Aalto University
School of Business

Increasing information intensity in industrial services:
Towards Industrial Internet and Industrie 4.0 in servitizing industrial OEMs

MSc program in Information and Service Management

Master's thesis

Tapio Melgin

2015

Department of Information and Service Economy
Aalto University
School of Business

Aalto University
School of Business

Increasing information intensity in industrial services

Towards Industrial Internet and Industrie 4.0 in servitizing industrial OEMs

Master's Thesis
Tapio Melgin
2 September 2015
Information and Service Economy

Approved in the Department of Information and Service Economy

__ / __ / 20__ and awarded the grade

____

Author Tapio Melgin

Title of thesis Increasing information intensity in industrial services

Degree Master of Science in Economics and Business Administration

Degree programme Information and Service Economy

Thesis advisors Supervising professors: Risto Rajala; Anu Bask. Instructor: Pekka Töytäri

Year of approval 2015 **Number of pages** 154 **Language** English

Abstract

Digitization has been transforming organizations for decades, but only recently has the general interest turned to digitization in industrial context. It has been proposed that new technologies are driving towards the next industrial revolution, having profound economic implications. This discussion is referred as Industrie 4.0 or Industrial Internet by industry practitioners.

Information is the key enabler and resource that companies use in achieving the higher productivity levels that the Industrial Internet promises. Industrial processes are often highly complex and companies are continually seeking to improve the efficiency of these processes.

In this work, many companies use services from various service providers, notably those of original equipment manufacturers (OEM). Over time, many OEMs have transformed from goods producers to advanced solutions providers, supporting their clients e.g., in asset availability with maintenance services and improving their process efficiency with consultancy services. Academic research has been interested in this transformation of OEMs towards service providers, but the role of information and related technologies have not been addressed in any satisfying depth.

This thesis investigates the impacts of the proposed industrial revolution from the OEM perspective, focusing on industrial services. Although focused on OEMs, most of the study's findings should be valuable also for other industrial value network participants. An abstract concept termed “information intensity” is developed and applied to avoid restricting the focus to contemporary development only. A broad, multidisciplinary literature review synthetizes existing knowledge on the topic, and a case study on a process manufacturing sector OEM provides further perspectives contributing to the discussion on servitization.

It was found that various sectors and service types differ greatly in the scale of benefits that increased information intensity offers. Especially in manufacturing, very high efficiency levels have been achieved relatively early, offering less radical improvement opportunities when compared to e.g., fleet management. In mature sectors, client focus on cost efficiency may also push service market backwards to lower information intensity services. A conceptual division into thing- and system-oriented businesses is proposed, structuring topic discussion and research.

Information-based businesses build on contextual expertise, protecting OEMs from disruption from IT-sector companies. However, the competitive environment is becoming more complex, and many players will be trying to encapsulate the service networks. Information may enable sector-specific OEMs to vertically expand further towards client processes while the largest cross-sector OEMs may drive ecosystem development forward horizontally. Basic services are becoming commoditized and consumerized. Importance of service network orchestration increases.

Industrial digitization is rapidly evolving, and an understanding of its technical and conceptual foundations would benefit both industry practitioners and academicians. The concept of information intensity provides a novel perspective on advanced services and offers an analytical tool with which to investigate digitization also outside this context. Findings have practical relevance and they contribute theoretically to services transformation and service strategy topics within the discourse on servitization, as well as others focusing on industrial sectors and digitization.

Keywords Servitization, Industrial services, OEM, Industrial Internet, Industrie 4.0, Information

Author Tapio Melgin

Title of thesis Increasing information intensity in industrial services

Degree Master of Science in Economics and Business Administration

Degree programme Information and Service Economy

Thesis advisors Supervising professors: Risto Rajala; Anu Bask. Instructor: Pekka Töytäri

Year of approval 2015 **Number of pages** 154 **Language** English

Abstract

Digitalisaatio on muuttanut organisaatioita jo vuosikymmeniä, mutta keskustelu teollisen ympäristön muutoksista on herännyt vasta hiljattain. Teknologisen kehityksen on esitetty johtavan uuteen teolliseen vallankumoukseen, jolla on huomattavia taloudellisia vaikutuksia. Tähän kehitykseen viitataan usein termeillä Teollinen internet tai Industrie 4.0.

Teollisen internetin keskeinen arvolupaus on korkeampi tuottavuuden taso. Sen saavuttamisessa informaatiolla on keskeinen rooli ja se on yrityksille olennainen resurssi. Tuottavuuden kehitys ei kuitenkaan ole helppoa sillä teolliset prosessit ovat komplekseja.

Pyrkimys prosessien parantamiseen on jatkuva, ja monet teollisuusyritykset hyödyntävät työssä ulkopuolisia palveluntarjoajia, joista erityisesti konepajat ovat keskeisessä roolissa. Ajan myötä konepajojen rooli onkin kehittynyt koneiden valmistajasta myös palveluntarjoajaksi, tarjoten sekä laitteisiin että asiakkaan prosesseihin liittyviä palveluita. Akateeminen tutkimus on ollut kiinnostunut tästä teollisuuden palvelullistumisesta, viitaten aiheeseen usein termillä servitization. Informaation roolia palvelullistumisessa ei ole kuitenkaan toistaiseksi pahemmin huomioitu.

Tämä opinnäytetyö tutkii ylläkuvattua ilmiötä konepajojen näkökulmasta, keskittyen teollisiin palveluihin muutosajureina ja käyttäen konseptia informaation intensiivisyys analyyttisenä työkaluna. Tutkimus antaa ilmiöstä kuvaa myös laajemmin. Laaja ja monitieteellinen kirjallisuusanalyysi vetää yhteen olemassa olevaa ymmärrystä aiheesta. Empiirisenä aineistona on case-tutkimus eräästä prosessiteollisuuden yrityksestä tietyin laajennuksin – sektorilta, jota nykyinen teolliseen internetiin liittyvä kirjallisuus harvoin käsittelee.

Tutkimuksessa huomattiin, että informaation mahdollisuudet eroavat merkittävästi sektoreittain ja palvelutyypeittäin. Erityisesti valmistusteollisuudessa jo nykyisellään korkea tehokkuustaso rajoittaa mahdollisuuksia lisätehokkuuteen enemmän kuin joillakin muilla sektoreilla. Pitkälle kehittyneillä sektoreilla kustannustehokkuus on myös ajanut kysyntää takaisin vähemmän sofistikoituneempiin palveluihin. Jakoa itsenäisiin objekteihin ja systeemeihin ehdotetaan konseptuaaliseksi työkaluksi alojen välisten erojen hahmottamiseen.

Informaatiopohjainen liiketoiminta rakentuu alakohtaiselle osaamiselle, suojaten konepajoja IT-yritysten disruptiolta. Kilpailuympäristö kuitenkin monimutkaistuu ja eri toimijat pyrkivät suojaamaan palveluverkostojaan. Informaatio edesauttaa konepajojen vertikaalista laajentumista, ja toisaalta horisontaalista integraatiota tukevat suurten monialakonepajojen pyrkimykset teknologisten alustojen saralla. Peruspalvelut hyödykkeistyvät ja niiden orkestroiminen muuttuu yhä tärkeämmäksi. Eri toimijoilla on eri osaamista ja yhteistyö on tärkeää.

Tutkijoiden tulisi huomioida nopeasti etenevä teollinen digitalisaatio paremmin, ja kuten teollisuuden edustajien, parantaa sekä konseptuaalista että teknistä ymmärrystä aiheesta. Informaation intensiivisyys antaa uuden perspektiivin kehittyneisiin palvelutarjontoihin ja tarjoaa analyyttisen työkalun digitalisaation analysointiin. Tutkimustuloksilla on käytännön relevanssia ja ne tukevat palvelukirjallisuutta erityisesti strategian ja palvelullistumisen näkökulmasta. Lisäksi monitieteellinen ote tarjoaa kosketuspintaa myös muihin aihetta sivuaviin tutkimusaiheisiin.

Keywords Servitization, Industrial services, OEM, Industrial Internet, Industrie 4.0, Information

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Introduction

In modern societies, the majority of material goods is created through industrial production. To produce these materials, machines, products, utilities, and infrastructure and to control their logistics, industrial companies require capital equipment such as generators, boilers, vehicles, and robots. Original equipment manufacturers (OEM), also known as capital equipment or machinery manufacturers, produce these assets.

Two major trends are affect these OEMs. For a few decades, management scholars have been tracking the transition of OEMs towards services in a process known as *servitization* (Vandermerwe & Rada, 1988). This transition has shifted the role of OEMs from mere producers of goods to service providers that offer asset availability, performance, or various consultative services–thus controlling an increasing amount of the value chain (e.g., Gebauer et al., 2013; Kohtamäki & Helo, 2015). This trend is still ongoing, although its ability to provide a competitive advantage with respect to competitors is being increasingly questioned (e.g., Opresnik & Taisch, 2015), as at least basic after-market services seem to be commoditizing.

A new trend has been proposed to transform OEMs and consequently their service provision also: digitization. The servitization literature, however, has barely acknowledged this trend. A few scholars have written about the role of data and technologies in services provision (e.g., Jonsson, 2006; Ala-Risku, 2009; Holmström et al., 2010; Kowalkowski et al., 2013; Opresnik & Taisch, 2015), but a holistic picture of the role information is beginning to increasingly play does not yet exist. Many other research streams, focusing increasingly on intelligent products and their enabling technologies, propose that manufacturing is undergoing a massive change: the next industrial revolution (Evans & Annunziata, 2012; Kagermann et al., 2013).

Management scholars and industry practitioners have invented and adopted many new hype terms to describe this change. What seems to be missing especially in servitization context is a holistic picture of the change: foundations of the proposed industrial revolution from the OEM viewpoint and its impact on services provision. Industrial assets are not transforming from “dumb” to “smart” overnight, at least in manufacturing. To increase understanding of this emerging and transformational issue, this thesis will (1) describe the increasing role information has begun to play in industrial service provision since the introduction of automation systems in the late 1960s and (2) investigate the impacts of digitization on services provision, focusing especially on strategic issues with respect to service offering and service strategy.

The economic impact of this hypothesized, next industrial revolution on factories and work sites alone has been estimated to be 1.4–4.6 US trillion dollars by 2025, mostly due to improved operations efficiency (Maniyka et al., 2015). OEMs, who design and produce the technologies manufacturers use, obviously play a key role in this change. This role, however, is not restricted to technology provision: OEMs often act as solution providers, helping their clients increase industrial asset availability and performance by providing goods-oriented and client process-oriented services (Mathieu, 2001; Gebauer et al., 2013). From the Finnish national perspective OEMs represent an important economic sector, whether measured by GDP, exports, or employment (The Federation of Finnish Technology Industries, 2015).

The revolutionizing role of digitization on servitizing OEMs, and its huge impact on global and national economies are strong arguments for both theoretical and practical research on the topic. This thesis aims to position the phenomenon to servitization, discussing its strategic and practical implications; and in light of the current lack of proper theoretical and analytical frameworks, to develop analytical tools with which the role of information also outside servitization context can be assessed.

1.2 Research objectives and research gaps

Previous research on technologies and information in relation to industrial services can be claimed to be still in its infancy, especially considering the rapidity with which digitization is evolving within manufacturing (e.g., Kagermann et al., 2013). New technologies apparently transform industrial value networks by blurring organizational boundaries (Jonsson et al., 2009) and act as catalysts for service business (Kowalkowski et al., 2013), offering new opportunities for industrial services provision (Brax & Jonsson, 2009). In a recent article, Opresnik and Taisch (2015) propose that, to escape commoditization of services, companies should revise their service strategies, big data being a major opportunity for competitive advantage. The author’s proposition challenges the view of services as a source of differentiation for OEMs (Raddats, 2011; Kohtamäki & Helo, 2015). That way, digitization can be an interesting perspective for services transformation and services offering discourses.

ICT infrastructure plays an important role in industrial services provision (Kowalkowski et al, 2013) and its role is also increasing rapidly (Porter & Heppelmann, 2014). Information Systems research reckons that IT has a strategic role in organizations (Henderson & Venkatraman, 1993), that companies vary greatly with respect to their capabilities in using ICT (Weill & Aral, 2006), but also that increasing collaboration of companies in value co-creation makes assessing the value of IT investments difficult (Grover & Kohli, 2012). Fundamentally, ICT's role is to improve internal efficiency and enable higher value-creation through the use of information. With continually increasing amounts of information available for OEMs' services provision – termed here as "information intensity" – the role of IT and information in servitization has as of yet gained surprisingly little attention by scholars in this area.

In particular, an overview of the impacts of increasing information intensity on industrial services is still missing. Ala-Risku (2009) has demonstrated the importance of installed base data for service providers and Holmström et al (2010) the benefits of tracking technologies for operations management. But an integrated view of the management and leverage of information is still missing in the industrial services context. The services-offering maturity model of Neff et al. (2014) and the recognition by Ulaga and Reinartz (2011) that both process data and installed base data are important assets for services provision have come the closest to such a view.

Multitude of research discourses may contribute to the topic

From the servitization scholar's viewpoint, a challenge is that many important viewpoints on digitization are published outside traditional servitization journals and typically refer to only a few selected servitization articles (e.g., Lee et al., 2014a; Neff et al., 2014), if referring to them at all. Servitization, as a research topic even in the industrial context, is quite fragmented, with scholars forming research communities and interest groups dedicated to such areas as service-dominant logic, product-service systems, services systems, hybrid offerings, and so on. Therefore, not all contributions may achieve the attention and impact they deserve.

Some relevant articles can be found within the context of operations management, such as Holmström et al. (2010) or Artto et al. (2014), which contains insights on the usage of tracking technologies in industrial projects and service delivery. A few researchers such as Jay Lee (Lee, 1998; Lee et al., 2013; 2014a; 2014b; 2015) look at industrial services such as maintenance from a more technical viewpoint and so publish in various engineering journals. These engineering articles are perhaps the most thorough with respect to the role of technology in the practice of services delivery, linking recent developments in sensor and communication technologies to the services provision.

Outside the services context, numerous engineering articles offer deeper technical perspectives that are insightful when trying to understand the transformative role of new technologies and the historical development of information usage in industrial settings. While conducting reviews within each industrial sector would be challenging, some technical articles on statistical methods usage (Yu, 2013; Yin et al, 2015) or control systems (e.g., Karnauskos & Colombo, 2011) significantly further an understanding of the development of technologies and information usage methods and thus provide perspective that is usually almost absent in management publications. Besides the industrial context, articles from the computer science and related fields on the “Internet of Things” and data science (e.g., Atzori et al., 2010; Gubbi et al., 2013; Provost & Fawcett, 2013) can provide useful overviews of different enabling technologies and tools and also highlight the technical and managerial challenges that can impact advanced industrial services provision. Moreover, “intelligent” or “smart product”-focused papers bring these technologies closer to the industrial services context (e.g., Zuboff, 1988; Meyer et al., 2009).

Other strategic management and information systems articles and books provide perspectives and a basis for reflection regarding the possibly disruptive power of digitization with respect to business models and industry logic (e.g., Brynjolfsson & McAfee, 2012; Eisenmann et al., 2006; Hagiu, 2014; Pagani, 2013).

In the big picture, existing research has identified that information and IT has an enabling role for industrial services provision. In the context of Industrial Internet, covering also manufacturers and OEM goods, research agendas have been proposed concerning strategic decision-making on digitization. These research agendas such as Porter and Heppelmann (2014), or Yoo et al (2012) outside the industrial context, are thought-provoking, but remain on a very general level, and in the case of Porter and Heppelmann (2014), possess the shortcoming of not focusing on such industrial systems as manufacturing.

Non-academic publications that lead the development of industrial digitization discourse

Lack of integrated views on digitization in industrial settings does not restrict to servitization. There are two highly separate discourses on industrial digitization: the Anglo-American “Industrial Internet” (e.g., Evans & Annunziata, 2012) and the German “Industrie 4.0” (Kagermann et al., 2013). While these discourses might be insightful for industry practitioners, they do not converge, either with one another or with academic research on the underlying technology or its management implications. To position the emerging trend of digitization within the servitization context, the existing literature on the topic has to be converged, first by linking Industrial Internet and Industrie 4.0 and then by positioning the trend within the existing stream(s) of academic research.

These non-academic discourses have a lot of tacit knowledge of the topic, likewise to many consultant reports and company publications. Digitization is increasing with such rapidity that academic research is hard pressed to remain current with its development, and therefore insights should be gathered from non-academic sources also where possible. Some academic publications (e.g., *Harvard Business Review*) which are also directed at business executives have published articles that address the current development and practical and theoretical questions related to digitization, such as data openness and access to data, business models, and outsourcing decisions on capabilities and enabling infrastructure (Iansiti & Lakhani, 2014; Porter & Heppelmann, 2014). However, these articles are quite general, do not provide academic references, and focus on intelligent products rather than services.

In his literature review on remote monitoring and servitization, Grubic (2014) states that servitization studies only seldom present technological context in any insightful depth. Context-heavy approaches reflecting both enabling technologies and service strategy level issues would thus be beneficial in laying the groundwork for future research on the topic.

Need for an analytical frame on information intensity

Additionally, within the context of industrial services or, more broadly, of the Internet of Things, which includes most economic sectors, the role of information has not been theorized to any great extent beyond the data-centric view of digitization often referred to as “big data.” Information systems research has studied the evolution of management information systems over time, but the role of machine data, control systems, and organizational knowledge within industrial organizations have not been studied systematically. Therefore, an integrated view of information or a general analytical framework on “information intensity” would prove beneficial for researchers in many fields.

To sum up the earlier it seems that there would be a need to:

- Position Industrial Internet and Industrie 4.0 discourses within the servitization context
- Develop an analytical framework within which to assess the role of information in services provision
- Form a coherent picture of the impact of increasing information intensity on services strategy and service offering so as to do the following
    - Understand the role of information intensity in services transition
    - Discuss changes in OEMs’ competitive environment
    - Assess the role of information in advanced solutions offering and evaluate opportunities provided by increasing information intensity for service development
    - Discuss practical implications, related, for instance, to sales
    - Formulate a future research agenda and position aforementioned to industry evolution perspectives

1.3 Research problem, questions and approach

To fulfill these needs, an unusually broad and deep approach to a literature review would be necessary; one that would reveal conversion points between different discourses. Because much knowledge and secondary data already exists on the topic, all knowledge does not have to be built from scratch. However, one industrial sector on which even professional publications seem to have few insights is the manufacturing sector, especially that of process manufacturing. A representative company from the process automation sector was therefore selected for extensive scrutiny and analysis in this thesis, wherein it is referred to as Case OEM. Presentation of this case will have novelty value outside the servitization context.

This work aims to build analytical frameworks for industrial digitization and information intensity, form a more coherent picture of the existing knowledge on information’s role and potential in industrial services provision, and provide theoretical and practical implications for further research. Since the topic is still immature, many important questions remain undiscovered within the wider research community, especially in the more complex industrial settings such as manufacturing.

Three research questions have been developed to guide the research process, and this study aims to provide reasonable answers to these questions but not to restrict itself to just these.

> RQ1: How does information intensity affect machinery manufacturers' industrial service provision?

To include the most up-to-date discourse meaningful to the analysis, discourses on Industrie 4.0 and Industrial Internet need to be included. However, lacking suitable sources for these, a literature review was conducted with the aim of tying together these two discourses.

> Supporting question 1: What are the foundations of the Industrial Internet and Industrie 4.0 discourses?

This question evolved during the research process into a framework that defines two views on the industrial applications of Industrie 4.0: "things" and "systems".

Additionally, an analytical frame for "information intensity" is required to assess the role of information in services provision.

> Supporting question 2: What is information intensity?

Answering the first research question together with its supporting questions provided the holistic understanding required to further discuss the role of digitization within the industrial context. The two questions used for this purpose were the following:

> RQ2: How increasing information intensity might affect OEMs competitive environment from service provision perspective?
>
> RQ3: What are the implications for service business strategy and services sales?

Although other interesting questions could also have been answered based on the material (and indeed some additional findings will be presented), these two questions were developed in dialogue with the Case OEM to also address its needs.

The case study on Case OEM provides a relatively unique perspective on the long-term development of increasing information usage at an industrial company and at its clients. Academic research in process manufacturing has no previous insightful case examples, making this empirical material interesting outside the servitization context. It was found, for example, that technical constraints for the adoption of Industrial Internet are much harder to overcome, and the technical basis for these solutions within the manufacturing context also differs greatly from that of fleet management or power generation. The case description thus further validates the propositions presented in the literature review regarding the importance of focusing also on complex “systems” besides smart “things”, the former being currently largely ignored outside the German Industrie 4.0 context.

Due to the multidisciplinary and academically non-converging characteristics of the topic, an abductive research approach (see e.g., Dubois & Gadde, 2002) was chosen. It allows systematic iteration of theory, analytical frame, the case itself, and the empirical world through systematic combining (Dubois & Gadde, 2002). In practice, abductive approach enabled iterative approach to research process, developing analytical frame and theory base as contextual understanding became deeper, giving insights to include e.g., new theoretical perspectives in the study that were not originally included when starting the research process. Empirical material was mostly based on a single case study (Yin, 2009) on a large original equipment manufacturer that is referred here with a pseudonym of “Case OEM”.

Focusing on one case company gave the desired depth required to understand the role of technical enablers. The scope was further broadened with various materials beyond those associated with Case OEM, including company materials and additional interviews with Case OEM clients and other companies within the IT sector. These additional interviews proved particularly useful because very few informants at Case OEM had knowledge of all of the three areas needed to answer the research questions: a broad understanding of business issues, hands-on technical insights, and knowledge of recent advancements in IoT-related technologies and analytics.

The author also conducted a few informal interviews or participated in conferences and discussions on the topic to gain further understanding and to triangulate findings (e.g., Modell, 2009). Because of the scope of the thesis and the desired depth in the case study, multi-case approach (Eisenhardt, 1989) was considered unsuitable. However, other case companies were studied based on such secondary sources as company investor materials, press releases, magazine articles, and reviews of cases presented in academic articles. Some, but not all, of these are presented as additional examples in this work when found useful. The role of secondary material was essentially to support the author in forming a holistic understanding of the topic and to support triangulation.

Because existing theory-base was considered to be still elusive, especially from the viewpoint of describing digitization in industrial settings, analytical and theoretical frames had to be created by combining various non-converging academic sources. Without deep contextual understanding this would not have been possible, and therefore Case OEM had a functional role in the "direction and redirection" of the reasoning and research process: theory base was build iteratively as contextual understanding improved, following Dubois & Gadde's (2002) methodology. Because the phenomenon of digitization is real and concrete, a critical realist (e.g., Easton, 2010) viewpoint was taken.

Due to the abduction, the literature (Chapters 3-5) is in an important role in this thesis. Case OEM provided some interesting new insights that contribute directly to servitization discourse, but at least equally important contribution of this thesis is the reconstruction of digitization-discourse based on academic sources and the new conceptualizations and frames that literature part presents. The role of the case study is therefore in a large extent only functional, new findings based on the interviews representing only one part of the thesis contributions.

The methodology is further explained in Chapter 2.

The major contributions of this thesis are considered to be the following:

- Integrating of various perspectives on industrial digitization so as to reveal links between various research discourses, notably, converging Industrial Internet and Industrie 4.0
- Developing an analytical frame for "information intensity"
- Forming a holistic, state-of-the-art picture of digitization within industrial context and providing the deep technical insights that Grubic (2014) also demands
- Framing digitization within the industrial services context and proposing theoretical and practical implications related but not restricted to services transition, services strategy, services offering, and services provision
- Providing an insightful case study on a process manufacturing sector OEM, which possesses novelty value outside the context of industrial services also

As part of the discussion, the most important findings will be presented beyond these questions. The research questions played an important role in shaping the scope and structure of the thesis, but the ultimate focus was to build a holistic representation of the topic, connecting it to existing relevant academic research and making theoretical and practical contributions based on primary material, secondary material, and existing literature using an abductive research approach. The applied analytical frame on information intensity is also considered to be potential for an integrated information theory.

1.4 Structure of the thesis

This study is structured in five parts as follows: introduction, methodology, literature, empirical part and discussion.

The introductory first chapter positions and frames this study, explaining the importance of the topic and identifying the study's research objectives and gaps within the current research. Next presented are the research problem, the approach to it, and the study research questions. The second chapter explains the methodology and research process followed in the course of the study.

The third, fourth, and fifth chapters cover additional literature and some secondary material examples. The third chapter begins with a brief introduction to the phenomenon. Next, the analytical frame of information intensity is posited, reflecting existing views on information. The technological context for the Internet of Things (IoT) and big data are then presented, and a literature review of IoT within an industrial context follows. This third chapter gives context and frames the work with information intensity analytical frame and a thing-system categorization based on IoT and industrial IoT literature.

The fourth chapter continues the literature review by positioning the findings from third part in the servitization context, and by discussing the role of information and its intensity in different service types. Much context with respect to technical descriptions is given, developing and validating further the conceptualizations from the third chapter.

Chapter five links the new perspective on industrial services to advanced offering, strategy perspectives, and practical implications for sales and services provisions proposed in existing research. The chapter ends with strategic perspectives on competitive advantage and competitive environments.

Chapter six summarizes the primary research material from interviews and other case company documents. Case OEM is presented and history on information usage described. Next, the current state of digitization and challenges related to data volume are explained. The remainder of that chapter covers viewpoints on advanced services provision, the Case OEM competitive environment, and concludes with further implications and challenges that arose in the interviews.

Chapter seven–discussion–summarizes findings derived from the literature research and empirical materials and provides answers to the research questions. Implications of findings are reflected upon, and implications for theory and practice are proposed. Finally, an overview on the specific recommendations for Case OEM is presented separately, and some ethical issues and limitations of the research are discussed.

Methodology and introductions to the following chapters further explain the study’s structure and logic, and the next page (Figure 1) graphically illustrates the interconnections of the chapters comprising the entire study, providing the reader a reference with which to orient himself.

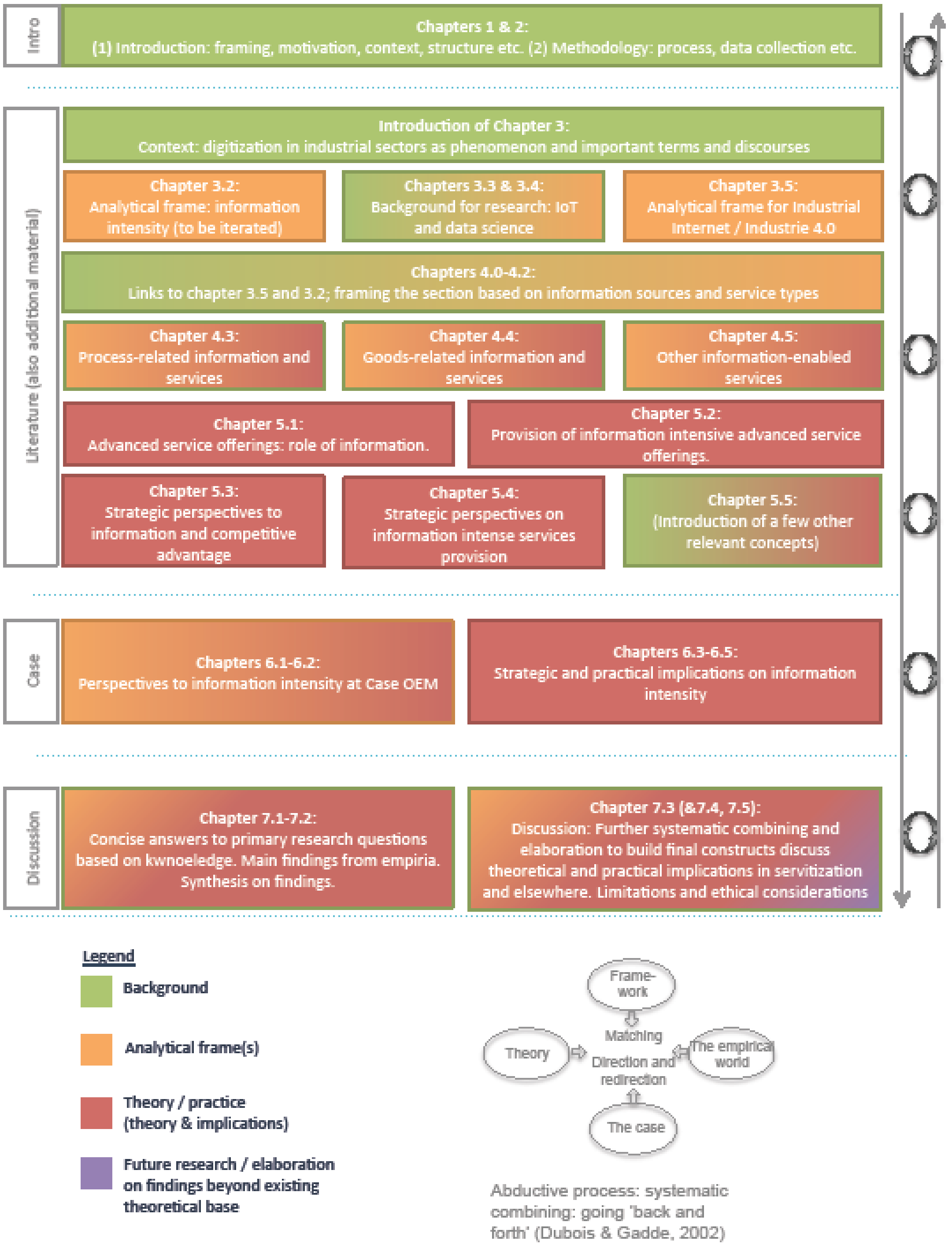


Figure 1: Structure of the thesis

2 Methodology

This thesis is a case study (Yin, 2009) to which an abductive research approach (Dubois & Gadde, 2002) has been applied. The breadth of the topic and desired depth in contextual understanding necessitated an iterative research process, where new perspectives and further information from new literature sources could be explored as new and important issues were identified.

