, the operating manager is firm about wanting to own both the pipes and the sensors. If they were to terminate their collaboration with Pipelife they would continue to offer water to their municipality the traditional way. The head of the department disagrees because he sees this as a good opportunity which is more cost efficient for them, that is, provided the partnership runs smoothly. They would have less organisational costs and they would have less bounded capital since they no longer would need to possess their own equipment. For the municipality, investing in equipment can be expensive as it is frequently idle for most of its lifetime. The head adds that the investments would be brought down further if Pipelife expanded their PSS offering to other customers and increased the use of the equipment.

Both interviewees recognise that the value lies in the data and not in the pipes. As already mentioned, this could generate new value streams and it would need to be determined who owned the data and who would benefit from buying the data. Both interviewees communicate that Surnadal would not benefit from possessing the data generated, albeit Pipelife could benefit from analysing the data. Hence, it would be logical that Pipelife possessed this information. The municipality is participating in the project because they are hoping to ease their operations. Owning the data and finding parties to sell the data to would create an additional complexity.

Feedback from Pipelife

Pipelife's margins are under pressure, their products are at the bottom of the value chain, the market is commoditising, and the competition is rising. A potential PSS structure would be a growth strategy, a blue ocean strategy, which would need to strengthen their position in the market and improve their margins. Till now this has been a white spot on the technology market, however the increasing research and matureness of technology is driving them to take an early position in penetrating the market.

Roald Boge, manager for digital innovation and transformation, agrees with the scale tailored for Pipelife (figure 7), both the different levels and the segmentation of them. He states that the PSS scale is highly relevant, interesting and makes perfect sense. As a result of research on sensors, particularly on quality monitoring sensors, Pipelife are not restrained by technology and can aim at any of the suggested states.

Regardless of their current capabilities, their objective is to become water providers. This goal has been inspired by the development contracts which will also become responsible for road maintenance in the 15-20 years to come. The top manager in the Wienerberger, Pipelife's mother company, has explicitly expressed a couple of times the past six months that Pipelife should aim at becoming service providers. Boge admits that the municipalities are probably not prepared for the manufacturer to completely take over the distribution. Nonetheless, the water delivery will transform and they "must climb the stairs together" to reach this. A further inspiration is the Netherland's strategy. In contrast to Norway's 300-400 water delivery companies, one for each individual municipality, the Netherlands have ten. For the time being, Pipelife should move gradually towards making the pipes a service economy. Boge explains it is a two-step process. First, they deliver sensor data into a system, either an existing one or hopefully their new developed system. Next, they deliver pipes as a service and transition to the far right of the PSS scale. Some technology is still lagging, and certain processes are still manual. Pipelife must decide whether they would be interested in becoming service providers by first taking over the manual labour, such as physically doing the water samples, till the technologies arrives on the market. This must be discussed in more detail, however Boge suggests that this could be interesting and worthwhile if the existing gap gets closed with the introduction of the advanced technology in the future.

Pipelife has identified the need for differentiating services offered to customers. Municipalities (e.g. Oslo and Surnadal) have different needs and require different solutions. Hence, solutions are tailormade, but they are based on standard technologies and pipes. It is highly important that they operate on open standards and systems such that customers do not experience being locked in. This is particularly a major threat to big customers.

Pipelife would highly benefit from having access to the generated data in the pipes since they could use it for R&D. It may be unrealistic for them to own it, however they could buy it or rent it from the municipality. They have not decided how this would work in practice. Their aim is that their systems could transport data to their cloud and that they could retrieve other generated data through an interface.

In addition to striving towards becoming service providers in the water distribution industry, they are also investigating how such a service strategy could be implemented in sewage and flooding systems.

While Pipelife are driven towards becoming solution providers, they would also benefit from equipping the pipes with RFID technology. They would gain better insight and visibility of their production which would allow them to identify areas for improvement. The enhanced visibility would benefit material flow in production and inventory handling. Inefficient transportation leading to bottlenecks could be analysed, redesigned and ameliorated with gained visibility. Installing RFID technology would assist with achieving the first suggested state on the PSS scale and a cost-benefit analysis would indicate the feasibility.