The methodology part is presented prior to the literature review, because the abductive research process iteratively combines the theoretical and empirical realms. Thus, findings presented in the literature impact empirical findings and vice versa, and the reader should understand the research process before reviewing the relevant literature and the case study itself. Additionally, the literature section is not restricted only to theoretical academic papers but includes secondary empirical material drawn from various sources.

Originally several possible directions were considered for the research, but during the research process, some branches were lopped off and others added to the research plan. For example, a multi-case setting was originally viewed as an interesting option for this thesis, but ultimately an in-depth case having one company as its subject with some additions was found best suited to answer the research questions in a meaningful way. Some topics that formed a starting point for the literature review were also omitted from the final work or de-emphasized. For example, buyer-seller relationships, firm boundaries, data sharing issues, business models, and innovation were initially viewed as being of interest within this context but were ultimately found to be unnecessary and to introduce needless complication. Some of these topics are covered or mentioned briefly to link these topics to the phenomenon and to suggest interesting directions for future research.

This chapter (1) explains the research methods applied, (2) presents the Case OEM, (3) explains the flow of the research process including case selection and data gathering, (4) describes the data analysis and reasoning process, and (5) provides details of the interviews. Because an abductive research approach was applied and much additional material beyond the case and academic literature was employed, practical steps taken during the process will be described in great detail, thus lending the transparency that is so often desired from abductive studies due to their non-linear nature.

2.1 Research methodology

How to study in a single thesis a weakly defined and emerging phenomenon, build new conceptualizations based on this phenomenon, study its impact on a case company where the target phenomenon is not present to any great degree, and employ these to generalize findings? Eisenhardt (1989) recommends a case study approach for a new and weakly known phenomenon because of the depth and comprehensiveness it can offer. Also, in such an approach, both the theoretical framework employed and analysis of the empirical world would, by necessity, co-evolve along the process. The abductive research approach (Dubois & Gadde, 2002) incorporates this dialogue between theoretical models and the empirical world and so was considered the most suitable research methodology for this study. Following Figure 2 by Järvensivu and Törnroos (2010) illustrates the dialogue between theory and empirical world during the research process in an insightful manner. This section will explain the decisions related to methodology and describe the methodologies employed; the following sections cover the data gathering process and analysis in more depth.

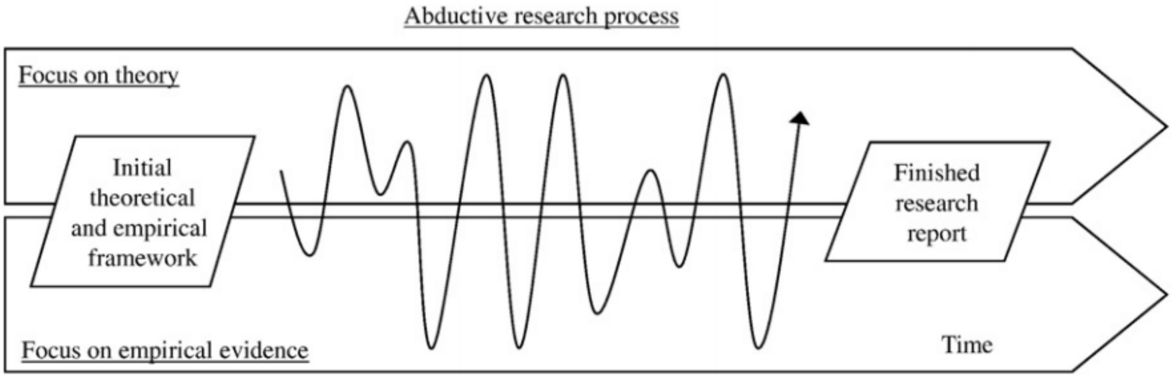


Figure 2: Abductive research process (Järvensivu & Törnroos, 2010)

This study adopted a critical realist viewpoint (Easton, 2010) to the phenomenon of digitization: It exists in reality but evolves constantly. Industry practitioners are trying to make sense of the impacts of the phenomenon but not to define the phenomenon itself. Academic practitioners traditionally focus on a phenomenon’s constructs and conceptualizations, but few relevant articles have been published at the start of this research and offer no satisfying framework. Therefore, conceptualizations should be independent of the insights of informants to avoid challenges to construct validity and to simplify the work.

The research objectives of this thesis focus in the impacts of digitization instead of defining the socially constructed phenomenon. Although this study proposes new conceptualizations for the Industrial Internet and Industrie 4.0, these are formed from literature sources or fact-based findings (from the critical realist view), thereby providing an analytical frame and context rather than itself constituting a research objective.

Dubois and Gadde (2002) the abductive reasoning process as having four components: a theoretical framework, the empirical world, the case, and an analytical frame. Servitization literature serves as the primary theoretical framework, although other management theories are applied in this work. Instead of only one analytical frame, this study employs two—the primary one being “information intensity”, which is further explained later on, and the other the conceptualizations on industrial digitization. However, the frame on information intensity is the primary analytical frame, conceptualizations on industrial digitization simply supporting the work and contributing to IoT-related discussion. Both frames are developed in Chapter 3 to the extent that the literature sources allow without extensive combination with other topics. These frames are developed further in the following sections, reflecting the abductive reasoning process. The whole industrial production sector constitutes the empirical world, and the case is the Case OEM, complemented with a few interviews with company clients and other value network participants.

Analytical frame: information intensity

To analyze simultaneously the phenomenon and its impacts, an analytical frame helps structuring and directing and redirecting the work (Dubois & Gadde, 2002). Therefore the concept of information intensity was introduced at a highly generalized level in an attempt to avoid the construct validity issues inherent in applying the hyped-up and often misunderstood terminology regarding the phenomenon.

This analytic frame has been loose throughout the study, more so at its beginning, thus opening the study to risks of indiscriminate data collection and data overload (Miles and Hubermann, 1994). To address the first risk, purposive sampling (Eisenhardt, 1989) was applied, both with respect to the case study and to additional secondary material. The author also educated himself on the various aspects of the topic to rapidly gain deep contextual knowledge. The second challenge of data overload could not be fully avoided, but this state was, to some extent, desirable and was thus manageable, providing the desired depth and breadth to the topic for which the research was aiming.

The analytical frame of information intensity became a research interest in its own right and was eventually further developed by combining empirical material and findings from the literature. Consequently, it evolved into what is considered a well-working abstraction and analytical frame for the general trend behind the Industrial Internet hype. Along with the evolution of the analytical frame, it also became a useful tool providing structure for the thesis.

The case

Based on preliminary analysis, Case OEM was thought to lag behind in the adoption of the Industrial Internet when compared to such reported examples as Rolls Royce’s power-by-hour turbines. However, there appeared to be few available manufacturing sector examples employing Industrial Internet applications, and the Case OEM would not differ much from these similar companies. Indeed, the question as to “why information has not yet been systematically employed in Case OEM services provision” offered a fruitful research setup to explore possible sectorial differences in information usage and to explain these differences. Thus, Case OEM selection applied purposive sampling although the company had already agreed to participate at the very beginning of the project.

Interview questions were developed by first forming several thematic questions based on research questions. Next, supplementary questions were formed under the thematic questions based on the contextual understanding as of the initial interviews. As understanding of the topic increased, these supplementary questions were focused more specifically or re-prioritized. In interviews, construct validity problems were avoided by avoiding hype terms and applying highly practical language, avoiding also epistemological and ontological issues regarding generalization, as recommended by Halinen and Törnroos (2005). A longitudinal approach was also applied to Case OEM with the aid of company materials and interviews. This longitudinal view was considered important to ensure that perspectives on information intensity and digitization avoided possible bias introduced through non-academic conceptualizations and propositions. Interviews were semi-structured and transcribed. Interviews continued until no new perspectives on the primary research interests emerged, reaching saturation.

Theory

With deepening understanding on the phenomenon, the abductive reasoning process began providing findings on its impact on day-to-day business. Improving contextual understanding and new findings sharpened the theoretical focus, locking it primarily on the servitization discourse (Vandermerwe & Rada, 1988), although also covering other viewpoints based on preconceptions. By going “back and forth” (Dubois & Gadde, 2002) between empirical material and theory and by matching findings for direction and redirection, the theoretical basis evolved and began offering explanations not considered when the research process started.

The empirical world - Generalization of the findings

This study aimed to be generalizable in two ways. Firstly, the conceptualizations on industrial digitization and the analytical frame are, by definition, generalizable. However, focusing on only one case would not prove generalizability unless other materials could be used to triangulate findings.

The appropriate number of case studies has been debated, with some authors preferring multiple cases (Eisenhardt, 1989) to achieve generalizability and others viewing single case studies as preferable when the phenomenon requires deep contextual understanding. Hence, the single case study setup was adopted, and the case study was conducted as a practically triadic value network case study, offering better opportunities for triangulation. Instead of three companies, triadic is understood here as three types of companies: the seller (Case OEM), buyers (clients) and IT providers. To better understand the long-term development of information intensity in the case company, other company materials were used to complement informant comments regarding the past. Although the case study and literature were analyzed with rigor and the application of systematic combining, such supporting secondary material as informal interviews, magazine articles, and various web-based documents were freely used to gain a deeper understanding of and direct the research process. This secondary material was realistic in nature, in comparison to the more constructive nature of some of the findings obtained in the Case OEM interviews.

The additional secondary material also elevated understanding to a level where determining whether the study conceptualizations and findings are generalizable beyond Case OEM was possible. More specifically, the basis for generalization was achieved by extensive study of other reported industry cases. Interviews outside Case OEM constituted triangulation points, showing that various actors in industrial value networks held similar views on the topic or, alternatively, providing perspectives and explanations differing from those of Case OEM informants or the existing literature. Thus, the secondary material was essentially a source of triangulation. The next section describes data collection, interview, transcription, and analysis methods individually, as parts of a process, but from a higher perspective, these followed the typical recommendations of Yin (2009) and Dubois and Gadde (2002).

Abduction: A challenge for the structure

Presentation order of material and findings were reflected from the methodology viewpoint. Due to the direction and redirection (Dubois & Gadde, 2002), literature was not developed independently from the empirical material. Therefore, the traditional structure for a thesis consisting of introduction, literature, methodology, empirical material, discussion and conclusions creates easily a false feeling of a linear research process. Without writing the thesis in a diary form, a true and fair picture on the evolution of findings would be challenging. To find a compromise between readability and illustrating the abductive reasoning process, following thesis structure-related decisions were made: Methodology is presented already here in Chapter 2, before literature analysis because empirical material influenced the literature. Second, this methodology chapter is very thorough and transparent, offering an opportunity for the reader to understand the research as a process.

Third, because of the high level of author-created conceptualizations applied as analytical frames (building on an abductive reasoning process during the entire process), the empirical material description in part 6 is presented in a highly transparent form, including actual quotations and avoiding interpretations where possible. Also the findings presented in part 7.1 avoid claims that are excessively bold unless evidence supporting the findings is very strong, leaving the reader leeway to re-interpret the material to some extent should he/she wish to do so. Overall, a very thorough understanding of the topic was thought to have been gained during the process, approaching state-of-the-art practitioner level knowledge in breadth, and therefore the phenomenon-related conceptualizations are considered valid and generalizable. This is aligned with Dubois and Gadde (2002) and Järvensivu and Törnroos (2010), who suggest that it is the deep contextual understanding that provides generalizability, not the high number of cases in contrast to Eisenhardt (1989).

2.2 Description of the Case OEM

Case OEM is a global manufacturer of industrial goods that also offers a broad range of industrial services, including process automation systems. Its primary market segment is one broadly defined process manufacturing sector, with a minor share of the turnover coming from other sectors. Case OEM's net sales exceeded one billion euros in 2014, and it is a publicly listed company having over 10,000 employees globally. It considers itself to be a market leader in some of its product and service areas, and it has several similar large competitors in technology solutions and some smaller specialized competitors in technology and services.

The average lifetime of its main industry units ranges from several decades to one-hundred years. Production lines built after the 1990s, or lines that have undergone major improvement projects, are considered to be modern, typically having modern automation systems with fieldbus, I/O, and possibly remote monitoring capability. Their machine units typically consist of both components of their own manufacture and of third party technology. Sometimes the Case OEM delivers the machinery for a whole production line, and can be considered as systems integrator. Besides big machine units, Case OEM provides spare parts and wear parts, which represent a significant share of their services sales.

Case OEM's services portfolio includes maintenance, spare parts and consultative services as the most important service offering classes. There are several hundreds of identifiable services altogether under these three main categories and some other smaller specialized service categories. Many of the service elements are often bundled to larger contracts, but also traditional transactional services sales are popular in some market areas and client segments. The Service Business Unit creates a significant share of the Case OEM turnover, this figure being typical in size to many other servitized OEMs. Case OEM's client base can be divided into two segments, although the boundaries dividing the two are blurred: large corporations having multiple production sites and small clients with one or several production lines. Altogether Case OEM has several thousand clients.

The company is divided into three units based on its main business areas: technology, goods, and automation. Technology unit is responsible for new industrial goods sales, services unit e.g., for spare parts and improvements after the installation. As a matrix company, Case OEM also has region-based sales and services organizations and corporate support functions.

2.3 Research process, case selection and data gathering

This study has been conducted as part of the Future Industrial Services (FutIS) research program, a five-year program belonging to the larger, state-funded industrial competence cluster FIMECC. The instructor, supervisor, and remainder of the FutIS research group at the Department of Industrial Engineering and Management have been working on value-based exchange-related topics for the past years, accumulating knowledge on industrial services. The FutIS research program is scheduled to end in 2015, and a new program focusing on digitization in the same context “S4Fleet” will start at the beginning of 2016. The instructor of this thesis will lead the new program, and although funded by FutIS, the primary contribution of this thesis is to the S4Fleet research program.

The research process started in late January 2015 with a preliminary literature search, inspired by digitization and Industrial Internet discourse. During the first month of the study, preconceptions (Dubois & Gadde, 2002) were formed based on the literature, leading to preliminary research objectives and research questions that were discussed with Case OEM, leading to iterations and including some practical viewpoints that would have been uninteresting from a theoretical perspective only. The analytical frame and research questions also evolved in a subsequent iteration made possible by improved contextual understanding.

Selection of primary research materials gradually evolved during the first months. Case OEM participation in the study was known from its inception: The company participates in FutIS research programs and had expressed interest to the themes of this thesis. A preliminary literature review confirmed the assumption that no cases on the topic from the process manufacturing context were available, and Case OEM was eventually included as one of the case companies. Although Case OEM is one of the technology leaders in its sector, it has not achieved the same level of sophistication in information usage in its services provision as some other industrial OEMs, such as Rolls Royce. Therefore, the research interest was not to discover current state-of-the-art practices but rather to understand the barriers that had prevented the company from moving forward with the Industrial Internet, while focusing on the main research questions. Case OEM interests were also focused on concrete new service development opportunities and sales, which were consequently included in the interview themes although not considered academically as interesting as some other research questions.

Because Case OEM had not yet developed or at least commercialized the concepts and solutions in which this study was interested, additional interviews were seen beneficial. To identify possibly relevant, more specific research questions, gain understanding on state-of-the-art solutions, and hear IT company perspectives on Industrial Internet, the CEO of an analytics company was interviewed prior to the start of the Case OEM interviews. In April and May 2015, nine interviews lasting on average 80 minutes [51min-103min] were conducted at Case OEM, mostly via videoconference due to the geographical distances involved. The Case OEM contact person gathered an interview list, taking into account the author's wishes and including representatives of experienced sales, strategy, services, technical, and IT-focused employees, some outside the European market area. From the original list of 12 names, eight were interviewed in the first wave, and one additional informant (second area VP, services) outside the original list was interviewed after a mid-review with the contact person.

After the mid-review, two client interviews and one additional IT company interview were decided on, booked, and conducted in June 2015. These were planned from the beginning, but their timing was subject to access to personnel and possible redirection of the research. The purpose of the client interviews was to validate that the Case OEM interviews gave an accurate picture of the client needs and thoughts and to uncover additional insights.

Although the same question set was more or less applied throughout the research process, the interviewer sometimes introduced factual findings, e.g., on technology or company histories, into the discussions to validate this information. In this manner, the question set co-evolved slightly understanding of the topic increased. Focus on the broader thematic questions was maintained throughout the process although additional and more specific questions evolved over time.

The inclusion of four to six other industrial companies as supplementary cases remained a possibility far into the research process. However, this idea was finally dropped when the Case OEM interview experiences and increased understanding of the topic made it apparent that firstly identifying those few people in the organizations knowledgeable enough to yield insightful interviews and secondly persuading those individuals to submit to interviews would be difficult. Therefore, to gain the sectorial breadth required, much second-hand material on other OEMs was reviewed.

Interviews were semi-structured, following a question set but allowing changes in the question order and focus based on the competence areas of the interviewees and the flow of the interview. Construct validity was not considered to be a major issue because of the generality of the research objectives: object was not theory development and key informants were not involved in construct creation directly (Eisenhardt, 1989). Rather, key constructs were formed on critical realist sources (Easton, 2010) in form of written or historical evidence, not based on analysis directed at informants' constructive understanding of the world. Nevertheless, to avoid unlikely challenges concerning construct validity, the interviewer avoided using any terms suggesting hype or any academic terms and requested clarification when an interviewee introduced a term that could compromise construct validity. Informants were also asked to explain how they defined such terms as "big data" if they employed the term and to provide practical examples. On business issues, layman's terms were used where possible and the focus was on rich contextual descriptions to ensure accurate understanding of issues. The Case OEM contact was queried for clarification on some technical issues or researched independently by the author following the interviews.

Case OEM interviews and those interviews of personnel from the two supplementary IT companies and the two clients were taped and transcribed. Although the transcription was outsourced to another company, the author also reviewed those tapes that contained much technical vocabulary or that quality of transcription suffered from poor taping quality. Two exceptions to the described procedure were made: The interview at the second IT company more closely resembled an open interview, although on topics outside the primary focus of the thesis, because of some co-creation elements. Secondly, only half of the interview with the global sales director (18.4.2015) was recorded only due to technical issues. To compensate for the lack of recording ability, extensive notes were taken during the remainder of this interview.

The following additional Case OEM information sources were gathered and served as secondary research material: several internal company documents and numerous public documents such as annual reports, press releases, and service and product descriptions. To fully understand the OEM business environment, some benchmarking, based on public documents, was conducted regarding Case OEM's competitors and clients. Also numerous process automation and IT-related writings and product descriptions were studied to deepen contextual understanding.

Some additional interviews and discussions were conducted for further validation and triangulation but were not recorded with notes taken only on key points. Two client employees with practical day-to-day experience on production sites were informally interviewed for 30 and 60 minutes, respectively. Additionally, the author purposely arranged informal discussions with people experienced on the topic to gain insights on technological solutions, practices, and their thoughts on Industrial Internet and advanced services solutions in other industrial sectors. A few industry representatives, researchers and consultants provided valuable insights. The topicality of digitization in an industrial context has led to many digitization projects in OEMs, and some insights on these were obtained in the various discussions.

The literature research was partly systematic, partly confirmatory, and partly exploratory. At the beginning of the research process, systematic searches were conducted on EBSCO and ProQuest using various combinations of the “hype” terms related to digitization, Industrial Internet, and Industrie 4.0 within the servitization context or referring alternatively to industrial companies or OEMs. Abstracts were reviewed and interesting articles gathered for deeper examination. Only a handful of insightful articles were identified, but following citations led to more. It was found that a highly dispersed terminology was used for describing various technologies and opportunities, and instead of terms commonly used by industry professionals, researchers were developing their own terms that were not typically gaining acceptance among other researchers. Additionally, the dispersed nature of servitization literature created further challenges in identifying the few relevant articles.

Concurrently with the research process, understanding of the technologies, their development, and various research discourses developed. New articles were then able to be identified periodically, typically by using Google Scholar to test whether certain terms had been applied in academic publications. Various recent consultant or company publications on the topic were reviewed, and a few of them were even included as references and therefore were apparently considered among the best available sources on the issue. This has also been the practice among academic researchers: For instance, Evans and Annunziata (2012) or Kagermann et al. (2013) have been referenced by academics, especially those writing about industrial digitization as a phenomenon. Additional source of inspiration for possibly relevant terms came from industry professionals’ writings and presentations on LinkedIn, SlideShare, and other content platforms. Google Scholar was used to identify the most relevant, or simply the most suitable, articles on the technical issues to be included in the literature section after learning of their importance to the topic from interviews and other sources.

Additionally, contemporary company cases on industrial digitization were collected to support triangulation and form a picture of the current development of the market. Relevant cases were found by searching presentations on Google where digitization terms and names of various global and local OEMs would co-occur. One benefit from being from a small language area having a strong machinery equipment sector was that companies had been granting interviews to a few industry magazines (in Finnish); they possibly would not have been doing so in English in an equally free manner. A database of Finnish industry magazines, Talentum, was systematically used to identify cases relevant to the topic from the past five years. Some other industry magazines were used as a source of inspiration and understanding of industry professionals' language and practices as, for example, *Maintworld* on industrial maintenance perspectives. Also S4Fleet research portal, with many insightful documents on company practices and fresh thinking of professionals and researchers, was thoroughly examined.

Finally, the meetings with the Case OEM contact person provided information on Case OEM, while also acting as a platform from which to reflect on some of the findings discovered during the process. There were five meetings in total: two introductory meetings, one meeting after the first round of interviews to review some initial practical findings, one half-day meeting to review most of the research findings, and one final presentation for the contact person's team. A summary of the results was delivered to the Case OEM representatives in a PowerPoint presentation, along with a longer and more detailed 100-plus-slide report and a shorter, approximately 50-page deck. The reviews of the presentation materials were conducted before Chapters 5 and 6 of this work were written. The shorter deck was also sent to all Case OEM informants, following the recommendation of Miles and Hubermann (1994) to provide informants with preliminary results to ensure research credibility and authenticity. No new issues were brought up or corrections proposed in the last meeting based on the delivered material, thereby supporting the view that saturation had been reached and the interviews interpreted correctly.

2.4 Analysis

The plethora of research materials and evident interrelatedness of various aspects of the research objectives argue for an intertwined analytical approach: an abductive process (Dubois & Gadde, 2002). Systematic combining of theory, empirical world, analytical frame and the case was applied throughout the research period.

The analysis of the empirical and of theoretical models drawn from the academic literature was iterative, going back and forth between data and theory. Analysis started with a review of the first sets of articles that were collected systematically (see Section 2.3), based on the understanding of the topic at that time. Such secondary, empirical materials as company materials and consultancy reports were compared to theory, thereby allowing the construction of preconceptions (Dubois & Gadde, 2002). The first interview with the IT company CEO was conducted soon thereafter, yielding insights on the topic from a knowledgeable industry practitioner. This first interview did not change preconceived notions to a great extent but did help justify research objectives and raise possible questions for future Case OEM interviews.

The first set of interviews was conducted over a two-month period, and although the results were not thoroughly analyzed until after the conclusion of the set, they nonetheless influenced the reasoning process ongoing throughout this first set of interviews due to reflection, systematic combining, and extensive note-taking. As new insights or important topics to study were identified, new literature sources were added and so the theory and the analytical frame subsequently evolved. After a preliminary analysis of the full set of interviews, the four additional interviews were scheduled and conducted. Saturation on theoretical issues was reached to a large extent after the first five to six interviews, but the existence of other viewpoints was acknowledged and so interviews were continued. After the interviews were completed, an initial analysis and a conceptual iteration of theory, frame, and additional materials were conducted and, in a mid-point discussion, presented to the Case OEM contact person.

After the additional interviews intended to introduce additional perspectives beyond those of Case OEM and representing purposive sampling (Eisenhardt, 1989) were conducted, all interview results were combined and analyzed. Because of the generality of the research, a few iterations were dedicated to categorization before a set of satisfactory themes were obtained that results could be compared against. Work was done both in the form of Excel spreadsheets and PowerPoint slides, the latter containing more detail on relevant client perspectives. Interviews were heavy on contextual descriptions of facts and technologies, and thus the focus of analysis and matching was on business-relevant issues. In contrast to a typical case study (Yin, 2009), even during the interview phase and the analysis that followed it, interview material was thought to be the most important source for research only on servitization-related issues, with other material being used primarily to build a picture of the phenomenon.

During the interview process, a lot of additional materials were gathered and read to deepen understanding. For example, the Talentum database articles and other publicly available descriptions of different OEM-led Industrial Internet case descriptions were collected into a folder and entered into the master Excel file. Otherwise, the data analysis was mostly performed through the traditional reasoning process: dedicating time to absorbing new information; comparing theory and empirical knowledge; deepening knowledge of some issues through further reading; and iterating existing conceptualizations or creating new ones based on new insights. Additional informal interviews were conducted and practitioner writings were read to achieve saturation with respect to technical knowledge and to gain insights from other organizations.

The systematic combining process of all research material continued until saturation was achieved (Patton, 1990) also with the broader phenomenon. Through this combination process, the original research questions evolved into their final forms, based on an adequate understanding of the topic due to a process of extensive data collection and analysis (Glaser & Strauss, 1967). Only after this did the writing process begin. Additional insights concerning contextual understanding were thus able to be included in the literature sections, adding contextual explanations and evidence on findings from literature, based on the combination. For example, the finding that the thing and system-oriented views on digitization do not converge in the existing research was elaborated further: A review of enabling technologies from both academic and practitioner articles provided insight on technological enablers and barriers discussed with some of the additional informants, supporting the finding and proposing explanations for it. Because the interviews at Case OEM, its clients, and the IT companies provided limited evidence on the phenomenon–described more fully in Chapter 6, the literature and the additional materials played an essential role in constructing the picture of the broader phenomenon.

Table 1 on the next page presents the details of the interviews. Their selection was discussed in section 2.3 and analysis earlier in this section.

Table 1: Interviews

Organization	Responsibility	Length (min)	Type	Date
Case OEM	Global Director, IT solutions	84	Semi-structured	7.4.2015
Case OEM	Director, services	85	Semi-structured	13.4.2015
Case OEM	Director, services	103	Semi-structured	15.5.2015
Case OEM	Global Sales Director, wear parts	90	Semi-structured	18.4.2015
Case OEM	Director, wear parts	63	Semi-structured	31.3.2015
Case OEM	Director, strategy	95	Semi-structured	8.4.2015
Case OEM	Director, services	51	Semi-structured	1.4.2015
Case OEM	Area VP, services	67	Semi-structured	20.4.2015
Case OEM	Area VP, services	83	Semi-structured	31.5.2015
IT company A	CEO	99	Semi-structured	12.3.2015
IT company B	Specialist	83	Open	16.6.2015
Client A	VP Maintenance	72	Semi-structured	12.6.2015
Client B	VP Strategy	61	Semi-structured	12.6.2015

Additionally, informal open interviews, only notes taken: Client A: Production shift foreman, 30min; Client C, Production shift foreman, 60min; Other OEM Project Manager, 90min; Industrial manufacturer IT director, 30min. Other informal discussions with OEMs, manufacturers, consultants, researchers, notes taken.

3 Literature part I: Information and Internet of Things – oriented research

As explained earlier, the initial inspiration for this thesis was the discussion known as Industrial Internet, or Industrial Internet of Things (IIoT) (Evans & Annunziata, 2012; Porter & Heppelmann, 2014). After the literature research began, it soon became apparent that the context of IIoT would be unsatisfyingly narrow to achieve the desired breadth and depth of the topic. First challenge with IIoT is that it primarily focuses on an IoT-related view of intelligent "things", whereas industrial manufacturing often forms complex "systems" and would thus benefit from a system-centric view rather than one emphasizing individual things. Eventually, another practitioner-led community has focused on systems rather than things, – the German Industrie 4.0 (Kagermann et al., 2013). Integration of these two discourses yielded tools allowing more universal conceptualizations of IIoT. The foundations of their terminology will therefore be reviewed in part 3.5.

Secondly, it was found that the technology-enabled change in industrial service provision has consisted of an ongoing, long-term continuum rather than a radical new, contemporary phenomenon. Therefore, an analytical frame (Dubois & Gadde, 2002) was developed to investigate the issue. Taking the view that a big data-related "3V" framework (Laney, 2001) is conceptually too data-centric and is moreover linked to the IoT discourse that views industrial service provision as a radical change rather than a phenomenon that is gradually moving forward, a more generalizable frame was needed. This conceptualization process co-evolved with the abductive analysis process and took the form of what is termed here as "information intensity" to provide structure for the work later on. This analytical frame is also considered one of the contributions of this research, providing conceptual tools with which to investigate the level of intelligence in various sectors without focusing excessively on data. The literature review on information [Part 3.1], historical perspectives on the development of control systems [embedded in Chapter 4], and technical development related to Case OEM [6.1] combine the empirical and secondary material on which this frame is ultimately based.

Thirdly, it became clear during the research process that underlying technological advancements explain to a great extent why some sectors have developed more rapidly than others. While industry professionals are typically highly knowledgeable about the technological basis of their own businesses, very few seem to possess a current knowledge of recent advancement in IoT-enabling technologies or else the terminology used for them varies from sector to sector. It was felt important to give a short overview to these technologies from the viewpoint of IoT [Part 3.3] and data science [Part 3.4], which are not exclusive to the industrial manufacturing context but rather are generalizable to most sectors.

Lastly, a presentation-logic related challenge emerged. Instead of integrating only two or three mature discourses, these several non-converging and still emerging practical and academic discourses had to be synthesized with the somewhat dispersed, but mature, servitization literature, simultaneously enriching that with industry-specific technical views and further elaborating and validating that with primary and secondary empirical materials. To reflect the integrative conceptualization process, some early conceptualizations will be presented in Chapters 3 and 4, reflecting what can be deducted from the literature, although the findings typically required a systematic synthesis of the empirical world and theory to discover the links between the concepts. This might contribute to a feeling of repetition every now and then when referring to earlier parts or to challenges in seeing the full line of logical reasoning behind the next development phase of the conceptualizations. Due to the multitude of integrated literature sources, this was employed as a compromise between using an easy-to-follow traditional thesis format and structuring the thesis so as to reflect the iterative abductive process. Chapter 2 explained in detail the flow of the research work.

Next, a short positioning of the phenomenon will be given to build contextual understanding for the following sections on information intensity, IoT, and big data, which form the basis for integration of the Industrie 4.0 and Industrial Internet discourses in Section 3.5. Conceptualizations on industrial digitization are then applied in the following chapters, and the analytical frame on information intensity in Chapter 6, so as to yield additional insights to these with respect to the abductive, combinatory process.

3.1.1 Introduction to the phenomenon of Industrie 4.0 and Industrial Internet, and its relation to industrial services

Personal computers, modern information systems, and the Internet transformed many traditional white-collar jobs at the end of nineties, driving the development of the so-called information economy (Castells, 2011). In industrial manufacturing, digital automation systems and personal computers were adopted during the same period but with some differences: although automation helped to reduce manual labor in such centralized production systems as factories, many processes, such as trucks and cranes, were still operated by a human. These production units and performance-creating units such as engines were benefitting from operational improvements made possible by computer-aided analysis and optimization less than B2C-directed companies, where many processes were optimized by way of constant number-crunching. Now, after almost two decades of an Internet-enabled economy and about a decade of cloud computing, the benefits of wireless communication technologies, increased computing power, additive manufacturing technologies (3D), and many more are starting to affect industrial manufacturing processes in scale–and thus also the capital equipment providers and their service provision.

This ongoing change is seen as a new industrial revolution. Depending on whether the context is Industrial Internet or Industrie 4.0, it is described as either a third (Rifkin, 2011) or a fourth industrial revolution (Kagermann et al., 2013), respectively. The two views differ as to whether process automation from the late 1960s is a separate revolution (German) or not. But both share the view that “smartness” (Zuboff, 1988) embedded in physical objects enables increased productivity and efficiency gains, optimization in decision-making, new value creation opportunities, novel business models, and rationalization of processes. Industrial Internet aids in solving some of the wicked problems related to energy and raw material resource consumption and fights deindustrialization through higher productivity, thereby possibly bringing industrial production back to developed economies.

Many interesting viewpoints with respect to Industrie 4.0 development have been identified, but a great deal of work by industry professionals and researchers is needed to realize these visions. These topics include, but are not restricted to, enabling technologies, new business models, increasing complexity of value networks, data sharing and security issues, social issues, work organization, and regulation. In this development, production equipment, smart or intelligent products (Meyer et al., 2009), and cyber-physical systems (e.g., Rajkumar et al., 2010) play an important role; they are provided by industrial capital equipment manufacturers, known also as original equipment manufacturers (OEM). One viewpoint to which little interest has so far been devoted in discussions concerning Industrie 4.0 is the role of this development in services, sometimes referred as Internet of Services (Kagermann et al., 2013) or smart services (Allmendinger & Lombreglia, 2005; Maglio, 2015; Spohrer & Demirkan, 2015; Medina-Borja, 2015).

Services transformation to information-age is often described as optimized availability and performance (i.e., condition-based maintenance), and new hybrid offerings of industrial goods lead to new pricing models such as output-based pricing or uptime-based pricing (e.g., Maniyka et al., 2015). These concepts belong to the core of servitization or service infusion research, but Industrial Internet terminology is still rarely applied in that context. This is understandable, firstly, because researchers seek to avoid the trap of using possibly soon-to-die “hype” terms, and, secondly, because of the relatively slow adoption of an information-dominant logic in services, a result of the decades-long lifecycles of industrial goods. Still, many relevant perspectives on servitization, especially with respect to advanced solutions, can be borrowed from Industrial Internet and various technical discourses. To facilitate the integration of perspectives and adoption of terminology, the terminology related to Industrial Internet of Things and Industrie 4.0 will be reviewed after presenting the conceptual background for this thesis and the technological basis for the Internet of Things.

3.2 Information intensity

The construct of “information intensity” will be applied in this thesis to explore the phenomenon of proposed industry evolution to an Industrie 4.0 (Kagermann et al., 2013) or Industrial Internet era (Evans & Annunziata, 2012). The construct is not strictly based on existing theory or grounded solely in a combination and elaboration of existing theories. Instead, although it has some theoretical foundations, it has co-evolved during the research and writing processes underlying this thesis, thus providing an analytical frame for the work (Dubois & Gadde, 2002).

It was found that the shift to “Big Data” or “Industrie 4.0” does not occur overnight, at least in a manufacturing context, and, in practice, there are huge differences in how different industrial sectors have used information in their operations over time. Adoption of more information to processes was identified as a gradual process, not a radical event. Because information has been increasingly used during past decades, there is no clear turning point at which the “Big Data” era began, and so the historical scope of the literature review should start early enough to fully encompass this phenomenon. Also, it would not have been meaningful to base this research on these recent, vaguely defined concepts, because big data typically disregards other than data-form information, and Industrie 4.0 is an evolving conceptualized future vision of the target phenomenon itself. Therefore the more abstract concept of “information intensity” was developed as the analytical frame for this work.

This section will present some interesting perspectives on information from the existing literature and, at its conclusion, present the concept “information intensity”. However, as described above, the concept is not built deductively based solely on existing theory but rather is the by-product of the abductive research process. Material presented in the following chapters will add insights to and further develop this analytical frame.

Although not among the original research objectives, the concept of information intensity is considered an additional valuable contribution of this thesis. Increased information intensity is a very real phenomenon but has not been theorized or even documented sufficiently and therefore could prove a highly interesting topic for future research.

3.2.1 Theoretical perspectives: physical view

Information theory (Nyquist, 1924; Hartley, 1928; Shannon, 1948) takes a physical view to information, and it is an important theory in electrical engineering, statistics and computer science (Thomas & Cover, 2006). It has an abstract approach to information, but focusing on its packaging (entropy) and transmission (channel capacity) related challenges, it does not theorize the contents or meaning of information (Thomas & Cover, 2006; Boisot & Canals, 2004). Shannon (1948) applies the concept of entropy from thermodynamics to define a variable H, which is the amount of (physical) information contained in a message.

With data viewed from a physical perspective (Shannon, 1948), huge volumes have been physically generated for as long as sensors have existed to transmit them. However, data have been stored and analyzed more or less sporadically and so have existed in a perishable form only. Therefore, they have been used only mechanically or electronically through programmed logic. After the introduction of the fieldbus and input-output (I/O) and the emergence of historians in process automation during the 1990s, more and more physical data have been practically as well as physically available, in process manufacturing for instance. The viewpoint adopted in this study is that, unless information is stored, it exists only physically and so can be used “on-the-fly”, either by process automation or by humans if able to be visualized. Programmable logic uses the information in reality, but a human actor has limited information processing capability (see e.g., Engle et al., 1999; Parasuraman et al., 2000) only when focusing attention to the particular, perishable data.

Hand-drawn trend analyses based on measurements of physical information can be seen as transforming it to information. Trend analyses are the first examples of employing machine-created information in service processes. Therefore, information intensity emerges only when physical information is stored and/or processed for a purpose and in that manner transformed into data and information.

Information theory focuses on some challenges that approach the concept of information. Besides technical problems related to transmission, there are semantic problems related to symbols and effectiveness in conveying a message (Shannon, 1948), although these are mostly technical in nature. The concept from information theory that most closely resembles that of information intensity is perhaps the Kolmogorov complexity variable *K*, which is defined as the required computational time and space needed for execution of a task (Thomas & Cover, 2006).

3.2.2 Theoretical perspectives: data-centric view

So-called Big Data has been temptingly theorized and connected also to servitization context (Opresnik & Taisch, 2015). Regardless of its popularity, Big Data theory applying such V-models as 3V “Volume, Variety, Velocity” (e.g., Laney, 2001) possesses limitation that render it just one lens through which to view the phenomenon: (1) It is not commonly accepted or well defined as a theoretical construct, (2) it has connotations of a radical rather than gradual evolution from “small data” to “big data”, and (3) it is based on a data-centric view and so disregards other information sources such as installed base and expert knowledge.

However, V-models such as 3V (Laney, 2001) can aid in conceptualizing raw-data related information intensity. Data volumes are interesting from a storage and computational viewpoint; the point at which relational database storage capacity is exceeded is sometimes referred to as the turning point with respect to big data and in reality does constitute a large infrastructural step. Data volumes are also interesting when viewed as a non-temporal variable, becoming intensity when combined with velocity.

For example, Rolls Royce’s Engine Health Management service concept uses data from approximately 25 sensors, measuring, for instance, pressure, temperature, vibration, and shaft speed (Lapworth, 2015). Information intensity on these two factors (Volume; Velocity) depends on the frequency–or velocity–of the data. Each transmitted data packet containing the measuring values from those 25 sensors provides a tiny spark of information, but as frequency of transmission increases, so do data volumes. In Rolls Royce’s case, this frequency is below 0.5 seconds (ibid.), but information is typically created at microsecond-level by sensors, and even programmable logic can use this information. In comparison to Rolls Royce’s engines, a modern oil offshore platform can have 30,000 sensors (Maniyka et al., 2015), and a modern paper line up to 100,000 sensors. Specialized publications dedicated to the study of technological solutions address the challenges posed by data, and the following sections will provide an introduction to those solutions.

Continuing with Rolls Royce's example (Lapworth, 2015) to discuss 3V model, variety of data constitutes still another data variable that is of interest. For instance, analytical models also incorporate such airplane control information as altitude and other mechanical information such as fuel levels. If the two first components (Volume, Velocity) form the data-based intensity, the variety of information adds additional variables to the computational models. Data accuracy, known in big data discourse as data veracity, is a fourth important variable, but it has less to do with data intensity than the first three Vs. This is also a subject of great interest in information theory, given the encoding challenges of noise-sensitivity (Thomas & Cover, 2006).

Although thought provoking, this primarily sensor-based, raw data-centric view of information is incomplete. Other interesting and codified sources are related to product type, event, and location in the form of the installed base data (Ala-Risku, 2009) and business information used for decision making. These could be included under the variety variable, but, in practice, they are often used separately for service provision, whereas the big data approach builds on the idea of integrated data sources. Besides codified information, there is also tacit information (e.g., Nonaka, 1994), which is typically not considered in discussions related to big data. Therefore, knowledge management perspectives (Nonaka & Takeuchi, 1995) are relevant to such discussions, because expert knowledge can play a central role in advanced services provision. All these data sources can be used in building an internal knowledge base, especially when combined, benefitting also from advanced analytics and data science methods (e.g., Provost & Fawcett, 2013) and thereby increasing information intensity in industrial services provision.

The above described "big data theory" with additional considerations should not be regarded as a theory per se, although it is sometimes referred as such (e.g., Opresnik & Taisch, 2015). The closest established theoretical contribution comes from technology-centric information theory (Shannon, 1948), although attempts to form a unified information theory have been made (Hidalgo, 2015). Based on the literature read for this thesis, it appears that Industrial Internet-related thinking is leaning towards this data-centric view, especially when big data, data science, and machine learning are proposed as the fundamental change aggregators. In contrast, German discourse (Kagermann et al., 2013) appears to place less emphasis on data and more on systemic views in which information is used to automate complex manufacturing processes

3.2.3 Theoretical perspectives: information-centric view and digitization

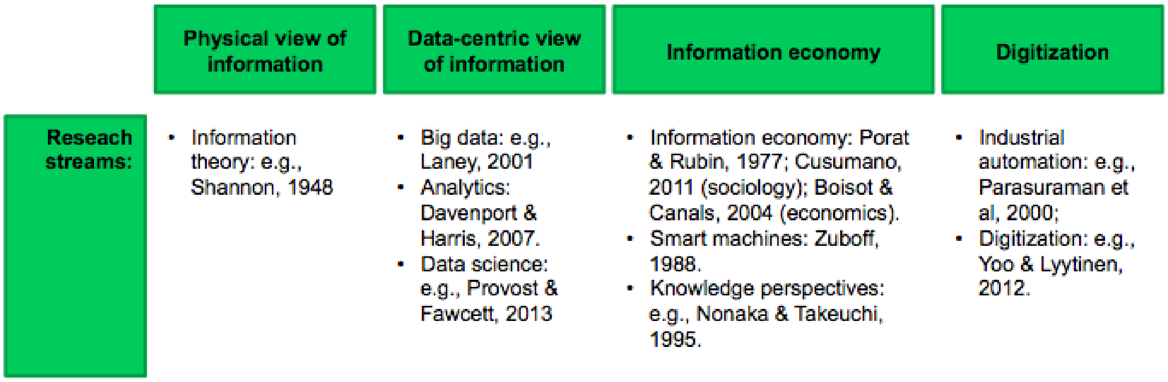
Social scientists such as economists and sociologists have studied the role of information as the driving force or economic commodity for growth and value creation (e.g., Arrow, 1984; Castells, 2011). In information sciences, taxonomy of data, information, and knowledge is often applied, but some ambiguity with respect to these definitions exists (Boisot & Canals, 2004; Zins, 2007). Although the information economy is often associated with the post-industrial economic model in which most jobs involve information handling rather than primary production, manufacturing, and manual services (Castells, 2011), Benkler (2003) remarks that the (industrial) information economy began to emerge approximately 150 years ago, when information began to be used to control processes and human behavior in the workplace. In these information-centric views, the human actor plays an important role in transforming information into value.

A term “informating” has been in conjunction with the first mentions of Smart Machine (Zuboff, 1988). This concept of informating is grounded on the process of mechanical automation systems producing information as the byproduct of the automated activities, which can in turn be used in the organization (ibid). In this manner, the emergence of the information-centric view of industrial processes can be traced to the late 1980s, the same time PCs were being increasingly used to control the production process and created information was increasingly being integrated into management information systems, thereby enabling better management of processes (Wilbanks, 1996). It seems natural that servitization (Vandermerwe & Rada, 1988) would emerge during the same period, with information from systems opening up opportunities to control human-led processes and also access historical information without physical access.

The process of turning information into insights did not begin to gain momentum until the 2000s, when the capability of conducting this value-creating process came to be viewed as a source of competitive advantage (Davenport, 2006). During the last decades of the 1900s, the role of information and its underlying technology for management usage was studied by Information Science (IS) scholars, as technologies such as Decision Support Systems (DSS) and Management Information Systems (MIS) were transitioning work into the information age and thereby increasing employee productivity in corporate support functions (Mortenson et al., 2015). Within the IS area, information was, and still is, viewed primarily through a management lens, although incorporating production process–related information views of the field would no doubt prove beneficial.

Tilson et al. (2010), Yoo et al. (2012), and McAfee and Brynjolfsson (2012) conceptualize the increasing automation of work using information as digitization. This view of information as a medium for automating work develops further the information-based view, enforcing the role of information as a transformative element and making systems intelligent. However, digitization is not always a go or no-go consideration. Parasuraman et al (2000) approach the issue by proposing that companies need to define, to what extent a human should interfere processes. Especially high-impact decisions are those where human role should remain high (ibid), thereby supporting the view of information as a resource and digitization as the process of automating processes. With information viewed as more than a commodity, human expertise and creativity transform it into value on a continuous basis rather than through decision-making rules programmed in advance.

Figure 3 below summarizes the various views on information based on above discussion.



	Physical view of information	Data-centric view of information	Information economy	Digitization
Reseach streams:	• Information theory: e.g., Shannon, 1948	• Big data: e.g., Laney, 2001 • Analytics: Davenport & Harris, 2007. • Data science: e.g., Provost & Fawcett, 2013	• Information economy: Porat & Rubin, 1977; Cusumano, 2011 (sociology); Boisot & Canals, 2004 (economics). • Smart machines: Zuboff, 1988. • Knowledge perspectives: e.g., Nonaka & Takeuchi, 1995.	• Industrial automation: e.g., Parasuraman et al, 2000; • Digitization: e.g., Yoo & Lyytinen, 2012.

Figure 3: Views on information

3.2.4 Information intensity – an integrated view

Within the context of this thesis, information is understood as a byproduct of codified processes and actions. Machines are able to produce physical data of unlimited velocity, but only sensor-based measuring transforms that into (unstructured) raw data. When data are also syntaxed, they can then be considered as information that can be transmitted and stored, thereby defining data in a mostly theoretical way. Besides sensor-produced data (information), other important information sources, notably from human operations, take the form of databases such as installed base data or management information systems in industrial settings. Although tacit expert knowledge is distinct from information, combining it with information transforms it into value, thereby codifying it to make it less perishable.

Information is an important resource enabling the creation of new services and solution concepts by industrial manufacturers. Information appears in many forms, but the ability to turn it into value is an important capability of companies. The intensity of information is based on the "Vs" of data and of other information sources, most notably humans using that information and turning it into value. The more information there is and the more intensively it is exploited, the higher the information intensity within a given business is. Digitization is the process of automating processes and should be understood within an industrial context as the transformation process towards the era of Industrie 4.0 and Industrial Internet.

3.3 Internet of Things (IoT)

Internet of Things (IoT), a widely used term among professionals and academics, refers to the practices of implementing communication technologies to objects, and resulting in increased abilities to use this connectivity and intelligence in transforming businesses (e.g., ITU-T, 2012; Xu et al., 2014). The term originated within the RFID-context–or within that of its predecessor Auto-ID, a key enabling technology used in, for instance, identification and location tracking (Ashton, 2009). Improved supply chain efficiency with traceability is one of its key applications, as is fleet management of production vehicles in, for instance, transportation or agriculture, resulting in higher operational efficiency due to GPS tracking and analytics (e.g., Meyer et al., 2014; Ruiz-Garcia and Lunadei, 2011). Different technologies, usage of portable devices, emergence of standards (Atzori, 2010), and data- and user-based platforms enabling new businesses (Eisenmann, 2006; Hagiu, 2014) are examples of other topics often linked to IoT.

Many businesses and sectors provide a suitable context for IoT to reflect the impacts of increasing information intensity. Similarly, there are sectors where IoT, with its background in RFID and location-based applications, is less applicable, a case in point being, for instance, process industries, where the focus is on process automation and service operations than on individual objects as is typical with respect to IoT. Because of these multisided context-based differences, the subsets of industrial IoT context are typically described with other such terms as Industrial Internet, Industrial Internet of Things (IIoT), or Industrie 4.0 (Kagermann et al., 2013), a jungle of terminology discussed further in the next sections. However, many underlying technological principles of IoT are also applicable to IIoT (WEF, 2015), which will be presented briefly below. Because of the breadth of the IoT context (or its quite synonymous term Internet of Everything (IoE)), many theories and frameworks on new business models, platforms, or other topics are typically linked to IoT rather than to IIoT. Following the traditions of theory building, many of these frameworks are proposed as universal, although distinguishing IIoT from IoT suggests that these sectors might have different driving logics, and the much hyped “disruption” of traditional businesses might be less radical or different than in some other businesses. Even the industrial context literature (e.g., Iansiti and Lakhani, 2014) on IoT might fall short of providing generalizations if the case examples used are solely based on fleet management solutions. The term Internet of

Things will be carried on in this paper for comparisons and generalizations to the industrial context.

3.3.1 Enabling technology for IoT

Two key technologies, RFID and WSN, are sometimes seen as practically defining components for IoT (Xu et al., 2014). These are undoubtedly important, but even though presenting different technologies in depth is not suitable for the scope of this thesis, a bit broader perspective will be taken here to allow technology-oriented reflections later on in the thesis.

Atzori et al. (2010) classify IoT-enabling technologies to (1) identification, sensing, and communication technology, (2) middleware, which Gubbi et al. (2013) define as "on-demand storage and computing tools for data analytics", and (3) presentations of visualized information. Gubbi et al. (2013) also add visualization as a third component, reflecting the role of information usage. However, these two papers, of which Atzori et al. (2010) can be seen as a seminal paper within the IoT literature, are both from a computer science background and thus present only one perspective on IoT technologies. In contrast, a data analytics viewpoint enforces the role of analytics over hardware. A more recent paper by Xu et al. (2014) points out the role of nanotechnology and control systems, but in general control systems gain less attention in the context of IoT than, for instance, in that of Industrie 4.0, and material science is discussed in its dedicated journals, separate from the computer science context. Besides technologies, managerial issues should be also considered, such as information security and standardization, as pointed out by Atzori et al. (2010) and Gubbi et al. (2013). In the interest of space and scope, this section classifies enabling technologies to (1) hardware and (2) middleware, analytics and visualization being left to the next section.

3.3.2 Identification, sensing and communication technology

One important function of Intelligent Products is their ability to identify themselves (McFarlane et al., 2003; Meyer et al., 2009), typically achieved with an RFID (radio frequency identification) tag, which, in its simplest form, is an induction-powered microchip with an antenna (Atzori et al., 2010). An RFID is able to broadcast its identity up to a distance of about a meter or, with some modifications, up to 7,5 meters (Meyer et al., 2009) using radio frequencies varying from low (LF) to ultra-high ones (UHF) (Atzori et al., 2010). Employing low-cost RFID to track products has transformed, for one example, operations management of supply chains, but it is also useful in industrial asset management and industrial services (Holmström et al., 2010). Other identification methods range from old-fashioned bar codes to DNA (Hakanen, 2015), but RFID greatly dominates identification technology.

RFID tags can be passive or active, the latter having their own energy source (Gubbi et al., 2013) and thus such extended capabilities as higher storage capacity and transmission signal strength (Ferrer et al., 2010). Active RFID tags address the electrical and capacity limitations of passive RFID tags, but their high cost reduces their applicability to high-value items. As a key enabling technology for Industrial Internet applications in e.g., cargo handling–related industries, active RFID is used, for instance, in port containers (Gubbi et al., 2013). Another industrial use case is in off-road vehicles and their environments to improve efficiency in fleet management such as in precision agriculture (Sjölander et al., 2011). Semi-passive RFID tags use battery to power the microchip but not the signal (Gubbi et al., 2013).

In a recent press release, Siemens (2015) claims to be experimenting in ways to address storage and signal challenges with a new passive, “intelligent” UHF RFID transponder, capable of storing up to 4 kilobytes instead of 64 bytes a typical passive RFID is capable of, and powered by electromagnetic fields. Higher storage capacity would thus be another option to store, for example, assembly plans or other data, reducing the need to be connected to ERP, PLM, or other systems. Another challenge is security; RFID tags can be read by practically anyone in the proximity of the tag (Atzori et al., 2010), which is likely to impact viewpoints on data openness in different sectors. Identification is not problematic, neither. The current addressing scheme, IPv4, does not support truly unique identification of objects, and IPv6 has been proposed as the next step supporting IoT, although it also does not address the problem of globally unique and standard identification alone (Atzori et al., 2010).

Besides identification, other sensor-based data such as that concerning temperature or moisture is important in many applications. These sensors are embedded in different objects and together form Wireless Sensor Networks (WSN) or Ubiquitous Sensor Networks (USN), depending on the definition. These terms are sometimes used synonymously, but, in general, WSN can be thought of as a specific, for-purpose-made connectivity, whereas USN operates under the assumption that, at some point, practically everything will contain sensors and be connected. Sensors, referred as nodes, are interconnected and have a so-called sink node with the ability to communicate to the outside world (Atzori et al., 2010). Challenges in WSN technology include energy efficiency related to the possibly continuous use of sensors (Atzori et al., 2010; Gubbi et al., 2013)– especially challenging when sensors need to be powered with a battery – and data reliability issues due to frequent failures in data measurement or transfer at node-level. Gubbi et al (2013) propose e.g., that the sensor could have an ability to heal itself to overcome this second limitation. Another opportunity would to go around failures in analytics phase. Security issues are also a concern with WSN because sensors are often linked directly to the so-called actuators (Gubbi, 2013), and manipulating sensor nodes through sink nodes might enable an intruder to, for instance, affect industrial processes not having protective measures. Sensor networks can also co-operate with RFID, adding information to the status of RFID tags (Atzori et al., 2010).

In process industry applications, (Industrial) WSN or IWSN (Kumar et al., 2014) offers many opportunities, but its adoption has been slow due to different challenges, although wireless transmission of data has been used for industrial purposes since around 2000 (e.g., Jonsson, 2006). One explanation is that assets can have lifespans of several decades, and, depending on differing requirements and needs, sensors might have to be wired physically, and thereby costs might not be associated with high return on investment. Machine-to-machine (M2M) solutions is another term associated with local solutions enabling machines to communicate with one another and impact their environment.

3.3.3 Middleware

The hardware of sensors, actuators, and tags is connected to applications using the data these generate by middleware (Atzori et al., 2010), which is needed to facilitate communication between different objects that often employ different communication protocols and so make applications hard to build without these data sources first being “translated”. Bandyopadhyay et al. (2011) define the functional components of IoT middleware as (1) interoperability, (2) context detection, (3) device discovery and management, (4) security and privacy, and (5) data volume management, achieved with four layers: interface protocols, syntax and semantics, central and management module, and application abstraction. Different visions of USN or IoT sometimes depict a future of common standards for IoT, but, due to the heterogeneity of the objects, middleware (Bandyopadhyay et al., 2011; Atzori et al., 2010) and standardization, such as OPC UA in process automation (Colombo et al., 2014), are needed to facilitate applications over the technology stack. Service Oriented Architecture (SOA) is often applied in IoT architecture development (Atzori et al., 2010), incorporating a lower level of complexity for the API (application programming interface).

Connectivity and middleware are of high interest in telecommunications and to IT hardware and software providers, and topics generating much interest around these technical solutions include such service models as Platform as a Service (PaaS) (Mell and Grance, 2011), cloud computing (Marston et al., 2011) and fog computing (Bonomi et al., 2012), and standardization efforts led by institutions such as ITU (International Telecommunication Union) (Atzori et al., 2010). Companies like Microsoft and SAP are building infrastructure for IoT platforms (Azure and HANA) and experimenting with different business models (Iansiti and Lakhani, 2014). Challenges related to the expansion of available data also make Quality of Service (QoS) a relevant topic with respect to accepted delays and required bandwidth for data and likewise to security issues (Gubbi et al., 2013). But even though the costs of bandwidth and data storage will continue to decrease, questions on what data should be gathered, frequency at which they should be gathered, and extent they should be processed remain essential (Gubbi et al., 2013).

3.4 Big data and analytics

Information Science and Computer Science literature on analytics, data science, and data mining provide still another perspective on IoT. Their linkage to decision sciences is also strong (Provost & Fawcett, 2013). Although the opportunities associated with big data-based analytics are typically discussed from a management viewpoint (McAfee et al., 2012; Chen et al., 2012), analysis of masses of big data with advanced statistical methods based on machine learning have been found useful in complicated industrial applications, such as the chemical industry (Yu, 2012). Despite the focus on traditional enterprise data, Dijcks (2013) notes that there are also two other common types of Big Data: machine-generated sensor data (logs, meters, sensors), and social data.

Several principles are introduced for later reference, as analytics is a topic that drives many IoT-enabled solutions, but few know what is meant by the term. The definition of Big Data is not regarded as clear cut (Gandomi & Haider, 2015), and it is often explained by way of its characteristics, the “Three Vs”: *volume*, *variety*, and *velocity* (Laney, 2001). More recent definitions have added two more, *value* and *veracity*, which are of more interest in the social sciences (Hitzler & Janowicz, 2013), and thus the characteristics are referred to as the “Five Vs”. The definition of volume for big data varies, but industry experts suggest 1-10 terabytes, based on the limits at which relational database management systems (RDBMS) approach non-relational solutions, notably the open-source Hadoop distributed file system (HDFS). At this limit, MapReduce (Dean & Ghemawat, 2004) are required to split the data into storable chunks, (Shvachko et al., 2010). This data is stored in unstructured form, and the extract-transform-load (ETL) process plays an important role in accessing and preparing the data for processing (Jacobs, 2009). For the processing of data, there are different open-source options such as R and commercial ones.

Various ways exist to illustrate the analytics process, and one by Miller and Mork (2013) includes the steps of data discovery, integration, and data exploitation, of which the last is split into analysis, visualization, and decisions. Analytics type is often categorized as descriptive, preventive, and prescriptive (Lustig et al., 2010). Descriptive represents information as-it-is, preventive provides information of what might happen, and prescriptive what should be done. Automated decision-making involving machine learning or artificial intelligence have been proposed, but at a minimum analysis of untapped data masses can be utilized to support human decision making in different settings, such as root cause analysis of machinery failures (Qin, 2014). Analytical processing is done using either simple queries, or, in many cases, advanced statistical methods, such as Single Vector Machine (SVM), Apriori, kNN, or C4.5 [or C5.0], using, for instance, decision trees powered by machine learning or cluster analysis (Wu et al., 2008). Methods successfully used in complicated industrial applications, such as principal component analysis (PCA) or partial least square (PLS), differ in their use of machine learning methods for data training and processing, which can aid in fault diagnosis, for instance (Yu, 2012).

Discussing the linkages of these views and presenting them further is beyond of the scope of this thesis , but referenced articles give an opportunity to delve more deeply in the topics if the reader so wishes. Firstly understanding the complexity of the technical and analytics viewpoints and secondly recognizing key terminology can help in creating a dialogue between professionals in the industry and analytics providers and so reduce possible prejudices. The overselling of Big Data analytics opportunities in particular may lead to criticism and misunderstandings (Perrons & Jensen, 2015), but as Ross et al. (2013) puts it, there might not be enough potential in data insights to argue for high investments and, even if there were, required organizational changes to capture this value might prove difficult to execute. Still, Barton and Court (2012) claim that a factory operations executive’s ability to grasp the value of hourly data is likely to become a core capability for future manufacturers. This section can be referenced later, when describing and explaining empirical material and discussing them with respect to other literature.

3.5 Industrial Internet and Industrie 4.0

3.5.1 Origins and focus of the high-level terminology

General Electric's vision paper on the future of industrial production (Evans and Annunziata, 2012) is a seminal article for Industrial Internet and has popularized the term. Another noteworthy instance affecting Industrial Internet terminology is Industrial Internet Consortium (IIC, 2014). Although the term does not have a generally accepted definition (Drath and Horch, 2014), and it originates from a non-academic paper, the industry has adopted it widely, sometimes using Industrial Internet of Things (IIoT) at its synonym (WEF, 2015).