Assimilation and consolidation of the feedbacks

All the interviews have independently confirmed that a project can be functioning in five years, and this agrees with the initial hypothesis and time frame for the PSS scale. For the municipality, this entails be offered pipes capable of monitoring the water flow. Boge communicates that the necessary research is moving rapidly worldwide. In Norway, an eight-year project has been launched with the water supply organisation, the water authorities, NTNU and SFI, the centre for innovation driven research. Therefore, major changes can occur in five years.

After evaluating the opinions, it appears evident that Pipelife will adopt a PSS structure, thus remaining stagnant as manufacturers is not an option. Their ultimate goal is to become water providers that own the pipes which they monitor, survey and maintain (right of the scale). Their revenues would come from selling water and data. Their ideal scenario is to possess the data and the municipality has initially expressed that they do not require the data themselves. However, this is an agreement which must be discussed in more detail. Until then, Boge has expressed that Pipelife could become solution providers by maintaining the pipes and gathering the data generated and sending the information to a platform they are developing. As solution providers, they would not be responsible for the monitoring of the water quality. However, he is open towards considering taking over the fortnightly manual water sampling provided this gap could be closed with appropriate technology in the future. This would need to be addressed with the municipality.

7.4 The challenges

The challenges identified earlier in the thesis will now be discussed from Pipelife's perspective.

Strategic challenges are the focus on the agenda, and they are addressed with SWOT analyses. Pipelife will continue to deliver pipes but they must decide whether the new services should be developed as a separate business unit in the form of a daughter company. In the beginning, this unit will take on new responsibilities, have different insurances and be vulnerable, so isolating the two entities would handle the risks separately. As a result, if something critical occured to the daughter company it would not influence Pipelife's performance and reputation. Creating an independent unit could also increase the flexibility in the decision-making. This could be very beneficial for a start-up where there initially is an abundance of uncertainties and where choices may need to be taken quickly. This could reduce the existing bureaucracy, something the product manager mentioned was present in the organisation and has up until now functioned as a barrier for innovation.

Pipelife must continue to have an open dialogue with the municipality because they are their first encounter with customers adopting a PSS. However, it is essential that they interview many employees working in the water distribution in Surnadal, preferably separately. It was experienced that the two interviewees in this thesis had very divergent opinions. Pipelife would have to accommodate for these disparities and understand the expectations from the various perspectives. They must eventually interview other municipalities, however in the meantime they gain a lot from using and understanding a case in so close vicinity. The municipality expressed that the politics play a major factor in favour of the manufacturer when deciding for the acceptance of the pilot project and they should embrace the support and the learning they can gain from such a collaboration.

Pipelife are fortunate to have a strong management commitment, both from Pipelife Norway and Wienerberger, the building material giant. Boge states that the top manager from the latter has continuously mentioned that Pipelife should aim at becoming service providers. This support is important and beneficial for financing and investments. Nonetheless, Boge admits that he is often met with scepticism from middle and bottom management as their industry is conservative and because their current business model, competences and partnerships would topple. However, as they gain increasing insight of the current market, trends and Pipelife's prospective, they realise that this project is the only way which can guarantee their dominance in the future. It remains imperative to continue to convince the cynics and ensure they get onboard.

Skills are essential to master and from the interviews it appears that Pipelife are very much aware of this. Key employees, especially in top and middle management, have recognised the need and the potential of PSS and are actively working towards developing it. They are good ambassadors and motivate co-workers to join and support the journey. The key players are aware of their own capabilities and are building relationships with companies that can serve as a springboard for them to reach higher heights. They have tactically developed a pilot in their own municipality. Being in proximity and being a cornerstone company, they have already built up the critical reputation and trust. These factors contribute to successful customer management. The complexities of knowledge management are also addressed when building their own information platform. They have identified the importance of having open systems and standards such that customers do not experience being locked in. Otherwise, this could cause a significant barrier for customers willing to benefit from Pipelife's services.

Competence is a vital enabler for the survival of the project, and this is something they have actively addressed. Boge states that they must employ the right people that are skilled, young and motivated who are excited to bring about change. Therefore, they have collaborated with the university and participated in master theses and PhDs to trigger research and attract stimulated minds.