Another term for the same phenomenon is Industrie 4.0 (sometimes Industry 4.0), first used at Hannover Messe 2011 (Kagermann et al., 2013). Although used primarily by German industry practitioners, it has been gaining in popularity in English language reports and within practitioner communities, perhaps due to the active input of Germans and the lack of system-based views in Industrial Internet reports (e.g., WEF, 2015, EU2020, 2015; Maniyka et al., 2015).

These two concepts refer to the same phenomenon but apply different terminologies, differ in background, and focus on different industrial solutions.

Firstly, Industrial Internet refers to the future technical network made up of interconnected industrial things whereas Industrie 4.0 refers to the next evolutionary state and the revolution of industrial production. Despite the conceptual differences, they are the most commonly used terms to refer to the same broad-based phenomenon. Another set of terms, "Third Industrial Revolution" (Rifkin, 2011) and "Third Wave" (Evans & Annunziata, 2012), also refer to the industrial revolution in Industrial Internet terminology, but these are rarely used. "Advanced manufacturing" is another term used less specifically for developed manufacturing practices. Also the concept of "smart" is applied in this context, both by Industrie 4.0 and Industrial Internet, the concept originating with Zuboff's "smart machine" (1988). Terms such as "Smart Production", "Smart Manufacturing", and "Smart Factory" appear in manufacturing contexts (Kagermann et al., 2013).

"Third Industrial Revolution" and "Industrie 4.0" differ in their categorization of earlier industrial revolutions. Mechanical production since the late 18th century constitutes the first one, and Fordian mass-production the second. In contrast to Anglo-Americans, Germans define the programmed logic automation dating from the 1970s (Kagermann et al., 2013) as the third revolution. This reflects the manufacturing-related backgrounds of Industry 4.0, in contrast to the smart product and object-related Industrial Internet.

As the word "Industrial" implies, the focus sectors are industrial ones. World Economic Forum defines this, referring both to Industrie 4.0 and Industrial Internet as physical industries, as opposed to non-physical industries.

> "Physical industries: Sectors of the economy featuring capital-intensive physical infrastructure or assets, including manufacturing, oil and gas, mining, agriculture, utilities, transportation and some parts of healthcare (e.g. hospitals)." (WEF, 2015)

In contrast to Drath and Horch (2014), who exclude smart grids, this definition on physical industries appears to encompass a slightly broader scope. There appear to be no exact sector boundaries for Industrie 4.0 or Industrial Internet, but in this thesis those sectors that do not produce physical goods–especially hospitals–are awarded less attention in order to reduce complexity.

Drath and Horth (2014) treat Industrie 4.0 and Industrial Internet as synonymous and as having same technical background. Although the enabling technologies are similar, the technology-related foundations of the terms highlight further their differing things-centric and system-centric views to next generation industrial processes.

Figure 4 below maps some key terms employed by Industrial Internet and Industrie 4.0 together. Some of the terms appear, or are presented in more depth, in the coming subsections.

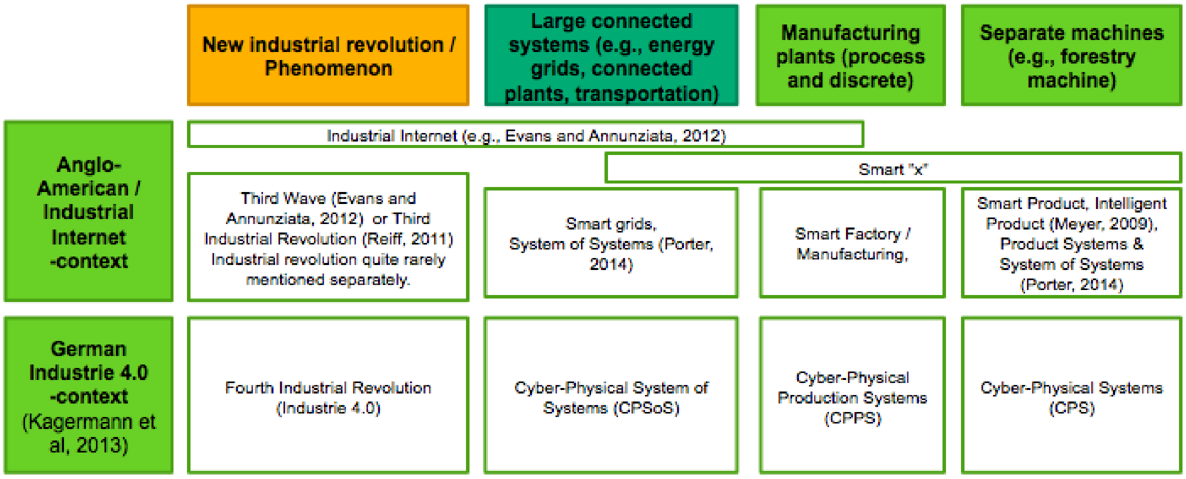


Figure 4: Terminology related to Industrie 4.0 and Industrial Internet

3.5.2 Industrial Internet of Things

A recent World Economic Forum report defines Industrial Internet as “A short-hand for the industrial applications of IoT, also known as the Industrial Internet of Things, or IIoT” (WEF, 2015). Drath and Horth (2014) also treat the terms Industrial Internet and Industrial Internet of Things as synonymous. Due to the active participation of industry professionals who are less rigid with respect to terminology, those views can be assumed to be good generalizations of the general public’s understanding of these terms in relation to one another. Moreover, the Evans and Annunziata (2012) seminal paper on Industrial Internet develops the concept from Internet of Things, further validating this view.

Now, if Internet of Things is the origin for Industrial Internet, RFID and wireless communication technologies form an important technological component of Industrial Internet. This viewpoint gets support from the industry examples that Industrial Internet papers (e.g., Evans & Annunziata, 2012; Iansiti & Lakhani, 2014; Porter & Heppelmann, 2014) are typically referring to: tracking and logistics-related solutions, either from a technological perspective or an end application usage perspective. Fleet Management of “smart” production vehicles such as John Deere agricultural machines, mining equipment, or other vehicles represent one often-referred type application of Industrial Internet. Independent units such as Rolls Royce’s turbines represent another application. While a turbine is a machine unit, it enables airplanes, ships, or other transportation vehicles to perform and therefore foundationally constitutes a logistics solution. GE’s report (Evans & Annunziata, 2012) pays special attention to those things “that spin”, and although often related to fleet management, other than logistics-related solutions also exist, even in process manufacturing. Other cases, such as the harbor cargo handling cranes of Konecranes, also belong to this logistics solution category, benefitting to a great extent from active RFID tags in providing their solutions, although using also sensor data in the data models. Therefore it can be concluded that Industrial Internet has primarily focused on IoT-enabled tracking solutions to date, and to single machine unit optimization such as turbines.

3.5.3 Cyber-Physical Systems

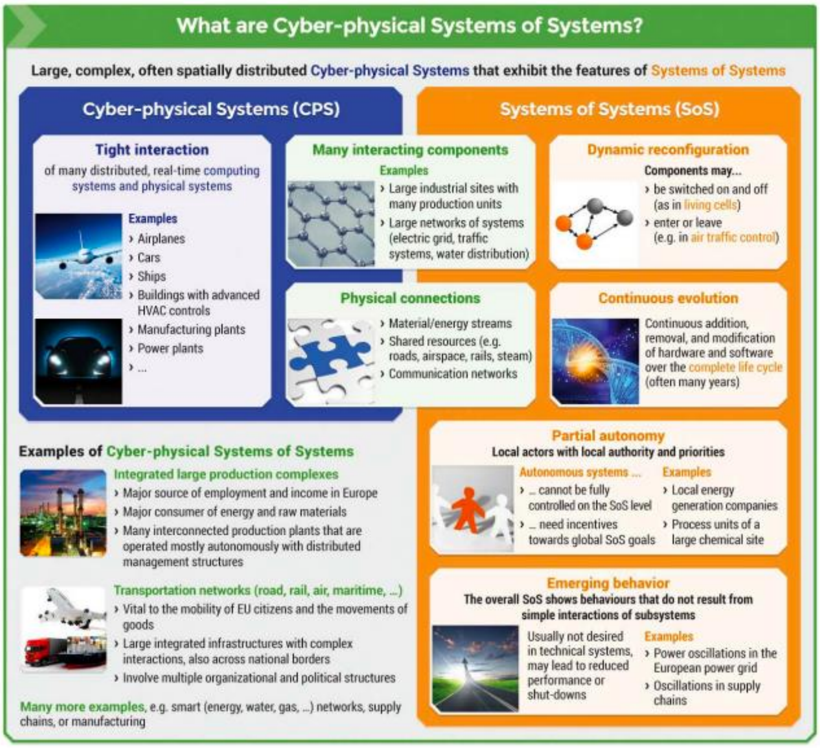
Industrie 4.0 requires the development of Cyber-Physical Systems (CPS), which “comprises smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently” (Kagermann et al., 2013, pp. 5). Cyber-Physical Systems appear often in conjunction with

Industrie 4.0 and could be viewed as the Industrial IoT application entity in which the Germans are interested. Two other terms are related to CPS. Cyber-Physical Production Systems (CPPS) is sometimes used to emphasize manufacturing plant context (e.g., Monostori, 2014). Cyber-Physical System of Systems (CPSoS) conceptualizes a combination of CPSs, such as transportation systems, energy infrastructure, or complex production networks (e.g., Kagermann et al., 2013; WEF, 2015).

Cyber-Physical Systems as a term emerged prior to Industrie 4.0 and embodies a system-based view of information-intensive manufacturing. An earlier definition of CPS aids in understanding the concept:

> Cyber-Physical Systems (CPS) are integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa (Lee, 2008, pp. 363).

This view resembles the concept of smart machines to some extent, but Kagermann et al. (2013) position it more clearly with respect to large manufacturing systems rather than independent machine units. See Figure 5 by Kagermann et al. (2013) for further reference.



What are Cyber-physical Systems of Systems?

Large, complex, often spatially distributed Cyber-physical Systems that exhibit the features of Systems of Systems

Cyber-physical Systems (CPS)

Tight interaction
of many distributed, real-time computing systems and physical systems

Examples
- Airplanes
- Cars
- Ships
- Buildings with advanced HVAC controls
- Manufacturing plants
- Power plants
- ...

Many interacting components

Examples
- Large industrial sites with many production units
- Large networks of systems (electric grid, traffic systems, water distribution)

Physical connections
- Material/energy streams
- Shared resources (e.g. roads, airspace, rails, steam)
- Communication networks

Systems of Systems (SoS)

Dynamic reconfiguration

Components may...
- be switched on and off (as in living cells)
- enter or leave (e.g. in air traffic control)

Continuous evolution

Continuous addition, removal, and modification of hardware and software over the complete life cycle (often many years)

Partial autonomy

Local actors with local authority and priorities

Autonomous systems ...
- ... cannot be fully controlled on the SoS level
- ... need incentives towards global SoS goals

Examples
- Local energy generation companies
- Process units of a large chemical site

Emerging behavior

The overall SoS shows behaviours that do not result from simple interactions of subsystems

Usually not desired in technical systems, may lead to reduced performance or shut-downs

Examples
- Power oscillations in the European power grid
- Oscillations in supply chains

Examples of Cyber-physical Systems of Systems

Integrated large production complexes
- Major source of employment and income in Europe
- Major consumer of energy and raw materials
- Many interconnected production plants that are operated mostly autonomously with distributed management structures

Transportation networks (road, rail, air, maritime, ...)
- Vital to the mobility of EU citizens and the movements of goods
- Large integrated infrastructures with complex interactions, also across national borders
- Involve multiple organizational and political structures

Many more examples, e.g. smart (energy, water, gas, ...) networks, supply chains, or manufacturing

Figure 5: CPS, SoS and CPSoS (Kagermann et al, 2013)

Based on the earlier descriptions of Industrie 4.0 and Industrial Internet, it can be seen that, while referring to the same phenomenon, these two concepts differ in background and focus, Industrial Internet being linked to a "things"–oriented view and Industrie 4.0 to a "system"-based one (see Figure 6). Next, the terminology related to these things and systems will be further elaborated, using smart product (or intelligent product) as a basis.

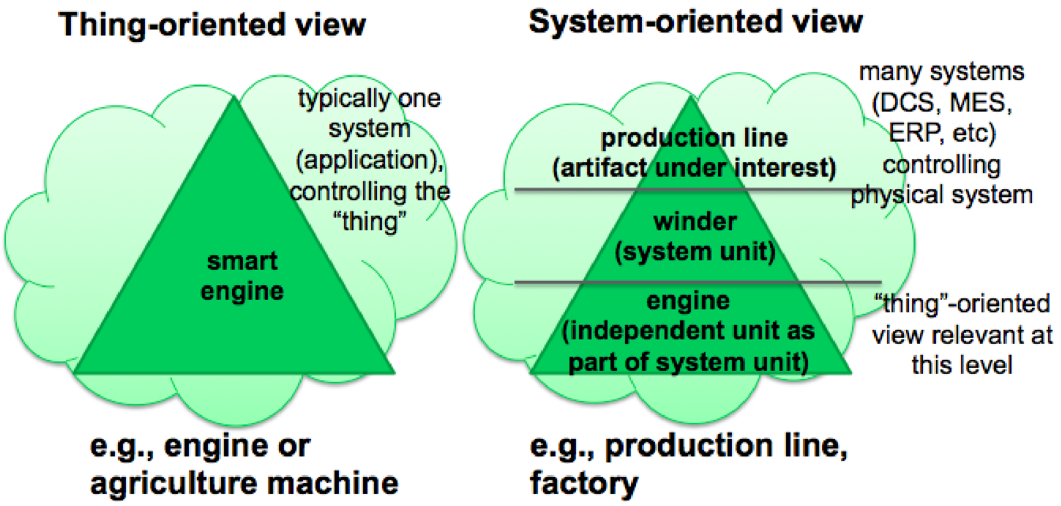


Figure 6: "Thing" vs "system"

3.5.4 Smart or Intelligent products

Zuboff (1988) coined the term "smart machine" over 25 years ago. Smartness in physical products is typically understood as the product's being capable of storing data about itself and participating in decision-making (McFarlane et al., 2003), thus helping reduce the role of humans in physical production.

Intelligent products and smart products are often regarded as synonymous (Meyer et al., 2009). McFarlane et al.'s (2003) definition is used quite often, and, while further developed by Meyer et al. (2009), it suits the purpose here.

> "(i) unique identity, (ii) capable of communicating effectively with its environment, (iii) able to retain or store data about itself, (iv) deploys a language to display its features, production requirements, etc., (v) capable of participating in or making decisions relevant to its own destiny" (McFarlane et al., 2003).

These characteristics resemble to a great extent functionalities of IoT-era smart products. For example, Ala-Risku (2009) and Holmström et al. (2010) have identified having a unique identity as important to delivery of efficient industrial service, but a universally unique identity for connected objects is so far lagging (e.g., Gubbi et al., 2013). Communication with environment could be understood either as M2M (local connectivity), or remote connections in the IoT era. Storage capacity might not any more be regarded as a fundamental requirement, if cloud storage is used, but regardless of the locus of data, storing is what creates the "information intensity" as explained in the earlier section.

The question as to what are the boundaries of "smart" and not "smart" might arise. Porter and Heppelmann (2014) see the ability to store and analyze information as being the basis for classifying a product as smart. This could be questioned in the cloud-centric view of product, especially if products and components are not smart as independent units, but instead communicate sensor data through wires or wireless technology to a central unit making the analysis for the product and sending possibly back instructions for it. This definition would violate what McFarlane et al. (2003) propose, but in practice if the same impact can be achieved with remote control units, this becomes merely a question of semantics rather than a truly relevant issue within Industrie 4.0 development. With that view, any object that has computing power either locally or globally can be classified as smart. An example illustrating the relatively low importance of local computing power as opposed to central unit–enabled smartness comes from process automation. A typical process line is hardwired, and if a component gives information from itself and that information can be used in the same way as for typical smart products, it is de-facto a smart product due to the capabilities of its control system and sensors. Another slightly different case is a distributed process manufacturing unit in, for instance, a mine, with a remote connection and achieving the same level of smartness without wires. However, this is a slightly more theoretical example because typically these units can operate somewhat independently in case of a broken connection, and local or fog computing is an easier way to implement smartness than global smartness.

From OEM's viewpoint what constitutes a product might be a good question. Many production units are assembled from components but might also include such units as engines that other OEMs see as "products" instead of components. And a combination of products might equally well form a construct of a product in the form of a production line. Also components are valuable enough that they have been embedded with sensors and so tracked separately. In Industrial Internet–related papers, this issue is typically not addressed, perhaps based on the Internet of Things–related "object" or "thing" view of smart objects that could be practically anything. However, for OEMs a further classification might prove useful, as otherwise the important difference between a component and a production unit might be lost.

Lee et al. (2014a) divide these into “component”, “machine”, and “production system”. These complex production systems can be referred to as cyber-physical systems, but between component and machine still one additional layer might be needed to avoid confusion between an assembled OEM product and a product consisting of assembled OEM products and components, but still being a single-function “machine”. The latter could be called a “system unit” in the context where that single-function product is still used in immediate conjunction with other units (but that might be sold separately) or simply as “product” when an independent production unit such as an agricultural machine. The former will be termed simply as a “unit” and a single component as a “component”, thus reducing the risk of confusion but not excluding it. Intelligent and smart will therefore be used interchangeably, with “intelligent” being more precisely defined by academics (e.g., McFarlane et al., 2003; Meyer et al., 2009).

The value of Porter and Heppelmann’s (2014) five-stage definition (see Figure 7) of a smart product is acknowledged, but this definition is regarded as too bound to a thing-oriented view of industrial assets to be universally applicable for Industrial Internet and Industrie 4.0. Its “System of Systems” is also confusing with a “Cyber-Physical System of Systems” (CPSoS), the first one referring to software combining data from other software to control a smart product and the latter a complex combination of complex systems. In service oriented architectures, it might be practical for Porter and Heppelmann’s (2014) system for other systems have its own term, but the definition should be kept separate from CPSoS to avoid confusion.

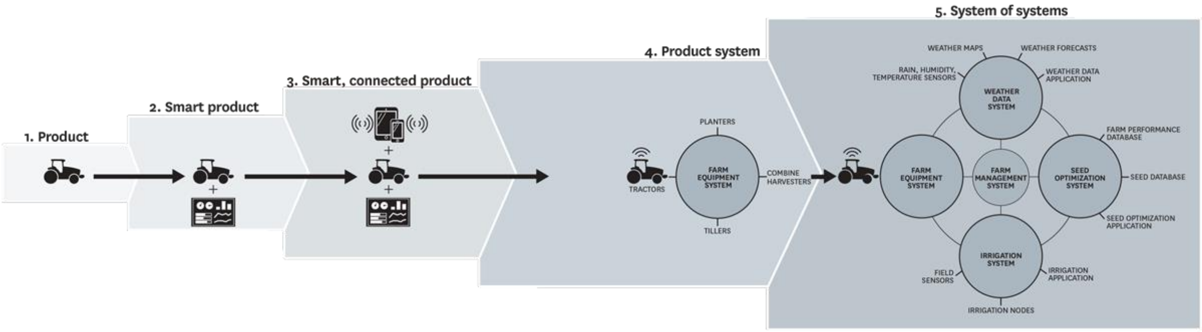


Figure 7 The 5-step classification of smart products of Porter and Heppelmann (2014)

Besides what could be typically understood as a product, also materials can be intelligent and similar to smart products (Hakanen, 2015). Material can be used for components and machine units, but unless it has a specific function and becomes in that way a component, it is an immeasurable unit, forming a base layer of Intelligent Product –taxonomy.

Based on the above descriptions, level of complexity can increase on three axes: (1) complexity of the product as a combination of intelligent units, (2) complexity of control technologies (systems and systems of systems), and (3) complexity by connecting several product-system combinations. While Kagermann et al.'s (2013) definitions match to these three axes quite well (CPS, CPSS and CPSoS, respectively), they start from system level, paying less attention to complexity below CPS-level (e.g., unit, component). Porter and Heppelmann's (2014) shortcomings have been described already above. Reflecting the lack of Industrial Internet benchmark cases, e.g., in process industry in comparison to industrial vehicle fleet management, level of complexity is an interesting topic for further discussion in the empirical portion of the thesis as possibly being a relevant conceptual lens through which to view the role of Industrie 4.0 companies based on value chain type and role in that value chain.

The Figure 8 on the next page integrates the above discussion and develops Figure 6 further, illustrating the abductive reasoning process. First, there are two columns: fleet management (thing-oriented view) and process automation (system-oriented view). Secondly, complexity or component-unit -combinations increases vertically. Where possible, corresponding term such as CPS in the practitioner terminology is applied. The vertical block in both columns illustrates the differing process operation or process optimization system on the background. It is notable that whereas in process automation there is a unified system-level, in fleet management there isn't – all the objects are independent. Only together they form a fleet, but the fleet units can operate independently, in contrast to process line units. Both types (thing-centric and system-centric view) share the last level – system of systems, integrating all operations together. This Figure 8 is a second iteration from Figure 6, and final construct (Figure 18) can be found from Chapter 7.

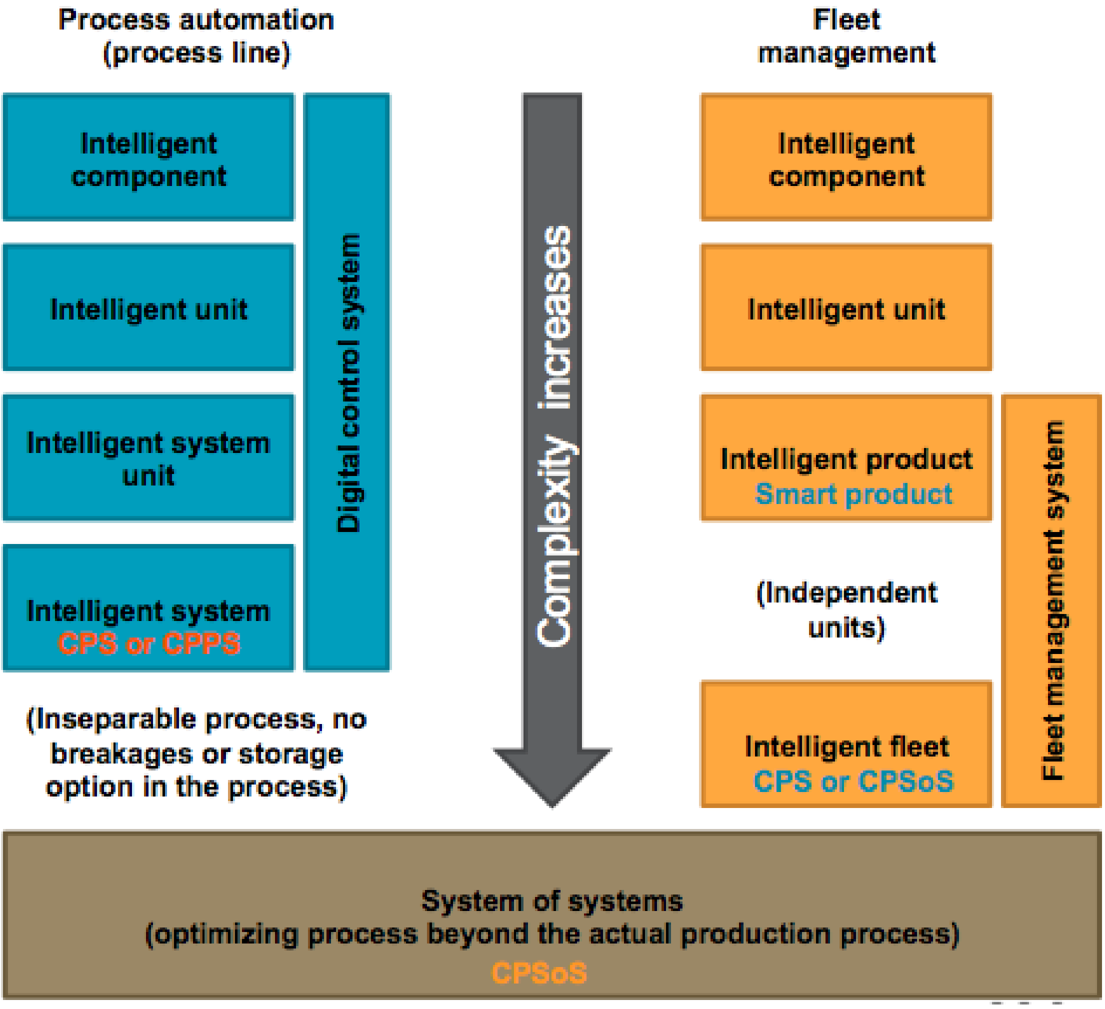


Figure 8: "Thing" vs "system" revised

4 Literature part II: Information intensity in industrial services

Servitization (Vandermerwe & Rada, 1988) literature focuses on the phenomena of companies extending and transitioning their offering from products to services. In industrial services context, another term “services infusion” is also applied (Eloranta & Turunen, 2015) for this phenomenon. Being popular among management scholars and based on strategic management theories, servitization is a good lens to discuss the transformation of capital equipment providers – or original equipment manufacturers (OEM) – during past decades.

Many capital equipment manufacturers have transformed from product-centric to offer increasingly also industrial services for their clients (e.g., Oliva & Kallenberg, 2003; Neely et al., 2011). The rationale for this transition has been explained with different management theories, notably as a response to Porterian market forces (Porter, 1980) or as proactively leveraging company resources (Barney, 1991) to sustain and achieve high profitability (Wise & Baumgartner, 1999).

Strategic management theories, especially those leaning to porterian views, are based on the assumption that competition is ongoing and companies need to strategize to stay ahead competition. Servitization strategy is largely based on the assumption that technology is not a sustainable source of competitive advantage (Eisenhardt & Martin, 2000), but along with the increasing offering of services among OEMs, servitization scholars have started to question its benefits, the debate being referred as services trap or servitization paradox (Brax, 2005; Gebauer et al., 2005; Neely, 2008).

The increasing usage of information in manufacturing has been devoted quite little interest among servitization scholars, most notable discussion being around the use of ICT (e.g., Kowalkowski et al., 2013) and remote monitoring (Grubic, 2014). Rapid development of Internet of Things –paradigm is understandably still too recent a phenomenon to study comprehensively in retrospect, but that should not restrict scholars to explore and discuss the phenomenon as it evolves.

4.1.1 Call for adoption of IoT and information paradigms in servitization

It seems that servitization scholars have been avoiding referring to the mushrooming IoT terminology, or doing it only anecdotally (e.g., Meyer et al., 2009). Instead, implications of increasing information intensity in industrial services have been addressed with more general terminology such as advanced services (e.g., Ulaga & Reinartz, 2011), or referring to the underlying technologies such as RFID-based tracking or remote monitoring (Holmström et al., 2010; Grubic, 2014). The few recent examples connecting servitization to IoT paradigm more concretely use quite selectively IoT terminology, focusing to one or several concepts at a time, like big data (Opresnik & Taisch, 2015) or German Industrie 4.0 and Cyber-Physical Systems (Lee et al., 2014b). These concepts and proposed connections to servitization are relevant, but insufficient alone to be the basis for future studies on digitization in industrial service.

As argued in the section 3.1, IoT paradigm is here to stay, also in industrial context, referred as Industrie 4.0 (Kagermann et al., 2013) or Industrial Internet (e.g., Evans & Annunziata, 2012; Porter & Heppelmann, 2014). Its implications for industrial manufacturers are proposed to be profound; affecting both product- and process-oriented services operations (e.g., Kagermann et al., 2013; WEF, 2015; Maniyka et al., 2015), but the constantly increasing role of information in these processes has yet been barely introduced in servitization context (e.g., Opresnik & Taisch, 2015; Lee et al., 2014b). The lack of shared terminology makes it challenging to integrate the discussion on IoT and servitization to information-age industrial services. Therefore, IoT paradigm should be addressed and reflected also by servitization scholars, getting into dialogue with other management and engineering scholars on this important topic. That way servitization literature can stay relevant within strategic management discourse, and have a meaningful dialogue also with industry professionals. As explained earlier, there is a clear distinction between industrial IoT and other discussion on IoT, suggesting for the distinction also within servitization literature. Here, the viewpoint is the one of OEMs, which are the traditional industrial service providers for manufacturers, studied intensively by service infusion scholars.

Following the logic of competitive forces (Porter, 1980), OEMs face a threat of competition from other OEMs, and with digitization, increasingly also from non-traditional companies (McAfee & Brynjolfsson, 2012). Services’ role as source of differentiation of value offerings (Kohtamäki & Helo, 2015) might not be significant enough to sustain competition or the proposed commoditization of services, whereas capabilities to leverage information may be the next source competitive advantage for OEMs (Opresnik & Taisch, 2015). Increasing intensity of information is the key underlying factor in IoT-paradigm, but rather than radical new phenomenon, information has been increasingly used in manufacturing during past decades or even centuries. Still, recent change has been rapid especially in fleet management (e.g., Sørensen & Bochtis, 2010; Holmström et al., 2010), and starting to affect also process industries (Kagermann et al., 2013). Rather than grounding to Industrial Internet or Industrie 4.0 discussion, this thesis will apply a more general perspective of increasing information intensity in industrial services as a long-term explaining factor for industrial transformation and source of competitive advantage for servitizing OEMs.

4.1.2 Structure of the section

This section will bridge chapter 3 analytical frame of information intensity to various industrial services and link the servitization literature in overall to the phenomenon. Chapter 5 will then move into strategic aspects and implications related to this new information-based view to services. In this chapter, complexity of information usage will be first explained from data source viewpoint. Next, three chapters will discuss role of information using the traditional division into process- and goods-oriented services (e.g., Mathieu, 2001; Oliva & Kallenberg, 2003; Ulaga & Reinartz, 2011), followed by some additional insights on other than these service types. This chapter is quite heavy on technical perspectives, following the recommendation of Grubic (2014) regarding remote monitoring. Manufacturing-related information sources will be covered in more depth due to fewer articles on them in management-type journals, while covering also other industries and giving insights on the technical differences on the background, explaining some sectoral differences on digitization.

4.2 Information intensity in industrial services – specificity of sector and sub-processes

Big data hype has entered into academic papers about industrial companies (e.g., Perrons & Jensen, 2015; Opresnik & Taisch, 2015; Porter and Heppelmann, 2014), applying related frameworks such as 3V (Volume, Variety, Velocity) to explain the changes industrial companies are expected to see with proposed data explosion. Challenge with big data is that it is vaguely defined concept (see Chapter 3), and addresses data intensity-related issues, but not industry evolution in the bigger picture. It also suggests a radical rather than incremental change, but in some sectors and industrial applications this change might be gradual rather than radical., like proposed in Chapter 3. Therefore, 3V (e.g., Perrons & Jensen, 2015) or 5V (e.g., Opresnik & Taisch, 2015) frameworks can be useful, but alone insufficient to ground theoretical basis for the proposed paradigm shift in industrial production to Industrie 4.0.

Rather than being radical leap, this change needs to be understood as a continuum of increasing information intensity.

In Chapter 3 a classification between “things” and “systems” was proposed to achieve conceptual clarity for Internet of Things –related discussion in industrial context (IIoT). Examples of RFID-enabled tracking solutions (e.g., Holmström et al., 2010) and process-automation –related systems (e.g., Kagermann et al., 2013) were introduced. This classification is also a useful lens to explain why various companies in different industrial sectors have adopted and benefitted from information at varying speed. Things-systems –division also resembles the typical product-process –based division of industrial services offering (e.g., Mathieu, 2001; Oliva & Kallenberg, 2003; Ulaga & Reinartz, 2011), further arguing its use in servitization context.

4.2.1 Sources of data

For OEMs, product lifecycle data (e.g., Yang et al., 2009), or installed base data (e.g., Ala-Risku, 2009; Ulaga & Reinartz, 2011) can be a valuable resource. That data includes static data about the product at its beginning-of-life phase such as component information, and dynamic data from its usage and service actions (Allmendinger & Lombreglia, 2005; Yang et al., 2009). Dynamic data from product condition and usage is the most valuable, enabling improvements in asset owner processes, optimizing asset efficiency and lifecycle cost, and in some cases going to downstream to outsourced process operation (Ulaga & Reinartz, 2011). Additionally, this installed base information can be used in R&D (Allmendinger & Lombreglia, 2005) and optimizing internal processes e.g., in service delivery (Ala-Risku, 2007).

Installed base data, despite its importance, is not the only source of information. Process data needs to be combined to installed base data to enable client process-targeted services (Ulaga & Reinartz, 2011). This process data can include e.g., location data (Holmström et al., 2010), process automation data (Kagermann et al., 2013). Outside manufacturing context, increasing opportunities to get value from management information systems data such as Business Intelligence data with big data analytics is one of the most typical sources of value in IoT literature (e.g., Chen et al., 2012; Barton & Court, 2012). When intelligence is brought to the whole production process at manufacturer, covering also supply chain, the futuristic Industrie 4.0 vision is an end-to-end perspective to intelligent Cyber-Physical Systems of Systems (e.g., Kagermann et al., 2013; WEF, 2015). Within servitization literature, these other key data sources besides installed base data have not been paid yet much attention, whereas IoT reports (e.g., Kagermann et al., 2013) see that as an important potential source of value at manufacturers, and examples e.g., from mining (Iansiti & Lakhani, 2014) report from holistic performance improvement efforts. One additional data source that seems to have been neglected is data from Quality Control Systems (QCS), important system supporting client core processes at process manufacturing. The multitude of different systems and their linkages is illustrated e.g., in the Purdue model (Figure 9, ANSI/ISA-95), grey dotted line showing the blurry line between production-related and other external information systems in manufacturing on production planning and management level (Purdue model level 3-4).

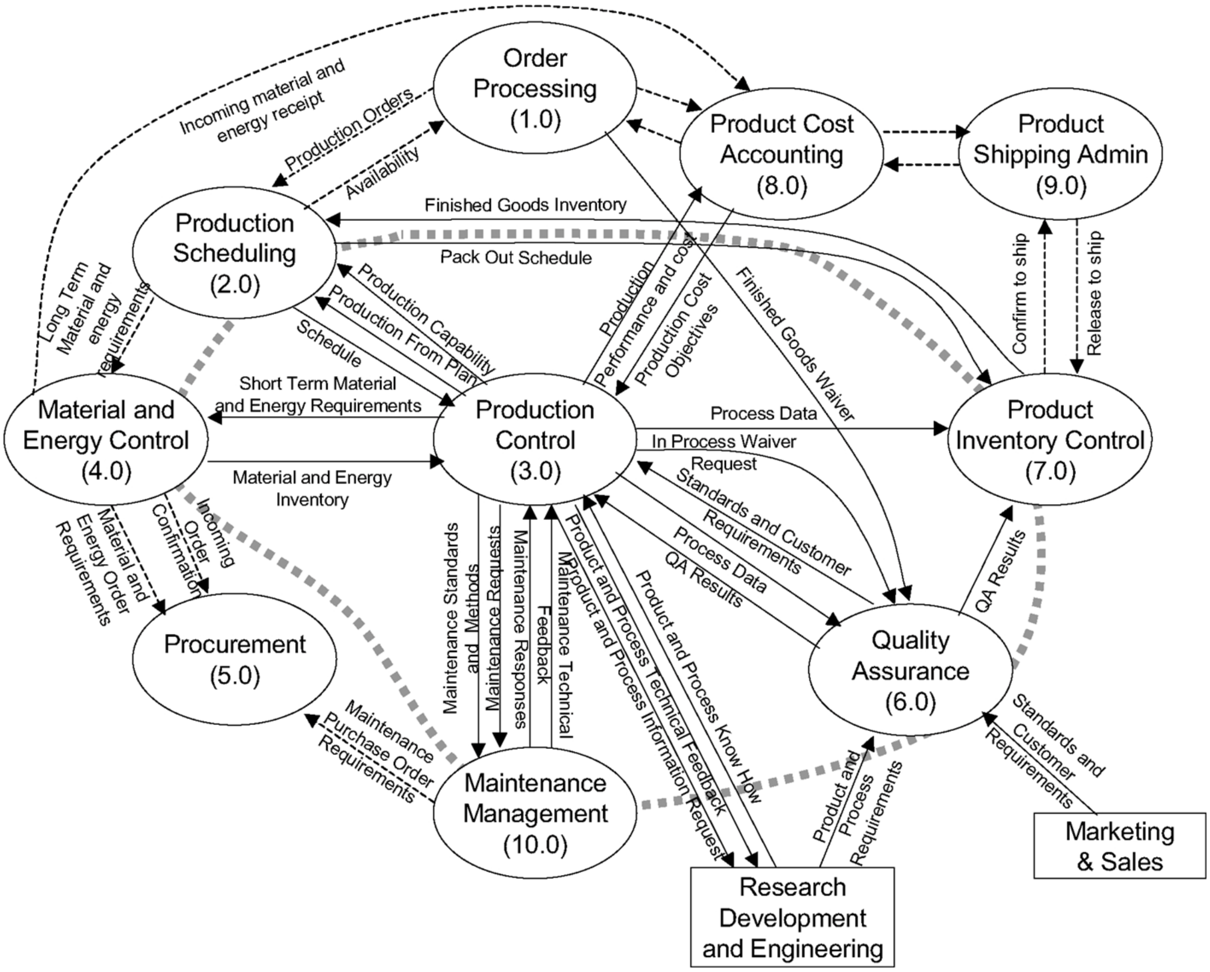


Figure 9: Management-level processes in process automation. Purdue reference model (ANSI/ISA-95)

It has been explained earlier that fleet management of smart products (e.g., Porter & Heppelmann, 2014; Sørensen & Bochtis, 2010) is one of the first widely adopted applications bringing significant new efficiency gains for some industrial sectors. In process manufacturing examples are still scarce, complexity of the systems being the likely explanation.

The complexity in process automation is based on the multitude of different systems, which Purdue Enterprise Reference Architecture (Williams, 1994) helps to link together (Figure 10). Business planning, scheduling, supply chain etc. are managed with enterprise resource planning (ERP) (Level 4), and at factory level, manufacturing execution system (MES) or Manufacturing Operations Management (MOM) system control the detailed production execution. Actual control, supervision and monitoring of the process are conducted with control systems: distributed control system (DCS) and/or Supervisory Control and Data Acquisition (SCADA) system and Human-Machine Interfaces (HMI) (Level 2). Below this are the independent units, having sensors, tags, actuators and Programmable Logic Controllers (PLC), forming the unit-level layer of process automation system (Level 1).

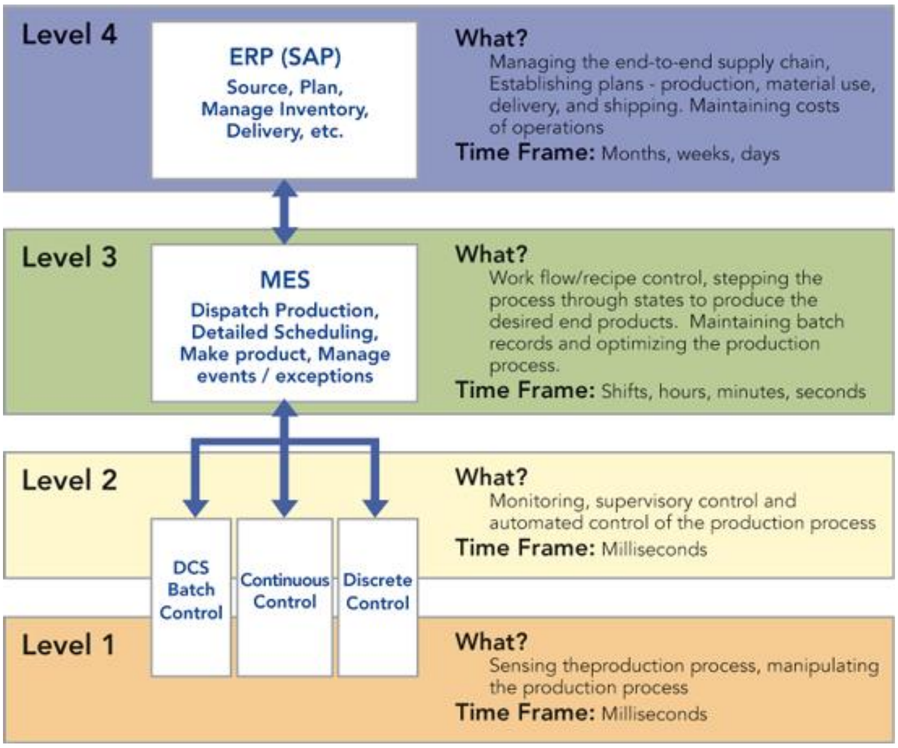


Figure 10: Purdue model (modified) (ANSI/ISA-95)

4.3 Process-related information intensity and services

4.3.1 Information in process automation

Automation systems started to revolutionize process automation from late 1960s when PLCs were introduced (Kagermann et al., 2013) and modern MES, ERP and DCS were increasingly in the late 1990s (Wilbanks, 1996). These modern production facilities with process automation systems were producing already high volumes of data from sensors, but cost and computing power were restricting its storage and use. Information for service operations such as for fault diagnosis in maintenance had been used since the advent of PLCs, but in a very restricted manner, drawing e.g., manually trend lines. Later in the 1990s with DCS and visual interfaces, important process data was accessible and followed constantly by production workers with HMIs, and production planning –related MES was increasingly adopted (Wilbanks, 1996), even though systems did not communicate with each other without high custom integration efforts. Standardization efforts were ongoing, including ANSI/ISA-95 and more recently OPC Unified Architecture (OPC UA), but a widely accepted standard for information is still missing and under development (Harjunkoski & Bauer, 2014).

Multivariate analysis on DCS-based data has been an industry practice since the 1990s (Qin, 2014). Neural networks and artificial intelligence were also adopted (Wilbanks, 1996). Some methods such as principal component analysis (PCA) or partial least squares (PLS) form still the basis for e.g., fault diagnosis, but also more advanced statistical methods have been adopted in process industries (Yu, 2012). Qin (2014) claims that these advanced methods such as machine learning, enabled by big data infrastructure such as Hadoop, represent a step forward in process data usage. This information has been traditionally accessible to servitizing OEMs only when they were involved in the service process, sporadically and either locally or using remote connections.

Remote connections to control-level systems (Level 2 and below) were adopted from the late 1990s, enabling e.g., remote monitoring with real-time information exchange for industrial service providers. Reflecting wireless connection speed and price at that time, remote monitoring was perhaps ahead its time, explaining the challenges of getting value from those systems (Grubic, 2014). Technically efficient remote monitoring –based, predictive solutions have been possible for almost two decades, first successful business cases emerging already a decade ago, such as Rolls-Royces turbines (e.g., Baines et al., 2009). But from client perspective, most “easy” efficiency gains were achieved already with pre-connectivity time systems: Juuso and Lahdelma (2013) report that e.g., in pulp and paper, very high efficiency (>85%) measured by OEE (availability*performance*quality) was reached already by early 2000s. Therefore, real-time information using ICT as enabler for advanced service offering (Kowalkowski et al., 2013) is only a medium, whereas the advanced service offering based on data requires also new analytics capabilities and supporting infrastructure to find new value creation opportunities from higher volume, variety and velocity data.

Process data is not necessarily always high in all dimensions of 3V framework. For example in oil refinement (Perrons & Jensen, 2015) or energy production especially at wind farms has been studied from Big Data perspective (Yin, 2015). These utility-sector processes might be less complex than process automation industries. For example, Moventas, a Finnish wind turbine gearbox producer has been successful in its big data initiatives, expanding from asset performance optimization to offer more process-related solutions covering whole wind farms. It is notable that a wind turbine is quite simple with only a few key units, having smaller veracity and volume than some complex process automation applications. Similar differences can be assumed with e.g., boilers, turbines or engines, which form relative simple entities, enabling simulations of factors such as temperature, pressure and vibration with less complex relations to other process parts, which is not the case in high volume, velocity and veracity process automation. It can be concluded that in utilities, information intensity and its usage have increased significantly during the past decade, but the intensity of information especially from process complexity viewpoint is typically lower than in e.g., process automation.

In geographically distributed, but process-oriented industries such as mining and mineral processing, efficiency gains enabled by remote connections have been much more concrete (Porter & Heppelmann, 2014). While information has been created in high volumes locally, it has not been possible to monitor that and optimize processes in the same way as physically centralized, unified production facility. Also the control systems in use have been slightly different: instead of DCS, location-wise distributed process industries such as mining have favored SCADA. Difference with the systems is that distributed 2nd generation SCADA has been able to store locally information and to operate independently in case of broken connectivity, whereas DCS has been traditionally hardwired (Karnouskos & Colombo, 2011).

That way, remote connectivity of 3rd generation networked SCADA has been bringing only quite recently a centralized real-time access to information from distributed machinery (Karnouskos & Colombo, 2011). It is proposed that the apparent differences in big data analytics adoption between automation process-based industries sectors are based at least partly on the physical distances to production fleet, leading to either distributed and/or centralized control systems, the former benefitting more from the adoption of remote connections.

4.3.2 Logistics as part of industrial process

Agriculture and forestry are examples of industries where human-operated vehicles are important part of the process. Some other industries such as mining employ also a lot of vehicles in the process, but after getting ore to the conveyor belt, focus from optimizing mineral streams from the mine changes to the mineral processing (e.g., Iansiti & Lakhani, 2014). In most industries, vehicles are important in supply chain logistics, but these processes might not be core processes, and outsourced. Like proposed earlier, tracking and management of this production vehicle fleet is a significant source of efficiency gains (e.g., Porter & Heppelmann, 2014), and much more radical than in more process-oriented businesses. Using RFID and GPS, and combined with vehicle data and other sources, operations on the production site can be managed more effectively. So-called precision agriculture (Sørensen & Bochtis, 2010) is a new technology-enabled paradigm in agriculture and other fleet-based production processes, enabling big efficiency gains. Field operation decisions can be done with precision, and drivers be given instructions on the operation of the vehicle with visualized dashboards – direction being in driverless and automated remote control of the fleet (e.g., Iansiti & Lakhani, 2014; Maniyka et al., 2015).

Comparing fleet management –based production processes to automation system –based processes, it is evident that information systems are less complex, layered, and therefore easier to optimize further with new technologies. A farm for instance might have only one central information system (Sørensen & Bochtis, 2010), able to support all core processes. Later phases in the process are also less volatile and complex than e.g., in energy production or paper production. It is useful to recognize that process-related logistics is a distinct function, which benefits highly from remote connections, tracking and GPS, and can be often optimized as a sub-process of production. It is often the key focus of Industrial Internet – discourse alongside with optimization of single units such as turbines (e.g., Porter & Heppelmann, 2014), whereas complex processes are mostly discussed within Industrie 4.0 and Cyber-Physical System context (e.g., Kagermann et al., 2013). Understanding both the role of complexity and specificity of logistics, Industrial Internet or Industrie 4.0 is easier to conceptualize and discuss the opportunities IoT brings for OEMs. OEMs that have published success cases units using IoT are also often other than production-related, like Rolls-Royce’s turbines or Wärtsilä’s engines. Traditional case companies used in Industrial Internet discourse are not necessarily lower information intensity companies, but either the focus is not in process, or the benefits are based in logistics-related optimization. Thus, change has been more radical and opportunities easier to seize because of lower complexity and interrelatedness to other sub-processes being a smaller constraint, like in the case of complex processes.

Continuing with industrial logistics: although supply chain management has been recognized as one of the biggest applications for Internet of Things (e.g., Atzori et al., 2010; Evans & Annunziata, 2012; Maniyka et al., 2015), it is rarely a key process for the clients of OEMs servitizing industrial companies – the focus of this thesis. Transportation vehicles are left out of scope in papers focusing on industrial processes, because they form such a unified group of smart products that are more fruitful to investigate in the context of smart transportation. Logistics in warehouses is also essentially a logistics sector process, although industrial companies might manage these by themselves. Acknowledging that logistics of industrial products benefit the optimization of non-process-related vehicle fleet, from key process viewpoint these are rarely interesting, and can be discussed specifically in logistics context, combining inventory control, smart buildings and fleet optimization (e.g., Atzori et al., 2010). Agriculture, forestry, mining and other production process-related machines are that way different.

One other logistics process that has an important role in the actual production is production-related logistics. Both fixed and fleet-based lifting equipment such as cranes are essential part in e.g., metal production. As a somewhat independent function within the process, these lifting systems have less complex interrelations with other process parts, and are easier to manage independently. For example the Finnish crane producer Konecranes has promoted actively its Industrial Internet strategy. It is proposed that the less a process function is from the main production process, the faster new technologies can be adopted. In the case of cranes used in logistics services, active RFIDs in containers are also likely to be an enabling new technology, providing new sources of relatively low volume information for the production, and thus easier to adapt. The boundaries between goods-oriented asset efficiency services and process-related services are blurry when it comes to information sources used, because traditionally only outsourced operation is seen as a process-related service, although installed base using also process data is essentially process-related. This ambiguity supports integrated solutions -based views to services, although Oliva and Kallenberg’s (2003) point that outsourced operations are distinct from relational goods-based services enforces well the importance of vertical integration for OEMs aiming to build capabilities for high information intense process data.

4.3.3 Synthesis on process-related information intensity

Based on the historical perspectives above, information intensity has been at a high level in process industries for a long time based on sensor output, but practically it has been accessible in scale only very recently with the technical advancement of wireless communications and availability of low-cost storage and computing power (e.g., Maniyka et al., 2015). However, in geographically centralized production, wireless technologies have not restricted process-related data, and OEMs servitizing in those sectors have less opportunities in innovating new valuable process control-related, IoT-enabled applications, as hardwired control systems (DCS) have served that purpose in limited scale already for some time. In geographically distributed processes, opportunities for efficiency gains are much higher, giving room for service and business model innovation. Slowly advancing standardization may slow down development due to high need to customize solutions, although individual OEM units can be brought to service-oriented architecture (SOA)-based IIoT platforms for e.g., energy consumption optimization. In contrast, industrial sectors using intensively human-controlled fleet or other location-based applications, legacy systems are much less restricting and information systems less layered, enabling perhaps highest and easiest productivity gains.

Although the owner of assets – manufacturer – typically controls industrial process, this process related data could be interesting also for capital equipment manufacturers. Outsourcing of fleet management emerges as an industry practice in some sectors, and different goods-related services especially in complex processes benefits from, or even requires process-related data in planning and executing service delivery. That way, also service provider can deliver IoT-enabled higher productivity for the client as part of contracts.

Besides process-focused services, opportunities to leverage information exist also in product-oriented services, and possibly also in completely new areas.

4.3.4 Servitization and opportunities related to process data

Industrial service offering is typically goods-related, only advanced offerings being also process-oriented. Many services are asset efficiency-based, which is shown also in various classifications of service offerings to maturity-like steps, where advanced offering means provision of asset availability, performance or solutions (e.g., Kohtamäki & Helo, 2015; Helander & Möller, 2007; Windahl & Lakemond, 2010; Kindström & Kowalkowski, 2014).

When the viewpoint to service provision is maturity or sophistication, popular among especially hybrid offerings or integrated solutions –related servitization literature, it is challenging to discuss the impact of process data to service provision separately. Therefore the classifications of Oliva & Kallenberg (2003), Mathieu (2001) or Ulaga & Reinartz (2011) are more suitable here, to be linked to hybrid offering or maturity model -based classifications later.

Mathieu's (2001) division to services supporting products (SSP) and customer's process (SSC) is a simple classification, developed further by other servitization academics and used in the few ICT-related servitization papers such as Kowalkowski et al (2013). Oliva & Kallenberg (2003) apply this same logic, and mention process-related services such as outsourced operations and maintenance planning, engineering, R&D, training and consultancy. It is evident that process-related information, accessed also by service provider, is in an important role in the service provision. This is especially the case in expert-knowledge –based transactional services such as consultancy, engineering and R&D, which are likely to often bundled to other service offering (Kowalkowski et al., 2013).

In these services on-demand information analysis capabilities can be assumed to be critical., supporting also Oliva & Kallenberg's (2003) division to relational and transactional services. Traditionally provision of expert services could be explained with the tacit knowledge (e.g., Nonaka & Takeuchi, 1995) service provider's experts accumulate in R&D and when visiting various client sites. However, if the expertise is more based on real-time monitoring of client machines and processes, knowledge becomes codified and explicit. This requires access to process data, which can be more sensitive than e.g., maintenance data, highlighting the role of relationship (e.g., Antioco et al., 2008).

In comparison to maintenance services, which can benefit also from sporadic usage of data for e.g., fault diagnosis, production process is constant, and thus higher in information intensity. Kowalkowski et al (2013) mention the importance of ICT to collect real-time data, but do not elaborate further the technical requirements. Qin (2014) analyses the usage of process data in big data era by using the same 5V model as Opresnik & Taisch (2015), and conclude that recent technological advancement enables more sophisticated usage of process data, in contrast to previous two decades using already multivariate analysis and time series data. To benefit from higher information intensity, companies need a data-centric system architecture, which can also tackle the challenges of multitude of data sources, and which enables high-velocity time series-based analysis of historical and real-time data using machine learning techniques (Qin, 2014).

In consultancy services, big data can be used more sporadically and less investments are required, if client provides access to also historical data. These transactional process services could be sold also separately from goods-based services, but seems to se seldom a practice (Kowalkowski et al., 2013). In relation-base outsourcing services, data access needs to be constant to create value from the high information intensity. This emphasizes further the role of trust and relationship, which Kowalkowski et al (2013) claims to segment clients into those that are possible buyers of process-related services and those that are not. Especially operations outsourcing and full maintenance outsourcing relationship-role can be expected to play a big role. Development of new services and service concepts can be challenging for a sole OEM (e.g., Gebauer et al., 2013), and it is advisable to build a partner network to overcome this challenge (Opresnik & Taisch, 2015) to offer customized solutions for biggest clients (Kowalkowski et al., 2013).

It is proposed that process-related services benefitting from data are the most information intense, and often requiring trust gained from long relationship-based services to gain access to data. To provide transactional professional services, service provider needs to have at least big data processing capabilities, but for outsourcing services especially in production processes, supporting data infrastructure becomes a key asset. Different industrial sectors have different processes and practices, creating various levels of information intensity. Recent technological advances have increased the intensity of practically available process information, but the higher the complexity of process is, the slower is the adoption of analytics capabilities. Separate sub-processes such as process logistics services are also easier to bring to information era in services, both due to lower complexity and different technological basis for change. When sub-process is highly independent and involving only one or few units, the distinction between a process service and goods-based service becomes blurry, this line being clearer when service provider has been outsourced the whole operation of the sub-process. Technologies used in the sector are also a key factor in explaining the adoption. Further empirical evidence will be presented in the empirical part later.

4.4 Industrial goods –oriented services and information intensity

Most servitization or related articles that cover the role of information or information technology focus mostly on goods-related services such as condition-based maintenance (e.g., Kohtamäki & Helo, 2015; Grubic, 2014; Ala-Risku, 2007). Installed base data (e.g., Ala-Risku, 2007) and remote monitoring (e.g., Grubic, 2014) have been dedicated specific academic interest, and some other articles with various research interests contribute to the topic in a more general level (e.g., Oliva & Kallenberg, 2003; Ulaga & Reinartz, 2011; Kohtamäki & Helo, 2015; Kowalkowski et al., 2013; Lee et al., 2014a; Opresnik & Taisch, 2015).

Goods-related services consist essentially of maintenance and repair services, spare parts, and different goods-related improvement projects (Oliva & Kallenberg, 2003). When companies sell uptime or availability instead of maintenance services, these services might be called e.g., service-level agreements or full maintenance contracts (e.g., Gebauer et al., 2010). Despite some embedded consultative elements, these are essentially product availability –related services, and closely related to maintenance. These advanced service concepts will be therefore discussed under section “maintenance”. Other good-related services will be discussed separately.

It has been traditionally recommended that new capital sales projects and after-sales goods-related services would be delivered by a different organization (e.g., Mathieu, 2001; Oliva & Kallenberg, 2003; Gebauer et al., 2010). This seems to be also a practice, and therefore project delivery is typically outside service offering of service units. Artto et al (2014) and Holmström et al (2010) present some perspectives on using information such as tracking in project delivery, a topic left out of the scope there. End-of-life services such as remanufacturing or recycling (e.g., Gaiardelli et al., 2011) are other distinct non-aftermarket services that could benefit from installed base data, but no articles discussing the role of information in end-of-life industrial services could be identified. With the increased interest in environmental issues, remanufacturing and disposal services might be fruitful topics also in servitization literature in the future.

4.4.1 Maintenance

Maintenance or MRO (Maintenance, Repair and Operations; or Maintenance, Repair and Overhaul) is one of the most typically mentioned industrial services, where information on devices and their maintenance history, and usage-related data from devices and environment are claimed to create value (e.g., McKinsey 2015; Kagermann et al., 2013; WEF, 2015). Improving uptime by minimizing downtime is often a key target, and a critical success factor for manufacturers (Armistead and Clark, 1991). Studied by servitization scholars as a part of service offering, MRO services are often described on a more technical and practical level in engineering literature (e.g., Juuso & Lahdelma, 2013; Lee et al., 2014a). These articles give more depth to an interested reader to complement the less technical servitization literature on the role of information in maintenance.

Practitioners and academics make typically a distinction of 3-4 maintenance strategies, and the more sophisticated the strategy is, the bigger role information has in them.

Low information intensity maintenance strategies:

The most cost-conscious maintenance strategy is reactive maintenance (Swanson, 2001), called also run-to-failure (Tsang, 2002), or corrective maintenance (Maintworld, 2014), aiming to minimize maintenance costs by running machine without special focus on preventing failures. Reactive maintenance by definition requires minimal information handling such as physical maintenance manuals (Jonsson, 2006), and focuses in replacing broken items after failure.

When aiming to reduce unplanned downtime, so-called preventive maintenance is a maintenance strategy leaning in a logic of making scheduled replacements of parts (Tsang, 2002; Maintworld, 2014), but without necessarily knowing the exact condition of an individual machine. It involves replacements of parts on fixed schedule, causing higher spare parts costs. Juuso & Lahdelma (2013) note that this approach was adopted already in the 1940s and developed further in Japan in the 1970s as Total Process Management (TPM), related to Total Quality Management (TQM), a central concept in operations management literature.

In comparison to reactive maintenance, preventive maintenance requires a database of machine types in use to create a schedule for parts replacements, but does not require identifiability of individual units, typical to condition-based maintenance (Juuso & Lahdelma, 2013; Holmström et al., 2010). It is noteworthy that identifiability might not be a trivial challenge in some manufacturing industries, although its importance in manufacturing services was recognized already in 1988 by Ives and Vitale. Production equipment can be several decades old, older than RFID technology, alternative options including e.g., barcodes, and installed base information might not be complete or faultless. Information used for preventive maintenance can thus rely largely on customer-owned information, often faulty and causing challenges for service delivery (Sampson & Froehle, 2006).

Simple logic suggests that richer and more reliable information on machines enables more efficient delivery of industrial services. Professionals and academics also acknowledge this logic, its internal benefits, and have discussed and studied higher-value maintenance strategies under concepts such as remote monitoring or condition-based maintenance at least for a decade (e.g., Oliva & Kallenberg; Lee et al., 2006). However, despite the hype and documented potential benefits, reactive and preventive maintenance might remain popular maintenance strategies in some industries for long. Holmberg et al (2013) note that despite the unpredictable downtime caused by failures, reactive maintenance can be the most cost-efficient maintenance strategy for an average paper machine. Only in some critical components a more advanced maintenance strategy might be chosen (ibid). Westergren (2011) point also out that there might be skepticism towards new technologies in businesses, which have traditionally relied on highly specialized expertise. As a consequence, benefits from higher information intensity in maintenance services can vary across industries, being bound by installed base and sector-related business characteristics.