Ecomomics needs to be developed with a heavy focus on the customer requirements as they must accept the new methods which value is delivered to them. The operator of the water distribution expressed his concerns and sensitivity towards pricing. He clearly would not pay for a service which they are currently doing themselves. Launching a pilot project is advantageous to Pipelife as it allows them to identify what is attractive to their customers. Since pipes are not very expensive products it is critical that superfluous technology is not installed because it would greatly increase the cost and hence the selling price.

Products and processes will not cause significant issues. Boge confirms that the pipes will not change much, thus the material flow and the layout in the manufacturing facilities will hardly be modified. This will especially be the case if the installation of sensors on the pipes occurs in the ditches. Furthermore, the equipment provided by suppliers will not change either, facilitating Pipelife's transition towards a PSS structure. They will need to forge new collaborations with sensor suppliers, and they will need to have an open dialogue with the coverage and internet provider in the valley. However, this criterium is specific to the case of Surnadal and cannot be generalised for all municipalities and similar projects. If they were to become responsible for the water quality, they would also have to collaborate with laboratories and the water authorities. Pipelife has already started with contacting the technology companies that can be appropriate in the future. Most of the technology they require does not exist, but it is being developed. The development is challenging since few suppliers deliver sensors with the correct specifications for humid, underground usage in remote areas where there is no power supply and coverage.

7.5 The impacts on operations

When Pipelife adopts a PSS structure, and thus develops a service orientation, they will need to adjust their business structure and reassess their remuneration of their products. Hence, they will need to reconfigure their functional areas and develop new capabilities. Five functional areas and their respective strategies (table 10) will determine the organisation's business strategy and business model (Beckman & Rosenfield, 2008). Since this thesis is written in the Department of Mechanical and Industrial Engineering, the functional area "Operations" will be analysed in detail (table 11 & table 12). Operations can be distinguished as either structural or infrastructural (Skinner, W., 1969; Hayes & Wheelwright, 1984; Baines et al., 2009). Structural decisions deal with more tangible outcomes such as buildings, how equipment and personnel are organised and how these link to other businesses. Infrastructural decisions create capabilities that support and leverage the company's structure. These decisions relate to systems used to enhance the utilisation of the structural resources and ensure that the highest levels of productivity are reached. They are developed over time based on coherent and consistent practice.

The tables have been created based on the insight and the interactions gained from the interviews, the literature study and personal reflection. The statements and the questions have been developed based on the categories suggested by previous authors and can be used by any pipe manufacturer who considers adopting a PSS structure. The category "Other" found in table 12 was created because there were certain elements which were considered important when reflecting which had not been covered by the categories suggested by Skinner, Hayes & Wheelwright and Baines et al.

Pipelife must consider all these aspects when they plan on adopting a PSS structure. While some aspects are essential to raise and must certainly change (i.e. the affirmations), other aspects must be addressed and discussed. For the latter, Pipelife must consider whether they wish to continue their business practices or whether they should modify these elements, too (i.e. raised questions).

Table 10. The main functional strategies in a company.

Functional areas	
Operations	Structural (table 11) and infrastructural (table 12) dimension.
Marketing	Price and price testing: different price configurations to optimise revenues and margins? Develop new revenue model?

	Who is billed: private water consumers or the municipality? When and how will the manufacturer be remunerated: performance contract? monthly? Develop new brand and image. What sort of market search? Brand promotions? Does the manufacturer scout and contact potential customers or do customers contact them? Should salesmen be sent to persuade municipalities to change their distribution network? Who are the manufacturer's competitors?
Research & Development	Develop new market research, business experimentation and product development. How will R&D use the generated data in the pipes? Collaborate with suppliers to test new technology on the market?
Human resources (i.e. people deployment, skillsets*)	New recruitment process, employee selection and induction. Different development training. Develop a different organisational culture. Which are the required worker characteristics? New recruitment test focused on personality? Where should differently skilled staff be distributed? Necessary skills: see table 13.
Finance & Accounting	Modify forecasting, budgeting, cost control, project management and annual audit.

Table 11. Adopting a PSS structure will incur structural changes in the organisation.

Structural	
Process technology	Remote asset monitoring to inform about maintenance, repairs and performance. Which system will be used? Connect to existing technology? Which technology?
Capacity	Can the pipe manufacturer serve both large and small municipalities? Can they serve all environments and landscapes?
Facilities and location	Where should the manufacturer be located? Centralised HQ and/or decentralised on-site units for maintaining and controlling individual municipalities? How many decentralised units? One employee per municipality or which municipalities could be coupled? Work in the municipality's main building or work from private facilities?
Vertical integration	What is the extent of the integration? Who are the closely integrated partners? Backwards to retain design and production capabilities? Forwards for extended responsibility of product management, condition monitoring, maintenance, repair and overhaul?

Table 12. Adopting a PSS structure will incur infrastructural changes to the organisation.

Infrastructural	
Business processes & policies (i.e. production & service generation,	What are the new planning and control systems? How to optimise the product availability? Will the product offerings vary? One standard solution for distributing water? Same technology for all environments?

order fulfilment, service & support, workforce & organisation design)	Water providers in private sector? Or only municipalities? How will the pipe manufacturer innovate their offering? Incremental or radical innovations? Will the firm introduce the product internationally? Will they assist with developing the know-how for other divisions within the same company? Front-office utilisation: 24/7 mind-set, customer interface and service. Which intangible requirements will shape customer perception? Final installation occurs in ditches. How will this occur? Who trains the operators to install the pipes with the appropriate technology? Will the pipe's specifications adapt to the installed devices?
Supply chain coordination	New strategic partnerships? Will there be a wholesaler? What will the role of the wholesaler be? Develop independent in-house capabilities? How are the logistics? Commission a distribution firm for the logistics of the onsite installations? Which new equipment is required?
Sourcing	Several or one supplier for each technology? International or domestic suppliers? What will the relationship be?
Information systems and technology	Will remote monitoring connect to existing technology? Which technology? Who is responsible for monitoring? Will the firm maintain the activity or outsource? How will data monitoring link to business processes? How will it link with budgeting and financing systems? Data generation: how will it be stored? Who owns the data generated in the pipes? Who can benefit from the data? Develop stronger information security. Should the firm be a follower or a leader in the development and in the use of state-of-the-art technology? How does the information technology investment fit with the other investments?
Capabilities (i.e. quality, lean operations, flexibility)	Which quality controls are necessary? Why and how are they deployed? Repair faulty technology? Or replace with new meters or sensors? Insource maintenance and repair skills for devices installed on pipes? Or send to supplier? Does this only depend on cost? Which are the new outputs for conformance? Develop a new quality assurance? Assess different root causes?
Other (i.e. performance measurements & demonstration of value, risk management)	Define new KPI's aligned with individual customers: Asset performance, availability, reliability? Customer-facing measures? Internal macro-measures? Localised measures of contract? Value demonstration? How will the overall KPI's cascade into various forms throughout the organisations? Which risks exist (for pipes and water quality)? Potential consequences and costs? How will failed events impact the firm's reputation?

People deployment and skillsets is a structural factor, marked with a (*), which facilitates and sustains a positive relationship with the customer. Adopting a PSS structure will require Pipelife to develop and possess skills specific to the service sector, skills that have till now not been as essential to them. All the skills represented in table 13 are important, however certain jobs will need individual skills to be stronger than others. All except for “technically adept” will be particularly fundamental to frontline employees who are in direct contact with the customer.

Table 13. Fundamental skillsets when a firm develops a service orientation. Based on Baines & Lightfoot (2013).

Skillsets*	Description of skillsets
Flexibility	Ability to modify working routings to meet customer requirements. Ability to have unpredictable work hours with the 24/7 mindset.
Relationship building	Forging strong relationships with both co-workers and customers. Developing and sustaining trust internally and externally.
Service-centricity	Empathy with the customer’s needs and problems. Talking and engaging with people.
Authenticity	Honesty towards the customer. Committed and faithful to a successful delivery.
Technically adept	Possessing a good understanding of the overall operations and products. Understanding the repercussions of a product failure for the customer.
Resilience	Ability to handle stress incurred from working with the customer. Ability to differentiate work and personal life, the problems remain at work.

The impacts on the manufacturing plant

As mentioned, the material flow and the layout in the manufacturing facility will not be greatly impacted. The municipality has expressed that the installation of meters and sensors could occur in the ditch and this assembly could also occur on pipes already in the ground.