High information intensity maintenance strategies:

Condition-based maintenance (CBM) is a maintenance strategy to prevent failures by monitoring the condition of machines and acting based on this information before a failure takes place (e.g., Lee et al., 2006; Maintworld, 2014; Juuso & Lahdelma, 2013; Maniyka et al., 2015). It is therefore an advanced maintenance strategy, relying heavily on information, and enabling different higher-value services and output-based business models such as promising asset availability (Ulaga & Reinartz, 2011).

Referred often as CBM within industry professionals, also other related or synonymous terms exist. Within servitization context CBM is often referred with closely related concepts such as remote monitoring (e.g., Westergren, 2011), remote diagnostics (e.g., Brax & Jonsson, 2009) or smart services (e.g., Allmendinger & Lombreglia, 2005). Some earlier papers do not define the concept at all (e.g., Wise & Baumgartner, 1999). Lee (1998) is one of the first to describe remote monitoring, naming it “teleservices”. Another author, Jay Lee has been publishing several industrial services-related papers from technical point-of-view in engineering journals, sometimes referring also to servitization literature. The author has used or introduced terms such as ”e-maintenance”, ”prognostics” or ”Prognostics and Health

Management" (e.g., Lee et al., 2006; Lee et al., 2014a). Besides CBM and remote monitoring, predictive maintenance is an important and increasingly used term (e.g., WEF, 2015; Maniyka et al., 2015; Lee et al., 2014b; Neff et al., 2014; Colombo et al., 2014; Holmberg et al., 2013; Maintworld, 2014), although not yet adopted in servitization discourse.

Variety of terms addressing the same phenomena of advanced maintenance services benefitting from data makes it challenging to consolidate discussion. Sometimes terms are used interchangeably, sometimes not. For example, Maniyka et al (2015) make a distinction between predictive maintenance and condition-based maintenance, understanding CBM as a more advanced approach using e.g., benchmarking data, but this distinction does not appear in the academic articles covered in this study. Perhaps to avoid the extinction of some hype terms, servitization literature often refers to services provision more generally such as based on sophistication "base, intermediate and advanced services" (Ulaga & Reinartz, 2011) or from business model perspective such as "full maintenance contracts" or "service-level agreements on maintenance" (Gebauer et al., 2010).

Understanding context and background of the terms could help the dialogue between terms and discussants, similarly to Industrie 4.0 and Industrial Internet –related terminology. For example, within data science and analytics, predictive maintenance can be understood as the application of big data for predictive analytics (e.g., Waller & Fawcett, 2013), thus based on the underlying analytics technology helping in prevention of failures. Remote monitoring and remote diagnostics is another example, popular and even hyped especially during early 2000s (e.g., Jonsson, 2006), enabled by the new connectivity (Grubic, 2014), resulting in "smartness" of products (e.g., Meyer et al., 2009; Porter & Heppelmann, 2014).

To bring clarity to the terminology and conceptualize information intensive maintenance services, technical aspects and discussion on intelligent products and cyber-physical systems (CPS) need to be considered.

First, identification of individual machines is important for efficient service provision (Ives & Vitale, 1988; Juuso & Lahdelma, 2013; Holmström et al., 2010), reducing reliability of client-based possibly faulty information (Sampson & Froehle, 2006), if combined with sensor data to form an installed base database (Ulaga & Reinartz, 2011). Linkages to company information systems (IS) such as ERP or maintenance systems increase opportunities for more efficient maintenance (Ala-Risku, 2007). When information is transferred with wireless communication (WSN) technologies, remote monitoring becomes possible and giving opportunity for real-time information e.g., on the status of the machine (e.g., Jonsson, 2006; Ala-Risku, 2007). If contracts and technical systems enable loading history data locally or remotely for root cause analysis, data can be gathered also for R&D purposes. These form the basis for condition-based maintenance with quite minimal and sporadically transferred data. Additionally, if these findings are systematically used for evaluating e.g., spare parts investments for lower downtime, a fourth maintenance strategy, pro-active maintenance strategy (Maintworld, 2014) or aggressive maintenance strategy (Swanson, 2001), is sometimes distinguished.

Thus, there seems to be several technical elements characterizing maintenance offering type. First, installed base information should at the basic level include item, event and location data as proposed by Ala-Risku (2009), and opportunities to access sensor data at the field. Analytics capabilities using traditional multivariate models with sporadically loaded data from faulty units is the basis for preventive and even proactive maintenance. With remote connections, condition-based monitoring and prognostics at a basic level becomes feasible, but velocity and volume of data is a constraint. More advanced condition-based monitoring requires linkages to high-volume process data and other data sources, supporting technical infrastructure for storage, communication and processing of data, and advanced analytics capabilities using machine learning techniques. To manage transferred data volumes, local computing or fog computing is required, to enable so-called self-maintenance (Lee et al., 2014a), data transfer being used on high velocity only in pre-defined cases of exceeding certain reference values. At the advanced level, these smart products or systems can be referred as Cyber-Physical Systems or Intelligent Products, the former being advisable when multiple units are closely interrelated and forming a system. Figure 11 classifies the above into three categories: basic, modern maintenance –enabling sources, remote monitoring as a separate element (not necessarily required at factories), and services requiring higher capabilities for information usage, such as condition-based monitoring.

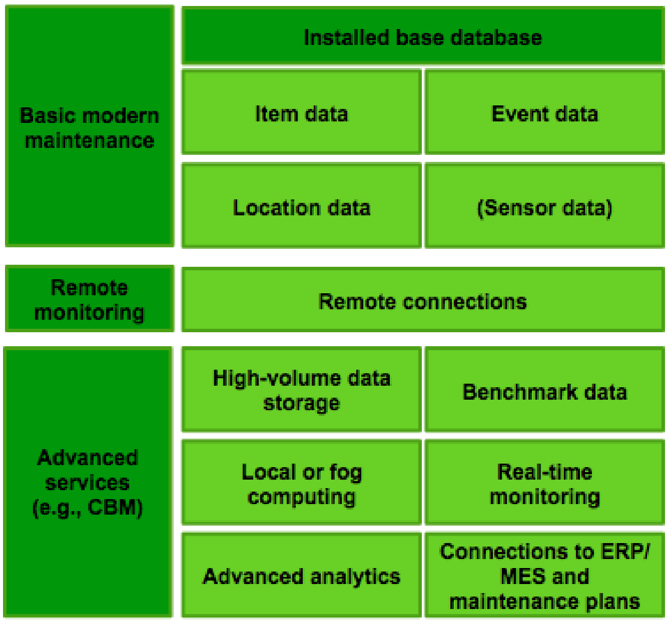


Figure 11: Elements of advanced industrial service provision

Capabilities to cope with high information intensity form the basis for advanced services such as condition-based maintenance, but also for other business models providing availability or performance.

Companies like Wärtsilä (Tivi, 2015) and Rolls Royce (e.g., Kohtamäki & Helo, 2015) have been using analytics in their service provision, in the case of Wärtsilä for about 15 years, but only in small scale (Tivi, 2015). In the case of performance-creating independent units such as generators and turbines outside manufacturing context it is questionable whether these cases should be seen as process or goods-related. From industrial asset management perspectives, they fit under goods, although discussed already in previous section. Reflecting the small scale of predictive analytics and remote monitoring usage, and the ambitious digitization strategies for example Wärtsilä has published (Wärtsilä, 2015), change seems to be still ahead. A possible explanation for the very limited usage of remote connections for maintenance comes from Kowalkowski et al (2013) with the notion that industrial service providers have been developing goods-oriented services often based on what is possible rather than actual needs. However, this is a basic dilemma with being a forerunner, and the same phenomena of limited roll-out of these services has been based both to technological challenges and being ahead of time.

It was proposed in the part 4.3 that information has been the key enabler for OEE increase and that after reaching very high OEE levels, further increases become increasingly difficult or costly. Wang et al (2011) (See Figure 12) have made similar suggestions in maintenance context: maintenance efficiency increases rapidly when moving from reactive to preventive and predictive maintenance. But with more sophisticated methods, the marginal utility seems to decrease. Therefore, maintenance excellence – achieved with high information intensity – might not always be a target in industrial companies, especially when benefits are hard to quantify or when very high asset availability is not required due to overcapacity.

.

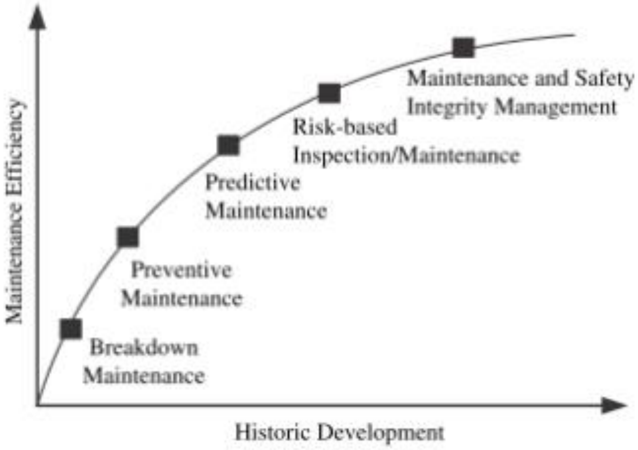


Figure 12: Maintenance models and their corresponding efficiency (Wang et al., 2011)

4.4.2 Information in other goods-related services

Besides maintenance services, goods-oriented industrial services include spare and wear part services, inspections and diagnostics, help desk services and end-of-life services among others (e.g., Oliva & Kallenberg, 2003). Out of these spare parts and wear parts are among the most important financially, and identified as a potential target for advanced analytics in predicting failures and creating thus value creation opportunities (Lee et al., 2014a). Difference between spare part and wear part is that wear parts are industrial consumables with shorter lifetime than spare parts, which have more specific, machine function related role, in comparison to e.g., belts and fabrics as wear parts. Spare parts could be also classified into parts that typically need to be changed at some point or interval, and parts that are supposed to last over the whole lifetime, but might accidentally break.

Operations management academics have been interested in demand forecasting, inventory and availability of spare parts (Ala-Risku, 2009). With installed base data, spare parts providers can allocate their inventory better and avoid sending wrong parts (ibid). In contrast, servitization literature rarely devotes much interest in spare parts services. They are often classified as “basic services” (e.g., Ulaga & Reinartz, 2011) and core of least advanced, after-sales service offering (e.g., Kohtamäki & Helo, 2015) that form the basis of service offering for customers having an in-house service provision strategy (“customers who want to do it themselves”), merely just buying spare parts outside (Baines & Lightfoot, 2013). However, as separate components they might be among the first to be included in Industrial Internet –type services benefitting from advanced analytics, and should be devoted more space and interest by servitization scholars.

In industries where lifecycles are long, some spare parts might become obsolete, or finding the correct spare part might be difficult. Traditionally customers might have simply called help desk of companies to place an order, but after adoption of electronic procurement at the turn of 2000s (Kaplan & Sawhney, 2000), procurement of also spare parts has been done increasingly online. Regardless of the relatively long existence of e-procurement, Witell et al (2014) note that e.g., paper industry has had challenges in adopting e-procurement. Indeed, it seems that industrial companies have introduced modern information systems to support spare parts quite late when compared to many consumer-centric companies, +1 billion euro turnover OEMs like Valmet launching their own eCommerce spare part platforms only in 2014, and Konecranes still developing their service. Therefore it can be concluded that the identification, sales and delivery of spare parts and wear parts benefitting from installed base information and Internet is still relatively new for industrial service providers, despite its low information intensity. ECommerce platforms also serve companies especially with low information intensity maintenance strategies (reactive and preventive).

When sensor data is used to predict a failure, this approach can be called as “predictive” (Holmberg et al., 2013) or “prognostic”, whereas after-event analysis is diagnostic (Lee et al., 2014a, see Figure 13). This logic applies to spare parts, wear parts, maintenance and other services. This approach requires much higher information intensity, using sensor-based information for condition monitoring and modeling the degradation. Modeling can be done on-site or using remote connections, which supports complete outsourcing solutions of condition-based maintenance. Predictive analytics helps achieving higher reliability and longer product lifetime, but involves also investments in technology (Holmberg et al., 2013). Therefore, a hybrid maintenance strategy might be applied, using predictive analytics only for some components such as roll bearings (ibid), optimizing spare parts costs in the highest-value or most critical components. Companies that offer complete outsourcing solutions or

Total Cost of Ownership of spare parts management might have also interest in re-designing components (Kim et al., 2007).

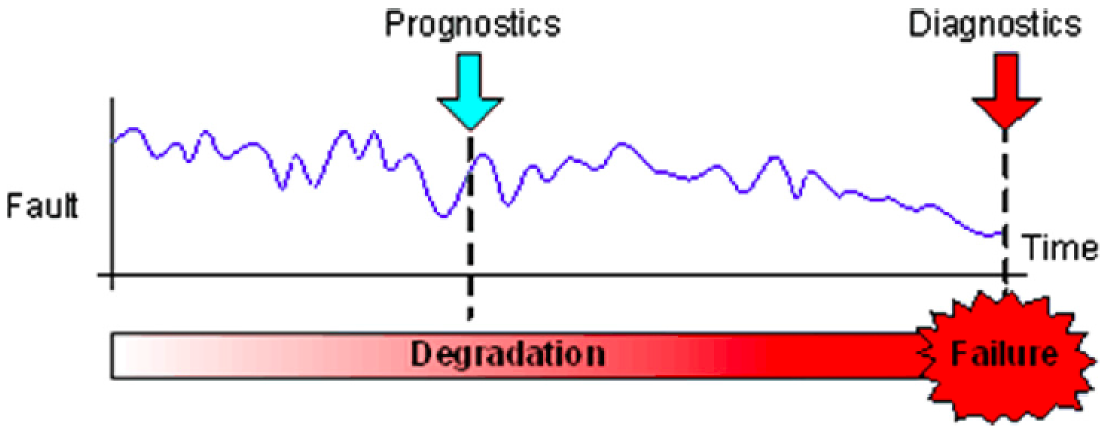


Figure 13: Difference of diagnostics and prognostics (Lee et al., 2014a)

Manufacturing capital equipment includes components coming from different supplier, and besides OEMs and systems integrators, also distributors are selling spare and wear parts. Therefore it is not necessarily the large OEM that provides complete production, which controls the sales, but also distributor, competing OEM or even counterfeit producer of spare parts that can seize the opportunity of predictive spare parts analysis. Suppliers of generators other components like Siemens have formed partnerships with IoT-platform providers, raising questions of platform competition (e.g., Eisenmann et al., 2006), enforcing the importance of full service contracts protecting OEMs from commoditization of even advanced fleet-related services.

Some other interesting perspectives to spare parts include 3D manufacturing and sustainability, both leveraged by information intensity. 3D printing of spare parts has been much hyped, improving availability and reducing downtime, but their reliability is still a challenge (Maniyka et al., 2015). Instead of selling physical spare parts, OEMs could simply sell licensed CAD-models, thus information.

Information intensity in spare part services has seen to a big extent the same development path as maintenance, explained in previous section. But when compared to condition monitoring of whole units, spare part condition monitoring is much simpler, focusing only on the condition of the component (Lee et al., 2014a) instead of including various other data sources and their interrelations in the analysis. Another opportunity in spare parts services is sales of refurbished or remanufactured components, traditional for automotive industry, and adopted already by industrial vehicle providers such as Volvo (Gaiardelli et al., 2011), John Deere and Ponsse.

Other goods-related services such as improvements and help desk services are closely related to spare parts and maintenance service provision. A proactive maintenance strategy may lead to decisions to improve a product, and many help desk services can become obsolete or be digitalized with eServices platforms. Highly specialized experts having tacit knowledge can become more reachable with tablets (WEF, 2015), and increased usage of advanced analytics may help codifying this tacit knowledge, reducing dependence on individual experts. Internal benefits from using installed base data can also be important, including service opportunity identification and quality control besides inventory and service delivery optimization (Ala-Risku, 2009).

4.5 Information as a service in manufacturing

Real-time data can provide opportunities for improving existing services or developing new services (Kowalkowski et al., 2013; Opresnik & Taisch, 2015). The line between an improved and new service can be grey, and depends on the perspective; companies transitioning to advanced service offerings are not necessarily innovating completely new services but adopting business models from their competitors or adjacent industries. Still, from OEM perspective the development of new offering together with client and the debundling that into separately sold services is new service development (Kowalkowski et al., 2013). An example of this is Wärtsilä possibly providing “megawatts instead of products” (Tivi, 2015) – new service model for the company, but existing e.g., at Rolls Royce’s as “power-by-the-hour” (e.g., Kohtamäki & Helo, 2015). Therefore, these models of selling “desired outcome” (Lightfoot et al., 2013) will be discussed in the next section, integrating these different perspectives to existing service offering frameworks.

However, the space of business models around asset efficiency services has room for service innovation beyond existing cases (WEF, 2015; Maniyka et al., 2015). For example self-maintaining and self-aware systems (Lee et al., 2014a), which when combined, have been proposed to form autonomous systems or Cyber-Physical Systems of Systems (Kagermann et al., 2013; WEF, 2015), a future vision that blurs firm boundaries firms due to digitization (Tilson et al., 2010) and may create needs for new services and business models.

One distinct service opportunity beyond industrial goods and processes is information, although in value this opportunity is likely to be quite limited. For example, a Finnish OEM producing weather information producing equipment has been rolling out a service of ready weather-data provision instead of simply delivering and maintaining the equipment, sales of the new service concept exceeding already 5% of turnover (Lano, 2015). This information-as-a-service business model (Delen & Demirkan, 2013) is an intriguing example, but is likely to be limited in the potential. The case example OEM is essentially in a business where information is the desired output from the devices, whereas typical manufacturing produces physical goods. From that perspective, weather data measuring equipment providers such as Vaisala are offering a solution of outsourced operations of their OEM devices, a process delegation service (Ulaga & Reinartz, 2011), when looked from servitization perspective.

When information is not the primary output of the value chain, pure information services can represent real services offering expansion out from goods-process space. Opresnik and Taisch (2015) propose that usage information, especially if behavioral., might have value for marketing agencies, and manufacturers could profit from selling this data, known as a data-as-a-service business model (Delen & Demirkan, 2013). Another example related to data usage and management can be built from the Siemens-SAP deal of building an IoT platform based on Siemens products; the alliance could charge other OEMs or manufacturers from the collected data in various ways, such as raw data, information, or even offering analytics services (Delen & Demirkan, 2013) if other companies adopt the platform for other data sources.

Another information-based service could be 3D printing enabled. Instead of delivering an OEM-produced spare part, client can already today print metal components based on CAD drawings, offering an alternative, information-based service for OEMs (Maniyka et al., 2015). Reliability of 3D printed components in manufacturing environments be a challenge, although the techniques have improved over time. When supplier sells these CAD models for OEMs R&D, they fall under consultative R&D services, but if supplier spare part CAD models are distributed over larger OEM or distributor portal, the end usage for on-site 3D production defines it as information-based spare part service.

5 Literature part III: Towards service offerings and service strategy

5.1 Advanced service offerings and information intensity

The previous chapter gave an evolutionary perspective for goods-, services-, and information-related industrial services. It was found that while process data and installed base data have been used in some forms for decades, the past decades with modern control systems, remote monitoring, and advanced analytics have opened up further opportunities for advanced service provisions. The role of information in advanced service provisions seems important. Servitization literature has proposed various categorizations of services offerings, and many of the more recent examples such as Ulaga and Reinartz (2011) or Kohtamäki and Helo (2015) conceptualize different availability and performance-based offerings, which are to a large extent enabled by information processing capabilities. It seems meaningful to reflect the relation of information to these categorizations, which also provides an opportunity to discuss other strategic viewpoints related to the role and position of OEM based on its offering.

Industrial service provider’s most basic services have traditionally been seen to include, e.g., spare parts provision and reactive maintenance service provision (e.g., Oliva & Kallenberg, 2003). These after-sales services are of low information intensity, benefitting but not requiring systematic installed base data collection and requiring only basic multivariate analysis in possible failure root cause analysis. Transactional services such as help desks could be included in the same category, and with installations project delivery, further capabilities are not required but would be beneficial for service delivery efficiency (Artto et al., 2014). Baines & Lightfoot (2013) do not include, however, maintenance services in their product provision-directed definition of base services, likewise also Neff et al. (2014). This view is well founded, because maintenance services require specific competencies of service providers, typically tacit expert information. Still, expert knowledge if in tacit form does not require additional codified databases, and if the aim is simple categorization, these can be bundled together. Kohtamäki and Helo (2015) call this first evolutionary phase the “equipment provider” phase in their recent paper, being in line with earlier views.

In previous sections, preventive maintenance was also argued to belong under a lower information intensity category. In contrast to the most basic services, it requires installed base data including that concerning item, location, and installation time event (Ala-Risku, 2009), although if restricted to only certain key components, it might be possible to be run on tacit expert knowledge. Practiced by a client, service offering would not differ from basic spare parts provision, but if managed by a service provider, it could be seen as a solution offering (e.g., Kohtamäki & Helo, 2015), approaching availability-based solutions (e.g., Helander & Möller, 2007; Windahl & Lakemond, 2010; Kindström & Kowalkowski, 2014). A vendor-managed inventory and preventive maintenance model is still facilitated with ERP-type information, which does not require high volumes or velocity of data and thus should be seen as a low information intensity service offering level.

An availability-based services model can be based on these databases, if machine status data is gathered simultaneously. It incentivizes OEM to use failure-based analysis results in their R&D (e.g., Allmendinger & Lombreglia, 2005), and in the cases of combining different data sources for this analysis, information intensity grows higher, and specific capabilities and possibly technologies are required for the processing. That sporadic, on-site analysis could be termed the first step in high information intensity capabilities and offerings. However, it is a good question whether this kind of advanced analytics can be sold as a stand-alone service or not. This is the capability point where categorizations start to vary from one another.

If these information-processing capabilities are leveraged and a condition-based monitoring (CBM) maintenance model is offered, some start to categorize that as the next maturity level. Neff et al. (2014) categorize this separately from lower reactive maintenance and the two higher maturity levels simply as CBM. For Kohtamäki & Helo (2015), that could be either the solution provider or performance provider role, the key variable being the business model being used. Availability-based business models (e.g., Helander & Möller, 2007; Windahl & Lakemond, 2010; Kindström & Kowalkowski, 2014) become easier if condition monitoring is applied. There are several variables explaining differing views. Firstly, CBM can be offered at a client site without remote connections, although this is often seen as a requisite (e.g., Neff et al., 2014; Grubic, 2014), possibly due to the role of remote monitoring as a target phenomenon in several servitization-related studies (Grubic, 2014). Organization of process manufacturing as a (centralized) production line was proposed as an example of on-site CBM. When the production site is large enough to support a full maintenance outsourcing solution provision at least in some important components with field service personnel, remote connection is not a necessity for advanced solution provision. And if machinery uptime is the principal element in performance provision, an advanced offering can be achieved locally, with somewhat high information processing.

The volume and velocity of data can vary a great deal, however. Lee et al. (2014a) (See Figure 14) use the earlier discussed classification of “thing” and “system” in their categorization of factory service operations, reflecting differences in components, machines, and production systems in advanced factories. Single components can be analyzed to a large extent separately without production-related data. The authors make a distinction between fault detection and self-aware components, the latter requiring embedded intelligence either in the component itself or through real-time monitoring of condition. It could be seen that predictive models applied for spare parts lifetime prediction, when combined with maintenance plans, represent the first Industrial Internet solutions using high volume data. This sort of optimization can be seen as an availability rather than a performance provision (Lee et al., 2014a; Kohtamäki & Helo, 2015), because single components do not typically have a performance output but are merely cost components. State-of-the-art examples of real-time monitoring and solution offering for single machines such as turbines at Rolls-Royce (Porter & Heppelmann, 2014) or production vehicles (Iansiti & Lakhani, 2014) enable client-relevant performance or productivity provision as noted also by Lee et al. (2014a), but in larger production facilities it might be challenging to operate a single unit. Although Porter and Heppelmann (2014) call fleet management systems combining different fleet operations optimization information as System of Systems, that is still rather simple machine-related optimization, and forming an advanced service instead of their product-centric view only when outsourcing also the operations with own service personnel, or automating them. In any case, machine-level performance provision fulfills definitions of highest level of solution provision of most authors (e.g., Porter & Heppelmann, 2014; Kohtamäki & Helo, 2015; Baines & Lightfoot, 2013; Kindström & Kowalkowski, 2014).

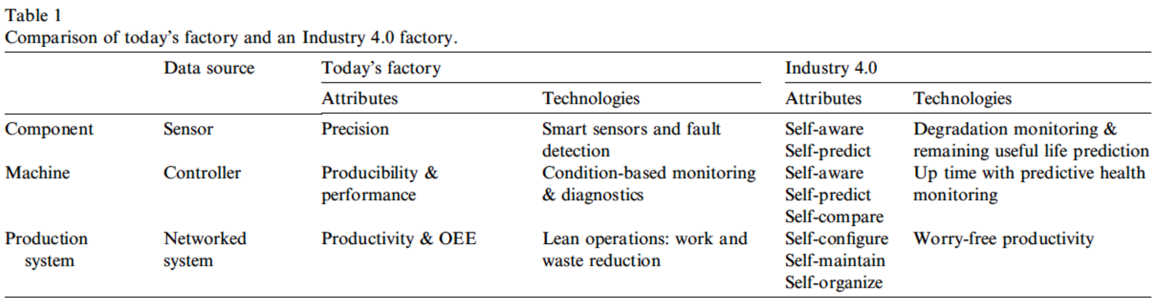


Table 1
Comparison of today’s factory and an Industry 4.0 factory.

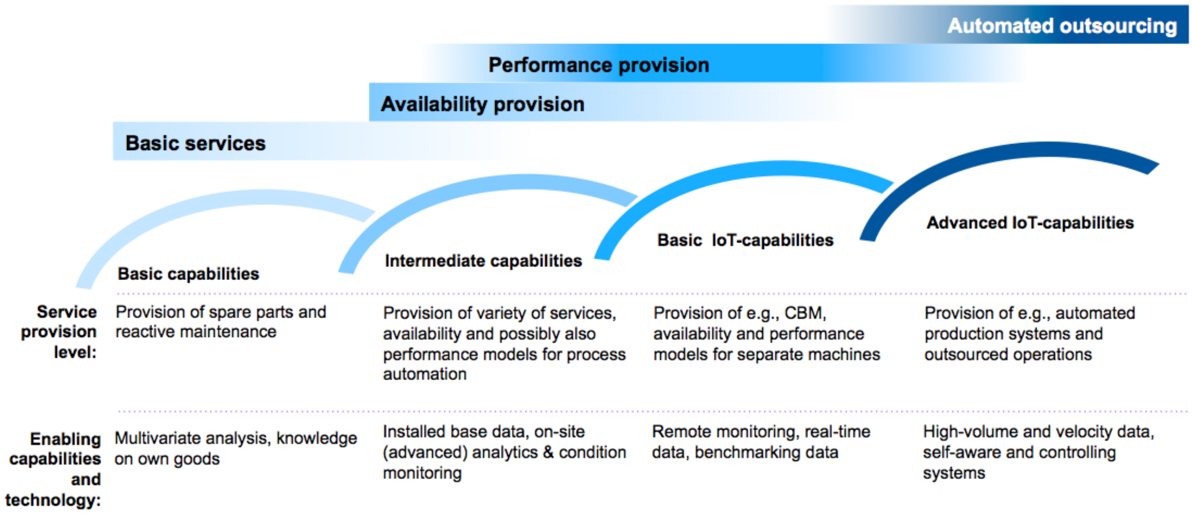
	Data source	Today’s factory		Industry 4.0	
		Attributes	Technologies	Attributes	Technologies
Component	Sensor	Precision	Smart sensors and fault detection	Self-aware Self-predict	Degradation monitoring & remaining useful life prediction
Machine	Controller	Producibility & performance	Condition-based monitoring & diagnostics	Self-aware Self-predict Self-compare	Up time with predictive health monitoring
Production system	Networked system	Productivity & OEE	Lean operations: work and waste reduction	Self-configure Self-maintain Self-organize	Worry-free productivity

Figure 14: Complexity of unit in Industry 4.0 (Lee et al., 2014a)

The viewpoint most servitization-relevant and even Industrial Internet articles miss is the additional complexity level of using process information in highly complex production systems. Lee et al (2014a) is a counter-example for this, and similar could be said from utilities-related cases (e.g., Perrons & Jensen, 2015). Solutions provision using real-time, high volume process data requires integration of multiple systems, which is still mostly visionary (e.g., Kagermann et al., 2013). In these advanced visions, the systems integrator role is likely to become more important for servitizing OEMs if the wish is to offer high-value integrated solutions. Complex but even self-maintaining cyber-physical (production) systems may require a network of service provider partners, making also information-based services relevant for suppliers or competitors. Even more likely this is in the German visions of cyber-physical system of systems, extending work site and process line operations focus to additional processes such as logistics, resulting in an “end-to-end” perspective for business processes in manufacturing.

Automation systems also play an important role in building these intelligent processes, and know-how on them might become an increasingly important competence for OEMs. Know-how and information analysis capabilities, when higher at OEM than at client, might also increase process outsourcing in various industries: core competence definitions may change and starting from separate and business-wise peripheral process parts, OEMs may be able to expand vertically downwards to client processes. This could be called automated outsourced.

Integrating these different views (Figure 15), information becomes an interesting lens through which to view a service offering provision. While Neff et al. (2014) provide a well-thought-out maturity model reflecting underlying technologies, it has its shortcomings, e.g., not reflecting specificities of on-site, sophisticated services.



	Basic capabilities	Intermediate capabilities	Basic IoT-capabilities	Advanced IoT-capabilities
Service provision level:	Provision of spare parts and reactive maintenance	Provision of variety of services, availability and possibly also performance models for process automation	Provision of e.g., CBM, availability and performance models for separate machines	Provision of e.g., automated production systems and outsourced operations
Enabling capabilities and technology:	Multivariate analysis, knowledge on own goods	Installed base data, on-site (advanced) analytics & condition monitoring	Remote monitoring, real-time data, benchmarking data	High-volume and velocity data, self-aware and controlling systems

Figure 15: Information-enabled service offering categorization

5.2 Provision of information-enabled advanced solutions

The existing servitization literature on advanced service provision and the role of information and systems are still scarce, but a couple of recent publications, most notably Kowalkowski et al. (2013; 2015), contribute to the topic.