A suggested add-on functionality are RFID tags. Their principal function is to provide information on location. Although the municipality received this proposal with mixed enthusiasm, Pipelife would greatly benefit from this upgrade. RFID technology does not directly increase the value of the product itself. The added value lies in the data since the insight gained in the production capabilities improves value-adding activities. Although barcode technology is both a cheaper, more mature and simpler solution for product identification, it requires optical in-line of sight technology (White et al., 2007) making it automatically inappropriate since it must function below ground.

Pipelife would benefit from RFID tags since they are facing three major challenges: inaccurate inventory levels, poor visibility in tracking and tracing products, and suboptimal information and material flow. This causes poor performance in production, inbound logistics and purchasing.

Regardless of the chosen PSS level, the pipes will not be subject to significant changes in design nor in processing. Therefore, the customer order decoupling point (CODP) will remain intact and most of the pipes will continue being make-to-stock (MTS). MTS indicates there is little demand visibility and that the necessary supply is based on speculation. This occurs because the wholesaler has much power and Pipelife has to endure rush orders sent in by wholesalers. This causes the bullwhip effect and incurs great costs for Pipelife who must reschedule their production plan.

RFID readers automatically register and update the ERP system and eliminates the need for manual counting. Manual counting is tedious work and can be incorrect due to human errors. This results in inaccurate inventory levels. RFID technology improves inventory visibility; thus, the production needs and orders and purchasing will be based on more real demand. Hence, the risk of stock-outs or overfilled storages are minimised and will directly reduce delays and unplanned downtime in production. Ultimately, the customer service level will be increased, and the improved visibility will reduce the holding costs as only the necessary volumes are stored.

Pipelife must handle large volumes of products and intermediary products. RFID enables a more detailed tracking and tracing of products and enables an enhanced coordination of the material flow. Tracking and tracing will help identify inefficient areas caused by bottlenecks, incompetent employees or poor material flow or layout of workstations. The flow can be improved by spending less time on non-value adding activities such as searching for individual items. The company gains a more accurate production control and leverages improvements in productivity.

The ability to capture real-time data makes RFID technology an enabler for decision support. The focus can be directed towards production control rather than production planning. The latter being a process managed by production planners that frequently risk basing plans on inaccurate data and human error. An ERP system can use the available real-time data and distribute the tasks and plans to the responsible departments. It is likely that jobs in production planning will become redundant in the future as the ERP system can do a more accurate job at a far lower cost.

8. Conclusion

The market is becoming increasingly competitive. A company can sustain its competitive advantage by launching new and inimitable value concepts, and by continuously reinventing the way value is created and delivered to the customer (Matthyssens, P., 2019). The growing presence of digitalised products and Industry 4.0 concepts on the market are significant motivators that can create opportunities and new value streams. Manufacturers can now develop unique solutions which they have never considered earlier. They have discovered in the recent years that equipping their traditional products with devices, such as sensors, enables the monitoring of the product's performance throughout its lifecycle. Surveying the performance enables manufacturers to offer additional services to their customers and these ultimate product offerings are frequently better aligned with the customer's needs and their own requirements. As a result, a manufacturer can go from simply offering a tangible product to bundling a product with various services. Taking it one step further, manufacturers could consider retaining the ownership of their products and offer value instead. This can be achieved by leasing or offering long-term maintenance contracts. The market conditions have now changed from valuing a cost-based competitive advantage to a value-adding competitive advantage, thus making it fundamental to develop excellence and flexibility (Issa et al., 2018).

By building stronger lasting relationships with customers, suppliers and third parties, manufacturers are trying to fight back and preserve their long-term competitive advantage (Eloranta & Turunen, 2015) which they have been slowly losing over time. The manufacturing sector has been slow with embracing change so adopting agile ways of working is challenging (Kowalkowski et al., 2012). This thesis has applied the concept of PSS to Pipelife Norway, a pipe manufacturer serving the water distribution network. They are an ambitious and driven company prepared and determined to shake up the water industry such that they can retain their market leading position as plastic pipe providers. The manufacturer's readiness has been assessed before launching an Industry 4.0 initiative and it has indicated that their products and data-driven services are lagging, thus answering RQ1. This indicates that it is no longer sufficient to physically improve the pipes (i.e. dimensioning, materials), but that there should be an emphasis on developing a smart digital pipe. The water distribution network is considered exceptionally conventional and they have experienced minimal innovation the past years. Based on the feedback from Pipelife and Surnadal, the PSS proposal has led to identifying different ways of combining products and services, hence answering RQ2. These different PSS combinations can assist the water distribution network in becoming more competitive by enabling them to distribute water with lower losses and generating greater profits. The manufacturer has to entirely change their business model when developing a PSS structure and with such drastic changes the challenges and the obstacles must be addressed meticulously. The challenges have been discussed and the impact a PSS model will have on the manufacturer's operations has been analysed, therefore answering RQ3.