Storbacka's (2011) value-based solution business framework has the following steps: (1) value research with the client for solutions development, (2) demand creation with appealing value propositions, (3) selling the solution with pre-sales value quantification, and (4) verifying results with after-delivery quantification. Although steps 2-4 are important for efficient advanced solutions sales, most OEMs have not yet fully started even with the step 1. Therefore, sales-related perspectives on high information intensity solutions might be still too early to represent, before the scope of strategic perspectives of building information age capabilities in industrial firms has been further investigated by academicians. Even though digitization would not be seen as a radical change (e.g., Opresnik & Taisch, 2015) but rather as a long-term continuum as this thesis has proposed, service development and sales are not independent of the other value network parties. Additionally, the different roles OEMs have in the value chain might prove to be major barriers for advanced services provision: The distributor might not have aligned interests (Kowalkowski et al., 2015), OEMs might try to be protective towards competition and service provision from their suppliers, or clients might try to avoid lock-in to a service provider, especially when advanced solutions are not seen as having a strategic role based on, e.g., Krajlic's (1983) influential view on procurement. Therefore, buyer perspectives need to be reflected, but equally so also do capabilities perspectives and the role of other parties beyond buyer-seller dyads. This sub-section will introduce relevant strategic themes, elaborated more in the next section, and continue with sales perspectives for advanced services provision.

Baines & Lightfoot (2013) view service offerings from the client perspective and classify clients into three groups: (1) those that do everything alone, (2) those that use service providers in supportive role, and (3) those that outsource processes that they do not regard as core competencies or otherwise decide to outsource. Therefore, many clients might try to capture the opportunities of digitization all alone, an approach that mining giant Rio Tinto has for example pursued. Digitization is at the top of the mind of many managers and proposed scale of change (Maniyka et al., 2015; Kagermann et al., 2013) ensures that many industrial companies will devote time to digitization strategies, as Wärtsilä and Konecranes have already done, and slow-movers might lose the potential of business to their clients, as the case of Rio Tinto suggests.

Sector-based variables might also affect advanced service offerings. It is known that offering availability or performance opens up new opportunities for pricing and business models such as selling uptime or productivity (Van Ostaeyen, 2014; Maniyka et al., 2015; Kowalkowski et al., 2015). But to the contrary, in mining, for instance, where uptime and productivity are key drivers (Kowalkowski et al., 2015), focus might be instead on cost cutting, as in paper production, a sector suffering from overproduction and decline of demand (Holmberg et al., 2014). Availability as an advanced solution might be one way to achieve cost savings, but arguing that to a client without having benchmark cases might be close to impossible. Therefore, opportunities of high information intensity may vary highly by sector and proposed maturity stages might not apply for all sectors, or there might be major challenges in commercializing advanced solutions.

Internal organizational issues might also cause inertia for advanced solution offerings. Many OEMs still have goods-dominant logic, and typical division to technology and services units (Artto et al., 2014) might result in conflicts of interest between units (Kowalkowski et al., 2015). Kowalkowski et al. (2013) also note that OEMs have developed new ICT-enabled services based on what is possible rather than on client needs. That way, Storbacka’s (2011) first step in joint value research might not be practiced as suggested. However, this can be a natural part of piloting new transformational service concepts, clients being also often unwilling to let a service provider standardize jointly developed services. Challenges to build business on remote connections during the first decade of the 2000s (Grubic, 2014) can be seen to support Kowalkowski et al.’s (2013) findings, but this paper presented earlier a counterargument that remote connections might have been ahead of their time, and the commercialization might still lie ahead. Explorative services development might be required to innovate completely new information-enabled services, and while easier to do with the client, that might not always be feasible. Indeed, Kowalkowski et al. (2013) propose that not all clients are sophisticated enough to buy ICT-enabled services, especially those supporting client processes.

It seems evident that seizing the opportunities of higher information intensity might not be easy for OEMs. Therefore one relevant viewpoint might be to stay out of that development, although Opresnik and Taisch (2015) see that as an imperative. But neglecting opportunities of information may require abandoning other services also. For example, pulp and paper

OEM Voith recently decided to sell its service unit, although the company is one of the leading capital equipment manufacturers in its industry. Servitization literature recognizes this as a possible active strategic decision (e.g., Cusumano et al., 2015), not driven by the service trap (e.g., Gebauer et al., 2005). Other opportunity to avoid possible commoditization of even advanced service provisions could be network-based service strategies or hybrid configuration for service network (Ulaga & Reinartz, 2011). With this approach, external service providers can be used to bring in the capabilities that OEM does not have in-house (e.g., Gebauer et al., 2013), or use the network to achieve cost competitiveness in services provision. Industrial service providers seem to be strategizing to find their approach for the Industrie 4.0 era. The challenge is that before developing solid business cases for the information age (e.g., Turber & Smiela, 2014; Porter & Heppelmann, 2014; Burmeister et al., 2015), this discussion might feel too early to have, but simultaneously the market might move rapidly forward and leave laggards behind.

Regarding sales-related views, steps 2-4 in Storbacka’s (2011) framework, there are already some relevant findings and propositions from the industrial services context. Increasing complexity seems to require increasing sophistication on the buyer side (Kowalkowski et al., 2013) and that could be seen as a supporting argument for the expansion of service offerings towards integrated, advanced solutions. And rather than selling new services separately, the greatest potential might lie in bundling them into existing service concepts (ibid.). Some clients being ready for advanced service adoption and some not in the so-called ambidextrous view (e.g., Gibson & Birkinshaw, 2008) might be required. Kowalkowski et al. (2015) propose that services transition is not a linear process, but both standardization efforts and new services development proceed simultaneously, thus enforcing the role of dynamic capabilities (Teece et al., 1997) in adopting new business models while maintaining current business.

Advanced services are often also highly customized, at least before standardization (Storbacka & Pennanen, 2014). Standardization by modularization might still be challenging in some industrial sectors; some industrial assets forming almost unique systems such as specialized factories and production sites require customization. Reflecting Baines and Lightfoot’s (2013) categorization of client core competencies approach, those willing to build their services operations with service providers might be potential for pilot case development. However, many clients might be reluctant to do this because they would have little to gain: the risk of losing proprietary know-how might create a game-theoretic situation encouraging them to wait for others to develop new service concepts that would then be standardized and sold with quantified value potential. Data access issues are amongst the most challenging for digitization (Tilson et al., 2010).

Based on the above perspectives, little is known about the provision of information-enabled advanced service offerings, and due to few reported success cases besides fleet management or individual unit optimization, empirical evidence especially from complex production environments and systems is required.

5.3 Strategic role of information and analytics capabilities

This section discusses the strategic role of information, using strategic management theories in servitization as lenses.

5.3.1 Information as a resource

Traditionally strategic management literature has seen delivered production assets–i.e., the installed base–as a resource and platform for OEMs' service provisions. Along with increasing availability and usage of machine data, this installed base is turning into an information hub (Thoben & Wortmann, 2013). The real-time usage and process information together enable advanced service offerings and can thus be a key resource for the company (Ulaga & Reinartz, 2011; Kowalkowski et al., 2015). That way, the resource-based view (RBV) (Barney, 1991) is an interesting lens to information.

Installed base as physical goods might be losing its role as a valuable asset because of commoditization of services (Opresnik & Taisch, 2015). As third party service providers and competitors are increasingly capable of providing services, the role of OEM's expert knowledge may decrease. In contrast, the data related to the machines can become a valuable resource for the company; if enriched with event data on service operations and time of spare parts installation, lifecycle services become easier to deliver, providing opportunities also for additional sales (Ala-Risku, 2009). In raw form, data can be valuable for service provision but not accessible, or at least not without pay, as being typically owned by the asset owner. It is only through enrichment of the data that they become a truly valuable resource for the OEM.

If product data supports goods-related businesses, client process-directed services also require process data (Ulaga & Reinartz, 2011). Data openness issues vary from sector to sector, but in the case of an open data policy, it is not necessarily the information but the capabilities of processing it that creates competitive advantage. Indeed, the master's thesis of Orpaneva (2015) quotes Cargotec's CEO stating that open data access will be a practice, and winners are those mastering the orchestration of service ecosystems. One theoretical viewpoint for data usage is value asymmetry (Stabell & Fjeldstadt, 1998); for asset owner machine usage data might not be as valuable as for the OEM in its R&D and services provision. The inability to quantify this value can also pose challenges for data access. In another master's thesis (Lano, 2015), the case company was reported to have made a strategic decision to provide information services instead of turnkey asset provision and maintenance to avoid commoditization. It seems likely that there will be different approaches to data openness, and the control of digital product platforms will be one of the most important research questions for digitization (Tilson et al., 2010). Depending on emerging industry practices, information can further increase its role as s strategic resource, especially if enriched, but can also lose it if turned into a commodity.

5.3.2 Information and processing capabilities as a competitive advantage

Vandermerwe & Rada (1988) approached servitization from a Porterian (Porter, 1980) market forces perspective. Commoditization of goods (e.g., Gebauer et al., 2010) has been seen as a driving force to services provision, because technology cannot provide a sustainable competitive advantage (Eisenhardt & Martin, 2000).

Opresnik and Taisch (2015) approach digitization in industrial services from the viewpoint of dynamic capabilities theory, but essentially their claim of commoditizing services and the new role of information as a resource is market forces based. However, it is a good question as whether data analytics capabilities can provide a sustainable competitive advantage. Kohtamäki & Helo (2015) see analytics capabilities as a potential way to differentiate, but its sustainability over time can be questioned, if the ability to develop new services is not internal and a dynamic capability (Teece et al., 1997) for new solution development.

5.3.3 Relational views for high information intensity services provision

Most OEMs and industrial manufacturers are likely to need external partners for data exploitation (Kowalkowski et al., 2013; Opresnik & Taisch, 2015). Smarter production systems and capability to manage service operations effectively with installed base data raise questions as to whether service delivery should be organized in-house or with third party partners in hybrid configurations (Ulaga & Reinartz, 2011). Also, if installed base data is developed into commercialized platforms as Siemens is doing with SAP, value networks may suddenly become more complex and questions on the incentives to join these platforms (Yoo et al., 2012) or platform business models (e.g., Hagiu, 2014) and control points on those platforms (Pagani, 2013) become relevant also in an industrial context. Contemporary value networks are complex and require co-operation for value creation, but existing literature even outside servitization on the role of IT is often dyadic with respect to this (Grover & Kohli, 2012).

Orchestration of value networks that provide services for industrial manufacturers is a trending topic in servitization (Eloranta & Turunen, 2015). With standardization, companies can aim to develop a "service factory" model (Spring & Araujo, 2013), but it has not been investigated whether highly customized production facilities are more challenging for service standardization than, e.g., highly standard fleet supporting services.

Altogether it can be concluded that all strategic management perspectives are important, but in varying ways. Information is essentially a resource, but if access to it is not restricted in the value ecosystem, it is not a rare resource and or source of sustainable competitive advantage. An installed base enriched with OEM information can be an important asset, and some companies might be trying to create product information platforms to develop control points for value creation. Besides information as a resource, companies need new capabilities for using these data, as well as dynamic capabilities to adapt to changing environments and lead the change. Although for first movers, new capabilities for advanced analytics might be a source of competitive advantage, it is likely that this advantage will vanish over time, as these capabilities become a commodity. What is unique is the capability to leverage information assets and constantly renew service offerings and internal operations. Value networks are becoming more complex, which raises questions on the relational view and organization of service provision in the long run.

5.4 Strategic opportunities on developing analytics capabilities

Industrial services providers face a challenging question, whether they should invest resources in new capabilities development for information age, and how to do this. On small scale, different experiments can fall within development projects, but a strategic decision on aiming to leverage the opportunities of information needs more. The opportunities of new services need to be visible, which the information-enabled solution offering conceptualization in Part 5.1 gives some clarity. Besides own actions, companies need to think about their competitive environment. There are competing views on who will seize the opportunities of increasing information intensity; and based on all the hype around Industrial Internet and Industrie 4.0, there will be many players on the battlefield.

It was proposed that clients are one possible threat for OEMs. With better analytics capabilities, they may become less dependent on their OEMs and achieve higher performance by themselves, as Rio Tinto has been doing. On the other hand, this is likely to be feasible only for large clients having much data available for benchmarking–otherwise the company would not be able to compare performances and set internal targets. Also by combining an internal knowledge base with client information and building this into a database, OEMs can protect themselves from commoditization. This could be viewed as a game theoretic situation, which is likely to end up in the acquisition or development of analytics capabilities both at client and at the OEM (See Figure 16). It is notable that the OEM is much more prone to competition than its clients with respect to analytics capabilities, the best case being when analytics are used for advanced services provision. If a client is highly capable in this, it is likely to have more buying power, when considering outsourcing operations. That way, it should be carefully analyzed by servitizing OEMs, as to whether their role can be commoditized or not. If a goods-focused strategy is not sustainable due to competition and the target sector is digitizing, market forces will push the OEM to adopt analytics capabilities sooner or later.

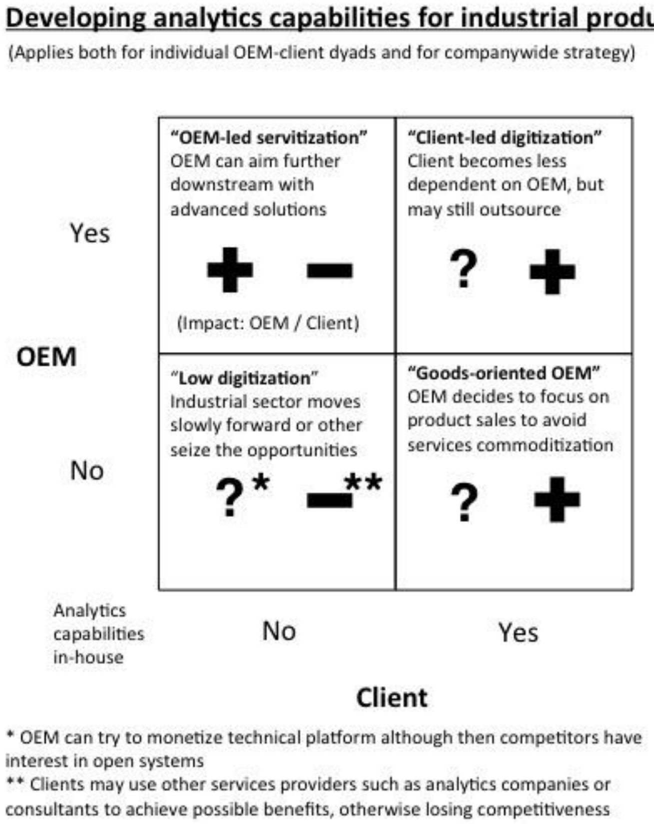


Figure 16: Game theoretic view for OEM and their clients on analytics capabilities

Also suppliers and other companies such as consultancies, process automation providers and even analytics providers with industry knowledge may engage in Industrie 4.0 servitization. It is likely that all capable parties will try to engage in value creation with higher information intensity, if data access issues are solved. Especially German or US industrial giants like General Electric and Siemens may pose a threat of building Industrial Internet platforms and expand both vertically and horizontally, a vision nurtured especially by the German Industrie 4.0 community (Kagermann et al., 2013). Alongside with industrial companies, platform technical providers such as CISCO, SAP or IBM may be able to have a similar control point to the platforms (Pagani, 2013) like some web-giants have for their multi-sided platforms (e.g., Hagiu, 2014). There are many competing IoT platforms under development, but without further standardization (e.g., Harjunkoski & Bauer, 2014) and very distant visions of self-controlling Cyber-Physical Systems of Systems (Kagermann et al., 2013), Winner Takes All –dynamics or envelopment (Eisenmann et al., 2006) are unlikely to be major threats for OEMs although lock-in effects for industrial IoT platforms may emerge. After all, data infrastructure or external analytics partners cannot offer expert-knowledge independent value-creating analytics services as easily as for e.g., Business Intelligence information, industrial control systems being highly sector specific and production systems being still for long too complex to achieve full automation (e.g., WEF, 2015). With this view, the so-called technological disruption is likely pass at least complex manufacturing sectors and be led as non-disruptive change by current industrial companies with the help of some technical help, big industrial giants posing the biggest, but moderate threat.

Opresnik and Taisch’s (2015) proposition of information services being future source of competitiveness does not seem a major issue in industrial production. It might be true in special cases such as Vaisala’s value streams where information is the de facto end product. Industrial manufacturer’s value chains might become more networked, but the desired outcome will not change, even though processes might become more efficient with more information and new business opportunities might be developed using or selling data. However, other opportunities might be available if companies decide to expand vertically to other businesses such as elevator producer Kone is doing with its people flow concepts, suggesting expansion to intelligent infrastructure and building control. That is still a question of capabilities and industry boundaries, many OEMs with highly specialized and focused offering having less opportunities in vertical expansion than more general e.g., engine or industrial electronics manufacturers.

One interesting and possible direction for development is the operation of client production processes as a service. Conceptually possible in efficiency or performance –providing advanced solution offerings (e.g., Kohtamäki & Helo, 2015), it is still rarely considered as a major opportunity. However, if OEM develops know-how on production process over time and client defines e.g., sales as their key core process, such development might be possible. In logistics-related machinery like turbines full service contracts are already offered (e.g., Porter & Heppelmann, 2014), and Finnish welding machinery company Kemppi offers solutions where both a machine and its operator are delivered for additional capacity, charging by output.

5.5 Additional perspectives on the implications of digitization

Before wrapping down the literature-based part, some implications of increasing information intensity that have not been earlier discussed will be shortly introduced. These concepts will be later referenced in the discussion.

Organizational boundaries

Relational view –part earlier explained how complexity in value networks increases because of higher vertical and horizontal integration (Kagermann et al., 2013), new value network participants such as analytics providers and organization of services delivery using suppliers, forming hybrid configurations (Ulaga & Reinartz, 2011). All this blurs product and industry boundaries, information or digitization being the key driver behind (Jonsson et al., 2009). Data exchange using remote monitoring spans the traditional service provider – client boundary (ibid). With possible open data access and more actors participating in client processes such as component suppliers, this picture becomes much more complex and highlights the challenges and importance of further research on company and industry boundaries, data sharing and digitization.

Value-based exchange

Westergren (2011) notes in his remote monitoring related paper that one explanation for the low adoption level of remote monitoring –enabled services is due to OEMs challenges in articulating service value. LaValle et al (2011) raise the same issue in the context of analytics adoption, highlighting the importance of proving the potential value of analytics. They consider (ibid) analytics adoption to be a long-term project, requiring also internal selling and iterating business models based on proof-of-case pilots.

Value-based exchange literature especially form industrial marketing context is applicable for advanced solution selling, targeting to quantifying and arguing the value of offerings using e.g., benchmark cases (e.g., Töytäri, 2015). Higher information intensity enables new service elements or completely new services, but does not make a difference to lower intensity advanced services sales. Both internal and external selling are mandatory in the early commercialization. Opportunities to analyze value creation potential may become easier with more accurate installed base data and other internal knowledge, requiring the integration of knowledge bases and sales processes. New services may also include new technical elements such as advanced analytics, which requires investments for sales organization training and simple enough conceptualizations to sell these new elements alone, or preferably bundled to existing concepts (Kowalkowski et al., 2013), for current and new customers.

6 Empirical material and analysis

This part starts with a description of the historical development on information usage by OEM, and also indirectly that of their clients. This acts as primary material for the analytic frame and explains why Case OEM's industry has used relatively much information long before many other typical Industrial Internet examples. Section 6.2 explains the current situation at Case OEM regarding information intensity and discusses some related challenges. To answer the research questions and present additional findings, rest of the Chapter is divided into three parts: value in service provision, the competitive environment, and practical implications. Interview material could have been interesting to address some other research questions and objectives, but e.g., data sharing issues were for the most part omitted, as they did not contribute new findings from an academic standpoint, likewise to many practical issues such as geographical differences and organizational issues, while being relevant to Case OEM internally.

6.1 Technical development related to information intensity

Case OEM is one of the technology leaders in its specific industry and therefore has a technological history similar to that of its competitors. Until the 1960s, the end product, a combination of OEM-delivered process automation units for manufacturing, was mechanical, with pneumatic tuning systems to control the process, and was the result of work that was much more labor intensive than that of today. The modern phase of process automation began sometime after 1950, but the transition from analogue to digital control systems took several decades, resulting in highly streamlined, high OEE (overall equipment effectiveness) manufacturing. Semiconductors, programmable logic controllers (PLC), and microprocessors had provided the foundation for digital automation systems by the late 1970s, and modern PC-controlled automation and control systems (SCADA, DCS) have been the technology norm since the 1990s. Although several other technological steps were taken between the introduction of the first PLCs in the 1970s and modern DCS, prior to the 1980-1990 period, machine information was used only on a very limited scale. Clients were taking primarily manual measurements of the process and storing them in manually written records. Troubleshooting and analysis were typically done by manually measuring data points and drawing these into a trend graph, possibly including, for example, energy consumption data. During this time period, increasingly large production lines were installed. Some production facilities have automation systems from this time, although most of the larger facilities were either upgraded or shut down after the introduction of modern automation and control systems since the 1990s.

At Case OEM, the 1990s was the decade when ICT and internal processes started to truly support internal operations, as in many other industries. Standards and procedures for customer documentation and naming of engineered parts were established around 1990-1995. Customer invoicing systems (EDI/OVT) came about in 1991, ERP in 1996, and a PDM (product document management) system in 1999. Product manuals were also brought into the Internet era, thus enabling clients to access installation instructions and drawings through a website. The introduction of ERP and maintenance management systems improved work practices, although installed base data was not yet reliable–still an issue today due to the same sort of challenges as Sampson and Froehle (2006) mention. In service operations, focus changed from maintenance process lead times to better process execution itself, along with pre-defined documentation and procurement processes.

At client sites where Case OEM provided both production machinery and process automation systems, technical development reached the de-facto current level by the 2000s. With PCs and modern, digital process automation systems, opportunities for statistical testing became increasingly feasible for, e.g., after-failure root cause analysis–as long as data was stored in data warehouses. So-called I/O and bus solutions enabled data collection from multiple nodes with reasonable cost, data being transferred to DCS at a rate of up to 100Mbs. With the availability of data and its ease of usability, due primarily to ready-made diagnostic tools in the DCS or separate software, machine data was now followed and analyzed on computers with more sophisticated regression models. Some process operations-related data, such as that related to machine start-up procedures, were also added to the analysis.

However, analysis in the late 1990s was and still is primarily hypothesis driven. Data storage in data warehouses or historians – if they have been installed – has typically been small, preserving only a restricted amount of data for later usage. Although energy consumption data have been available, many other relevant data sources, such as that concerning maintenance or operations practices, were collected for a specific purpose at a satisfactory level of accuracy. Computing power and storage price in the late 1990s were also high relative to the amount of data that could be stored, with on-the-fly analyses by production site engineers as issues occurred being the more typical practice. With constantly improving tools to reduce unplanned downtime and quality problems, best performer OEEs gradually climbed up to high levels (~80%) by the 2000s, continuing the trend but at a lower rate of improvement in recent times.

By the turn of the new millennium, another feature was being added to client sites: remote connections. Case OEM launched a company-wide initiative to bring its service delivery to the next level. The company installed remote monitoring systems to modern client facilities (modern SCADA/DCS), and began setting up centralized competence centers where experts could support clients and field maintenance staff with data transferred over the Internet. Pilots were also conducted with product tracking and identification.

Technically, these solutions resembled to a large extent descriptions of Industrial Internet or intelligent products. As of 2000, new process controls were embedded in systems, and Case OEM even began calling these self-analyzing products “smart machines”.

When the theme Industrial Internet or “smartness” was brought up in the interviews, many informants mentioned this era with a sort of nostalgia or even a slight cynicism towards the proposed transformative potential of remote connectivity. Indeed, this original company-wide service concept did not meet its targets, and it was reconfigured along with a major cost-cutting program within a few years of its introduction. Those manufacturers that were in the program typically cut data flows the connections were planned to be open, and data access is even today granted only for a specifically agreed upon purpose.

> “We were possibly ahead of our time” – Director, services

Many informants thought that the technology used was not fully mature or cost competitive when introduced for the first time in the late 1990s. Client engineers or Case OEM experts visiting client sites were using the local relatively high-volume data for hypothesis testing even after the first years of the 2000s but were employing remote connections to a lesser extent. Firstly, connection speed or price was much different than today, typical wired connections being below the current 3G or even GPRS. Optical fibers were also an option but were costly, like even today. Storage and computing options also made it much more expensive to capture and analyze even a fraction of the produced data. Additionally, although a smaller pilot, tracking solutions were developed using non-mature tracking technologies in contrast to RFID.

With that view, while the service concept itself was relatively well developed and resembled state-of-the-art organizational configurations today, the “big data” analytics part was still missing, even locally at the client sites. Real-time data was already accessible with I/O and fieldbus solutions providing a perishable data stream not stored in large volumes. Other technological maturity-related issues further explain that, while technologically advanced at the time, Case OEM had developed solutions that were not yet fully suitable for commercialization. This is in line with Kowalkowski et al.'s (2013) later conclusion that OEMs have developed solutions often on the basis of what is technically possible rather than on existing client need.

6.2 Current technological basis and information intensity challenges

Increasing, production in Asia and decreasing demand has led to notable overcapacity problems in the industry subsequent to the 2000s. Adding new sites has become rare compared to previous decades, although investments have been simultaneously shifting to other product types offered by Case OEM.

Due to decreasing client investments in industrial assets, the importance of services has further increased at Case OEM. On the technological front, Case OEM has been piloting various new solutions for maintenance over the past few years. Some of these new service concepts have been successful, leading to multi-year contracts with availability or performance-based business models. Recently, pilot projects have been conducted to adopt advanced analytics to further improve service quality. Additionally, Case OEM has also developed technologies to improve efficiency of internal service delivery, one example being use of artificial intelligence and virtual reality to support practical maintenance work at client sites.

Analytics pilots are conducted with the traditional big data approach, combining different data sources and using machine learning analytics. However, those pilots that Case OEM calls “big data” do not use big data in the traditional sense since the data masses being used are still sufficiently small to use traditional industrial PCs instead of Hadoop-type storage. Pilots are also conducted on-site at client facilities, and data is stored locally instead of on cloud servers. Analyses are run with single-facility data instead of vast benchmark databases.

Case OEM experiences challenges with their analytics pilots comparable to those in the industry at large. Machine units and different process automation layers constitute “islands” of sorts. New systems are based on OPC UA servers, but without existing information models on the market, much work is necessary to build these information models. A high level of customization, low level of modularity, and an average high age of the machinery lead to hardly any plug-and-play opportunities even after first pilots, although much less work is required than on the first ones.

If advanced analytics are introduced on an organization-wide basis, organizational capabilities could become an issue. One informant described an advanced analytics case that occurred in the mid-2000s, where service delivery organization experienced challenges in using a new tool:

> "When the neural model was implemented for [client X], it became internally a highly time-consuming project because the service organization staff did not really understand what the model was calculating. These new analytical tools need to be offered in a way that does not depend on the know-how of the average maintenance employee." – Director, Services

Currently, a third party analytics partner is involved in the pilot analytics projects, tackling partly the aforementioned problem.

Also data volumes and velocity are issues to be addressed. An average production line has about 30 000 tags compared to about 25 in Rolls-Royce turbines. The number is high relative to many early IoT cases in other industries and resembles that of an oil rig (Maniyka et al., 2015), although in some industries the number of data tags might be ten-fold this. Besides number of tags, high velocity of data measurements creates a challenge. The majority of Case OEM's turnover comes from sectors where the process speed is relatively rapid, and thus data measurements in terms of data velocity may need to be very high, depending on the application. For example, downtime-causing events might need to be analyzed with an averaged measurement frequency of <1 second. Where an analytics model is connected back to the actuators controlling, e.g., valves, the rate should be in microseconds.

Number of tags and need for high frequency data create challenges both for data storage and transfer, requiring local computing or "fog" computing solutions to reduce data volumes. Not all data should be transferred or even stored, and so highly relevant are questions concerning data to be stored and rate at which they should be averaged for storage. Because fog computing aims to process information locally and to store only long-term (minutes, hours) averages when a process is running well and to store at higher rate when problems occur, exact rules need to be formulated for storage frequency under these different scenarios. These questions define the storage capacity needed locally and other technical requirements for local computing. Additionally, if this data is not only stored at client site but also transferred to Case OEM cloud or physical storage, communication speed becomes a consideration. In many industrial settings, speed is not a challenge, but at large manufacturing sites the limits imposed by lines of even 100Mb could become a constraint, if data reduction is not performed locally prior to transfer. Calculation below (Figure 17) illustrates the challenges related to data volumes on large systems and work sites, resulted by high velocity and number of tags.