The research on the PSS phenomena is still at a nascent stage and therefore much research remains. Firstly, it would be valuable to assess other pipe manufacturers' and municipalities' opinion on bundling pipes with additional sensors and services. It is essential to understand whether there exists a market which could be expanded to a larger scale. It would be interesting to analyse whether the location and the size of the municipality can influence either the attractiveness of the concept or the segmentation of the PSS scale tailored towards water utilities and the water distribution network. Moreover, it can be interesting to extend the research abroad and assess how the response towards PSS for the water distribution is there. As it has been pointed out, the term "smart pipes" already exists in other countries and some initiatory research has been carried out, but it has not been applied on an industrial scale. Nonetheless, the limited information which exists suggests that it is plausible that it can become successful.

Additional research can be done if the theory on PSS and the PSS scale is transferred to other industries, like other utility industries other than the water distribution network.

8.1 Contribution

The pipe manufacturing industry and the water distribution industry are conventional industries where innovation has been slow and limited. Nonetheless, times are changing, and several manufactures have identified lucrative opportunities which arise with the increasing digitalisation of their basic products.

The thesis starts with a structured literature review and identifies, compares and analyses the existing knowledge on PSS. Based on these findings, a framework for the water pipe industry is created which suggests new methods for creating and delivering value. It appears that PSS has not been analysed in the context of utility products before. This can only be stated with certainty for the two databases used and the specific inclusion and exclusion criteria which have been applied. Furthermore, following the same assumptions, this thesis is the first paper which represents the different bundled solutions with their respective segmentations along a linear digitalisation scale. This framework is heavily influenced by the two case companies, though it is adaptable for companies with similar traits in the same industries. It was discovered in the structured literature review that the research on the possible challenges and barriers, and the impacts this transition has on the manufacturer's operations was limited. To ensure a successful transition towards a PSS structure in the mentioned industries, the thesis addresses these aspects which are essential to acknowledge and attempts to fill this lacuna. This is achieved by determining the challenges with PSS and specifically reflecting on these in the context of a pipe manufacturer. Then, the impact on their operations has been addressed by suggesting different questions and uncertainties that must be considered during this transition. How the manufacturer's facilities will physically change and how they can benefit from the PSS has also been discussed. From a broader perspective, the scale serves as inspiration to stimulate similar research in utility industries, i.e. wastewater, pipelines, energy.

8.2 The limitations

Due to time constraints, the first limitation regards the research methodology. By only using two databases, a great body of information spread across a variety of databases which have not been considered can have disappeared. The impact of these losses has been mitigated by selecting two databases which are renowned for their accuracy and extensiveness. However, by having performed a structured literature review it can be considered that no stones have been left unturned in Emerald Insight and Science Direct and, therefore no holes should remain.

An additional limitation as a result of the time constraint is the use of only one pipe manufacturer and one customer. The discussion and the results only reflect the opinion of these two major stakeholders. It would be beneficial for both research and industry to explore how these conclusions would vary as a result of different sizes and geographical locations of both the manufacturer and the municipality. By "size", this parameter will have different definitions depending on its context (e.g. number of employees, the municipality's areal size, demographics).

Furthermore, due to the time constraint, it has not been possible to confer an expert's opinion on the feasibility and the practicalities of implementing sensors on underground pipes. Minor research is found on the instrumentation of smart water pipes and it is suggested to install flow liquid meter sensors, microcontrollers like Arduino Uno and micromechanical systems (MEMS). Installing sensors in the soil complicates the type of communication required for the sensors and an additional challenge is to understand how these sensors located in a humid and harsh environment can be powered. Before a potential PSS project is deployed it is essential to research how to efficiently overcome these issues.

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