	Application Variable	Application			
		Single unit (turbine)	System unit (process line)	Production system (process line)	Large production site
	# of tags	30	3000	30000	300000
	bytes per load (row)	8	8	8	8
2 loads per second	loads per second	2	2	2	2
	rows per day	5184000	518400000	5184000000	51840000000
	Gbs per day	**0,04**	**4,1**	**41,5**	**414,7**
	Historian buffer (days)	14	14	14	14
	Buffer storage requirement (Gb)	0,6	58	581	5806
	Required storage for 10 years (Gb)	151	15137	151373	1513728
	Required connection speed (Mb)	0,0048	0,48	4,8	48
	Required connection type	**GPRS**	**3G**	**4G**	**4G or optical fibre**
2 loads per hour	loads per second	0,000555556	0,000555556	0,000555556	0,000555556
	rows per day	1440	144000	1440000	14400000
	Gbs per day	**0,000**	**0,001**	**0,012**	**0,115**
	Historian buffer (days)	14	14	14	14
	Buffer storage requirement (Gb)	0,00	0,02	0,16	1,61
	Required storage for 10 years (Gb)	0,04	4	42	420
	Required connection speed (Mb)	0,00	0,00	0,00	0,01
	Required connection type	**GPRS**	**GPRS**	**GPRS**	**GPRS**
2 loads per hour AND 2 loads per second for 2% of time	loads per second (normal)	0,000555556	0,000555556	0,000555556	0,000555556
	loads per second (failure)	2	2	2	2
	average failure % of total time	2%	2%	2%	2%
	rows per day	105120	10512000	105120000	1051200000
	Gbs per day	**0,001**	**0,084**	**0,841**	**8,410**
	Historian buffer (days)	14	14	14	14
	Buffer storage requirement (Gb)	0,0	1,2	11,8	117,7
	Required storage for 10 years (Gb)	3	307	3070	30695
	Required connection speed (Mb)	0,00	0,01	0,10	0,97
	Required connection type	**GPRS**	**GPRS / 3G**	**3G / 4G**	**3G / optical fibre**
Assumptions: bytes per load: 8; network line allowed usage 10%. In case three, failure data can be either transferred from buffer over time, or instantly, requiring faster connection speed for the latter option.					

Figure 17: Data volumes by data source (unit/system) and data velocity

As a consequence of differing data volumes, velocities, and storage location and buffer decisions, cost of technological investments might or might not become an important decision variable. Current pilots remain below the traditional big data limits and are therefore also relatively low with respect to required connection speed. But should it be decided that a higher data velocity is desired for some specific purpose, the cost of technological solutions needed to accomplish this would rise significantly.

Installed base data is another challenging information source for Case OEM. Currently the company does not maintain complete records of client goods, or at least their exact locations, past maintenance events, or installation dates. Therefore, Case OEM often relies on client information, which may vary from client to client in accuracy. Another perspective on challenges related to information gathering issues comes from data-sharing practices, which are discussed later in this chapter.

6.3 Value from data – towards advanced solutions offerings by supporting client core processes

> “What is happening now in these businesses has happened in process manufacturing already 30 years ago // -- // If you compare our business or [X] to construction, discrete manufacturing, or many other businesses, our processes are much more refined.” – Client B, VP Strategy

> “Process operation and maintenance practices define whether unplanned downtime is below or above 1 percent. // -- // If it rises above 1.5%, quality problems arise, leading to scrapping. This is very expensive. We should rather run production on high performance rates and shut down then the machines.” – Client A, VP Maintenance

As proposed in the literature review and earlier in this chapter, average OEE is high in this process manufacturing industry, and unplanned downtime is thus very low. Overcapacity also leads to optimization of cost performance instead of maximizing output. Therefore, the potential of analytics to achieve process efficiency improvements is relatively limited, although even a minor decrease in unplanned downtime could contribute saving of up to 1 million euro yearly at a big site. Still, maintenance services seem even less interesting than in the history:

> “Process automation industries have changed. In the past, maintenance was regarded important because uptime implied sales. If you had shortage of capacity, maintenance was always preventive and planned. That had a cost, but you needed to have the capabilities. Well, the industry changed and now we are constantly dealing with overcapacity. Therefore, cost cutting mentality is dominant all the time, and maintenance is not preventive anymore because capacity does not have the same value as before. If there is a breakage, neighboring factory has idle capacity. Of course this does not apply to all product types. ” – Client B, VP Strategy

Case OEM big data pilots have focused on root cause analysis and optimization of wear parts. In general, spare and wear parts optimization is seen as only having a small cost savings potential for a client, but it reduces risks and improves process predictability. In this manner, condition monitoring and prediction can support core processes of clients.

> "We should have a more holistic focus to client problems than current point-sales mindset. Streamlining client core processes would be ideal; maintenance is only a support process, after all. // -- // Client would get significant savings from quality if their operations staff would blunder less. // -- // We could aim to control variation in client output quality, cost performance and energy consumption." – Director, Services

Most Case OEM representatives regard energy consumption, raw material consumption, and client quality aspirations as the most valuable opportunities to be derived from advanced analytics. The first two are important cost components–even more so than cost of employees–and the last becomes important only if there are problems with quality.

Compared to many other servitizing OEMs, Case OEM has sold relatively few large contracts that would fall into the category of advanced solutions or availability and performance services (e.g., Ulaga & Reinartz, 2011; Kohtamäki et al., 2015). Case OEM service offerings include these concepts, but their clients have traditionally relied on internal capabilities. From the Case OEM viewpoint, these large contracts are attractive due to their value creation potential for clients. Although only a few informants could be characterized as fully aware of new opportunities related to analytics, many consider it as a way to win more of these large contracts.

> "By tracking the usage of our products with our recommended tunings and reducing that way unnecessary energy consumption from friction we could achieve easily hundreds of thousands of euros savings for the client per production line. In some cases these services could be offered as bonus tools that are sold with profit sharing models." – Director, Services

Therefore, Case OEM could potentially increase its share of advanced solutions of their services turnover with advanced analytics. Value for the client arises fundamentally from the ability to provide either something that the client does not already do for themselves or the ability to do it more cost effectively than the client can. Analytics capabilities could represent a source for differentiation based on know-how, at least in the short term before competitors will catch up. That way, analytics capabilities could be also a key enabler in the transition to advanced solutions with more appealing value offerings, even though competitors and clients would over time develop the same basic capabilities.

Opportunities to expand to client process outsourcing were also considered, although mostly theoretically because that is almost unheard of in Case OEM's industry. Still, many informants mentioned one or several separate units in the production line as an interesting opportunity for process outsourcing services. Client A mentioned the same unit to be highly problematic, but also its own "island", not related to key production phases.

> "Well, [X] is one of the most problematic technical units, and practically thinking, if the OEM would be there, it could kind of follow it, dig deeper and find new answers to challenges. But that whole process line, that is hard to see…" – Client A, VP Maintenance

Both client representatives regarded production operations as having less significance than in the past with respect to competitive advantage. But although Case OEM could at least theoretically expand its capabilities from the start-up of the production line to continuous operations, that seems unlikely without new private equity owners or new clients with non-traditional leadership, which again are less likely due to overcapacity. Still, over the long term, a few informants viewed operations outsourcing as a theoretical additional alternative for the current consultative services.

Besides traditional after-market and consultative services, opportunities to provide clients with tools to aid them in furthering their performance aspirations also exist. Although dashboards that combine information for decision-making are typical applications of data visualization in other industries, many Case OEM informants questioned whether similar services would be valuable enough for clients to justify the required development costs. Two possible use cases for dashboards were identified by clients and Case OEM representatives. The first consists of large corporations that lack the ability to view operations at factories and that might provide less-than-reliable information. Real-time information on cost performance could enable the company to allocate production more efficiently and better identify sites that require special attention. Another issue is factory-level standardization efforts. In some countries professional pride is very high amongst factory employees, and different production shifts employ their own control tunings without documenting these for the next shift. Logs and information on shift-level differences and recommendations for tuning controls could help factories with their standardization efforts. Some informants also recounted examples of maverick behavior at sites, with production shift employees modifying machine speed measurements in order to alter the values reported to HQ. However, these maverick practices exist mostly in developing markets.

Case OEM could also benefit from higher information intensity internally. As described earlier, the installed base information is not very reliable and does not typically contain event or even fleet location information. Installed base data, enriched with machine condition data, was seen as a useful tool to improve internal service delivery efficiency. Information internally on optimal contact time for the client based on machine condition or planned replacement was also mentioned as a potential sales point for additional services.

In the interviews, various new opportunities to use machine/process data and tracking technologies that could be implemented already in short-term perspective were discussed. Additionally, some completely new service opportunities were proposed that would benefit from client data. Documentation regarding these opportunities and reflections on them has been delivered separately to Case OEM along with further considerations and recommendations.

6.4 Competitive environment

Many informants assumed that Case OEM’s competitive environment might change at least to some extent with the adoption of Internet of Things –type solutions in their industry. However, most preferred not to speculate to any great extent on the issue, although some common themes did emerge.

For instance, traditional Case OEM rivals were thought to have a weaker set of capabilities with which to seize the opportunities of analytics and IoT than Case OEM itself.

“They could [enter the game], but they don’t have the same process knowledge as we have.” – VP, services

Large OEMs in the business have differentiated to some extent, and Case OEM has the largest offering of all within its market. In contrast to other OEMs, Case OEM has a process automation business unit and so can bring to the table process knowledge that can be leveraged in service solutions also. Additionally, Case OEM has a strong maintenance services unit, which not all of its competitors have.

These large OEMs are able to act as systems integrators, providing clients with an entire plant’s machinery, but smaller, specialized OEMs and pure service providers also exist.

Strengthening Case OEM’s advanced services solution portfolio by employing analytics was seen as a way to distinguish it from small competitors, but large third party service providers were identified as a potential threat. Traditionally, these service providers have been more competitive with respect to cost but were seen as less capable than OEMs. The core business for these third party service providers has been in basic maintenance services, but advanced analytics might aid them in marketing consultancy-type performance improvements. Still, analytics do not replace the need for experts. One informant recounted a situation where the client used an external service provider that, against the expert opinion, applied analytics-based “optimal” control tunings, leading to a major physical breakage of the machinery.

Besides traditional competitors, also non-traditional suppliers might try to get their share of the wallet from the opportunities of data. One of the IT sector informants was excited about a recent development in their business.

> “Traditionally we have seen OEMs as normal clients, but now it seems that they can be also partners to offer our IoT platforms to their industrial clients.” – Specialist, IT company

This IT firm had entered into an arrangement with a large power and automation hardware provider that aims to build new business from data. Its operational logic is to load the data generated by its equipment onto cloud servers and charge for access to that data. Although the clients or their service partners might be able to obtain the same data from the equipment, doing so might not be as cost effective as to simply buy access to it. In this manner, the IT company could entice more companies to adopt its platform for data storage and even for access to analytics tools that are run on the cloud server.

IT providers, however, are not, by themselves, likely to become a threat to service providers. Many informants emphasized the need for expertise on client processes and machinery, and this expertise provided some protection for this highly specialized sector from disruption by IT companies. One analytics service provider shares this opinion and does not aim to replace industrial service providers but rather to partner with them.

> “In my opinion it is crucial to understand the physics and operations of the production machinery. // -- // Additionally, we IT –providers have limited ability to keep us updated about new manufacturing technologies. Understanding on client processes and the results from analytics is based is, after all, what makes difference. But there are trials amongst IT providers to go there [analytics-based industrial

> services] because there are incredible value creation opportunities. The ecosystem is still completely unstructured and it might be possible to get an important role there with relatively weak competences." – CEO, IT company

Besides various existing and potential new competitors, client decisions are another important variable helping to define the competitive environment. One such decision is whether clients develop analytics capabilities for themselves, and various views on this decision were expressed.

> ”I might be wrong, but if a big IT company would approach alone a huge client like [X], I think it is possible that some sort of project would go forward. But if the same IT provider would approach a single factory, I can't see that happening, or at least it would be difficult" – Director, Services

According to various Case OEM representatives, only their largest clients would have the resources to develop their own analytics capabilities and so reduce their need for Case OEM's services, and only those clients that also have a core competence strategy to conduct all support processes on their own would be likely to do so. Besides scarce internal dynamic capabilities, only huge clients would have enough factories to obtain meaningful benchmarking between sites. The analytics company informant linked the issue to outsourcing strategy:

> ”Client does not have access to service data although in the case where they do it by themselves. In that case they have the opportunities to do it by themselves. However, they still would not have OEM's product data, but it is a good question, what would be the role of that data in the analytical models." – CEO, IT company

When two of OEM's clients were asked the same questions, they refer to small internal budgets for development projects not related to their core processes and state that they expect OEMs to develop the new solutions related to machinery and services associated with the machinery. Both companies are large even on a global scale and rely on industrial service providers where their support is viewed as beneficial. Case OEM representatives from different market regions noted that regional differences might be an important factor in these decisions. In some regions, factories are more independent from HQs than in others, leading to weaker corporate-level shared resources but also weakening the OEM's ability to sell company-wide contracts.

From the client viewpoint, process operations may not constitute the most consequential questions regarding digitization:

> ”One of the biggest challenges in the coming decades is to understand how our client needs change due to digitization. And then, logistics is important; that the whole supply chain works, we don’t have material laying in warehouses, and delivered products are what they should be.” – Client B, VP Strategy

Based on the interviews, digitization would seem to provide an opportunity for OEMs to increase their roles as suppliers to clients, but with respect to those companies ”who want to do it themselves” (Baines & Lightfoot, 2013), market opportunities might be restricted. However, competitive threat may arise from third party providers, new competitors from the IT sector, or suppliers not previously seen as traditional competitors, such as power and automation hardware providers. Indeed, a representative from the latter sector commented concerning the move towards digitization-based services:

> ”I think everyone will be involved in a way or other, but those with closest relationships with the clients will be likely to succeed the best” – SVP Services, power and automation hardware supplier

Lastly, regardless of client approaches to outsourcing, new entrants to the competitive environment, or possible data-sharing challenges, OEMs have a unique resource when compared to others:

> ”In order to get value from data, insights and information, knowledge of client processes and especially, expertise on machinery, are crucial. That or those are the most important assets of OEMs. Therefore I hope that it is the OEMs that will take this role of creating value from information.” – CEO, IT company

6.5 Challenges and practical issues in relation to the increasing information intensity

Higher information intensity, using more machine data, process data and other information sources, has been identified as an interesting source of new value creation for clients. Interviewing informants revealed many challenges with respect to adoption of higher information intensity and elicited many practical organizational issues. The scope of the empirical part of the thesis does not allow for a full presentation of these proposed implications, but some of the most interesting ones will be briefly described here.

Most informants claimed to lack a full understanding of what could be done with analytics or other information sources. Moreover, many from the sales frontier stated that the interview was the first serious discussion on the opportunities of information in regards to big data that they had had. There seemed to be an important gap of understanding as to what could technologically be done and what should be done from a client perspective. Technological experts claimed that technology is not a significant challenge, but at the same time stated that they were not as knowledgeable about client needs as employees who dealt directly with the clients. On the other hand, less technically oriented managers seemed to have a relatively weak understanding of the capabilities, limitations, and investments associated with analytics. Thus, the focus was very knowledge intense, and many experts were willing to talk specifically only about their own, relatively narrow niches in which they were experts.

> “We don’t necessarily understand, what could be done yet more [regarding current processes] and what else could be done, as there is more and more data. There is already a lot of it, and we might not always understand what data we have, or think how that could be combined together. Process automation does a lot of automatic control, after all.” – Client B, VP Strategy

Client representatives also admitted that they had not thought much about recent technological advances that had the potential to improve service delivery and production process. This lack of consideration concerning technology’s potential is understandable at an early phase of development, but many informants also emphasized the importance of cross-organizational development teams to bridge this knowledge gap. Silos between business units and even within them were also identified as a barrier to development.

> “We would need to integrate all our dimensions. Automation, after-market, capital projects, IT, R&D, our customer-facing processes. Then, how these are organized and run is the question.” Global Director, IT Solutions

Because only a few seemed to understand the usage of advanced analytics, service concept development could prove challenging. And without benchmark cases, it is hard to show the client its value.

> “We can use general approach for new products. So we select some pilot customers and propose a solution. Or on the other hand, we may from the beginning develop something with the customer. // -- // In the second approach it would be easier to find

> test customers… but if the customer find [the service] very interesting and valuable, they might ask an exclusivity for it." – VP, Services

> "If you are selling something, the client needs to understand how it will benefit from it and how that value will be achieved. // -- // Of course, it is always difficult to have strong argumentation if you have propositions that are hard to prove. // -- // And it is not always about the payback of the investment, but about the budget. You have a budget, out of which most is allocated to necessary investments. And then there is typically only a small fraction that can be used for new or otherwise risky projects because they have lower success rate than others." – Client B, VP Strategy

Thus, new service development seems challenging. Few clients are willing to be involved in new service development, and without strong argumentation and benchmark cases, selling even the first cases is difficult. Clients also do not wish service providers to commercialize something that they have learned from them. In spite of possibly strong client relationships, commercialization of slightly more radical service concepts is seen as difficult. One Case OEM representative pointed out that relatively few companies are open to new proposals and recounted a recent case involving a private equity company whose owner subscribed to an operational logic based on a "we do it by ourselves" mentality, even though client representatives interviewed for this study agreed that factory operations are not a source of competitive advantage for that company.

Data-sharing agreements are also seen as difficult, even more so than in many other industries.

> "Client owns [the process data]. It is a big challenge and has huge impact in the opportunities to realize the value from data. // -- // For example, all new deliveries of [OEM X] have contractual agreements for data sharing. But there have been system deliveries for about 100 years, and all these older contracts do not have clausules for data sharing. That is what we are working on. It might be that the old facilities, if they do not see the point, will be excluded from the group that will be even offered new services. That new services would be only for new generation facilities." – CEO, IT provider

The Case OEM agrees that client owns by definition the machine data besides all their process data. IT provider informants take a viewpoint that typically service data is owned by OEMs, and propose that this qualitative data, when combined with internal knowledge base, is a source of competitive advantage. But in Case OEM's target industry, clients are performing many service operations themselves and thus own their own service data. Companies that outsource their entire maintenance operations are a rarity in the industry.

> ”Many clients might be also very jealous of sharing their own data. These are not negotiation or relationship issues, these have to be solved in practice by showing the value.” – CEO, IT provider

Currently customer data is typically accessed only during start-up.

> “[Remote connection] is used only for start-up and after that we are not allowed to collect all the product information. If we need to, we need a very special agreement with customer and we need to show what kind of benefit they can get.” – VP, Services

Data sharing appears to be a harder issue in Case OEM's industry than in other industries for several reasons. Clients are performing many service operations themselves and use external service providers only for some cases. Therefore, Case OEM occupies a weaker position than many OEMs in other industries due to the rarity of advanced services provision by clients. Earlier, information intensity was identified as an important tool with which to move forward in advanced solution offering. Regarding opportunities for building new services and capabilities for information usage, the low level of advanced solutions adoption by clients would seem to also restrict development of advanced solutions. Conceptually, this resembles the “service trap” but involving the entire industrial sector and with the variable being information sharing instead of profitability.

Another barrier seems to be a low level of modularization and a high level of customized client key performance indicators (KPI) because of different core competencies and factory set-ups.

> ”In order to have any value [in benchmarking] there would be a way to compare KPIs around the globe. That you measure same things and they can be compared with each other. In many industries there is a challenges that there are no identical machines. That way, defining good KPIs that are comparable is challenging.” – Client B, VP Strategy

With respect to the big picture, top management attention is seen as an important issue both at Case OEM and its clients. At clients, getting top management interest and support for process operations improvements is essential from Case OEM viewpoint, especially if otherwise pilot projects would be bound to tight factory-level budgets. Also, if client would define their core business not to include process operations (but only for example sales and market knowledge), bigger investments to outsourcing services might get easier the top management attention to go forward. Internally, at Case OEM, top management attention was also found to be important. Providing new services might not bring additional high turnover alone in an appealing extent, at least in the short term, to justify continuation of development. Also, development might require non-traditional approaches on the parts of R&D and service development and larger internal investments if building stronger competencies with respect to information usage were the aim. Thus, in light of lack of measurable business potential and resource allocations for development in excess of typical budgets, visionary leadership by top management would probably be necessary for Case OEM to broaden its capability with respect to usage of high information intensity

7 Discussion

7.1 Answers to research questions

The original research questions for this study were crafted to be highly generic so as to explore the potential impacts of the proposed next industrial revolution from the servitizing OEM viewpoint. Key findings from the literature and empirical materials collected in support of the research questions will be summarized here and elaborated along with additional findings presented in the next section.

7.1.1 RQ1: How does information intensity affect machinery manufacturers' industrial service provision?

As the literature suggests, increases in information intensity enable more efficient after-market services such as condition-based maintenance or spare and wear parts optimization. Installed base data, if collected satisfactorily, can also be leveraged to increase service delivery efficiency (e.g., Ala-Risku, 2009). Asset availability and asset performance –type business models are also enabled by information intensity increase, data enabling OEE improvements, lifecycle cost decreases and proving the created additional value. Empirical findings and literature revealed that OEE improvement potential as a result of higher information usage varies greatly. The marginal cost of improvement in efficiency increases as OEE increase. Further analysis of the literature and empirical findings suggest that availability of data improves industrial service providers' opportunities to offer consultative services to support client production processes. By providing information-enabled services, service providers may gain further understanding of client production processes and expand vertically downwards in the value chain. Thus, installed base data can become an important asset for OEMs providing industrial services, if enriched with other data sources.

As one research approach, this thesis adopted a historical perspective with respect to information intensity in industrial settings. It was found that, in many cases, increases in information intensity are not as radical as Industrial Internet or big data publications suggest. Especially in process automation, increases have been gradual, and much of the efficiency improvement potential has already been realized during the past three decades with the use of relatively light analytical models and low information intensity.

It was found that information intensity affects different sectors in different ways. Many reported success cases from “big data” usage are essentially tracking-based solutions for industrial vehicle fleet (e.g., Sørensen & Bochtis, 2010; Porter & Heppelmann, 2014). Another similar success cases, Rolls Royce turbines or Wärtsilä engines, are also related to fleet management, but as power-generating units. In both cases information intensity helps in after-market sales provision, as installed base data can be enriched with machine data. In the case of fleet management, OEM may also develop new decision support tools such as dashboards giving suggestions for asset performance optimization. These can be sold as hybrid offerings, providing smart products and different services with availability or performance as value proposition.

Industrial assets that produce physical goods differ from logistics-related assets. In addition to after-market services, machine availability, and performance value propositions, increased information intensity enables various client process-supporting services. By combining an OEM’s internal knowledge base with service data, client process data, machine data, and possibly data from other sources, OEMs can leverage their knowledge to achieve process-related performance improvements or cost savings. With deepening process understanding, OEMs that are able to offer full production systems or act as systems integrators may be able to move further down in the value stream to process outsourcing solutions.

Figure 18 conceptualizes further Figure 6’s and Figure 8’s thing-oriented and system oriented view on two axis: decentralization and centralization (thing-system) and complexity of the unit (system). In between thing-oriented industrial applications of IoT, such as production vehicles, and system-oriented applications such as a process line, a hybrid combination of both has been added. An example for this sort of decentralized production system is for example mining. Next, Figure 19 links earlier discussion on thing-system view to advanced services provision, suggesting that complexity of OEMs feasible solution offering increases along with offered product/system complexity.

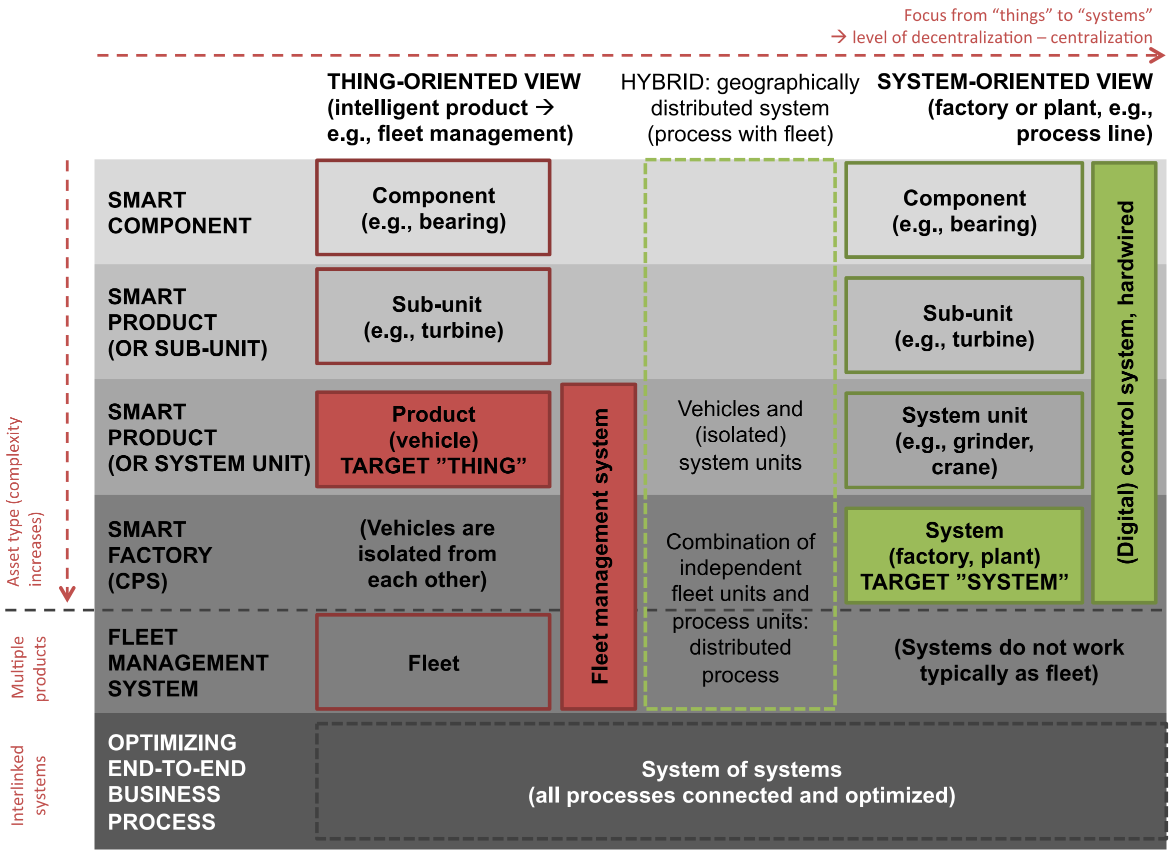


Figure 18: Conceptualization of key components for information-enabled services provision by unit complexity and process geographical distribution

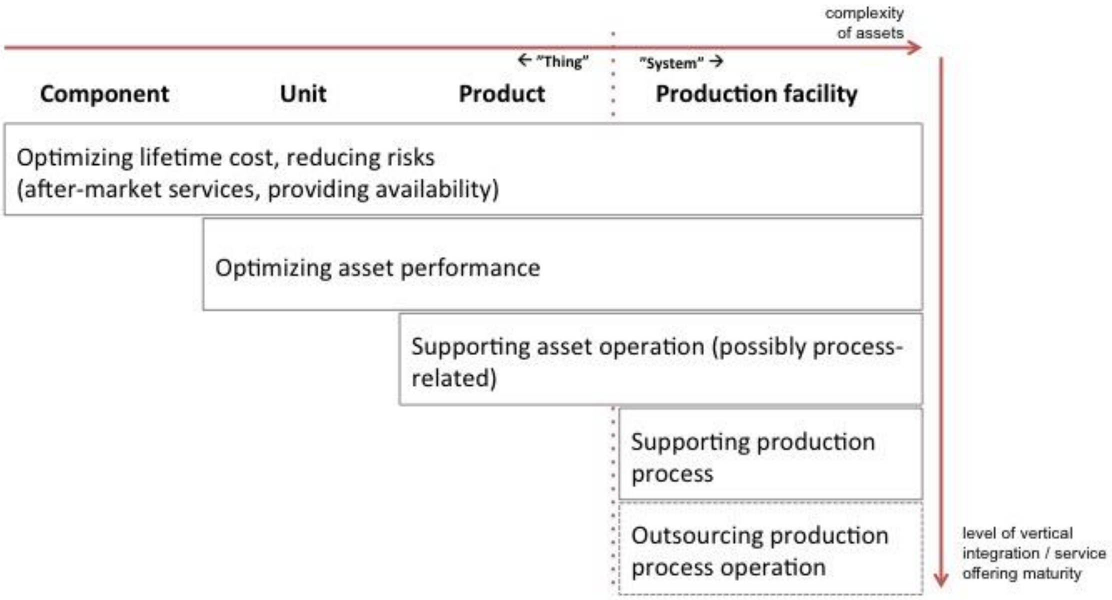


Figure 19: Complexity of asset offering and solution offering

Moving forward in advanced solution offering requires new capabilities, and only the largest clients or OEMs seem able to develop these capabilities completely internally. Therefore, value networks for industrial services become increasingly complex with the addition of new IT and analytics providers.

The empirical part of this study also suggested further segmentation of clients between those that are offered new advanced solutions and those that are not. Two important variables determining this segmentation are client size and installed base age. In industries where industrial assets are highly customized or form unique systems, services also need to be customized. If fleet age is high, the cost of making all required information available may be commensurately high, and data access issues then must be solved separately. Cost of hardware installation and work related to information model mapping may also become a constraint with small clients or small client sites.

The size of the industrial services market grows when companies expand vertically. However, the interesting question is how the market opportunity will be divided.

7.1.2 RQ2: What are the influences of increasing information intensity on the competitive environment of OEMs service provision?

Originally this research question was posed from the viewpoint of potential disruption. However, it was soon discovered that disruptive forces are much smaller in production–related industries than, for instance, in intangible or platform-based businesses (Eisenmann et al., 2006). Replacing industrial assets, physical manufacturing, or even know-how of highly specialized industrial assets is difficult. However, some parts of a service offering might be disrupted or disruptive towards other value network partners and data platforms might create opportunities for new entrants to gain a “control point” (Pagani, 2013) in the value stream. Information intensity requires new capabilities and seems to make value networks more complex.

Machine learning models reduce the need for expert-led hypothesis-based testing to investigate failure root causes or to discover productivity and cost-reduction opportunities. Therefore, information intensity in industrial services creates the possibility of a competitive threat from third party service providers. IT sector companies, however, are not viewed as genuine competitive threats with respect to process consultation services, at least where production systems are highly complex and customized. Expert knowledge was seen as fundamental in assuring that simulated solutions would also be feasible in practice.

Information intensity requires new capabilities, and, while some of the largest clients might be able to gain these capabilities with the aid of analytics partners reducing their dependency on OEMs, it seems unlikely that this would become industry standard. OEMs were considered to have the highest value-creation potential with respect to increased information intensity. An important factor proposed to affect this development was a client outsourcing/core competence strategy, proposed also by Lightfoot and Baines (2013) as an interesting lens through which to view servitization. Changing roles in the value network are illustrated in Figure 20 below.

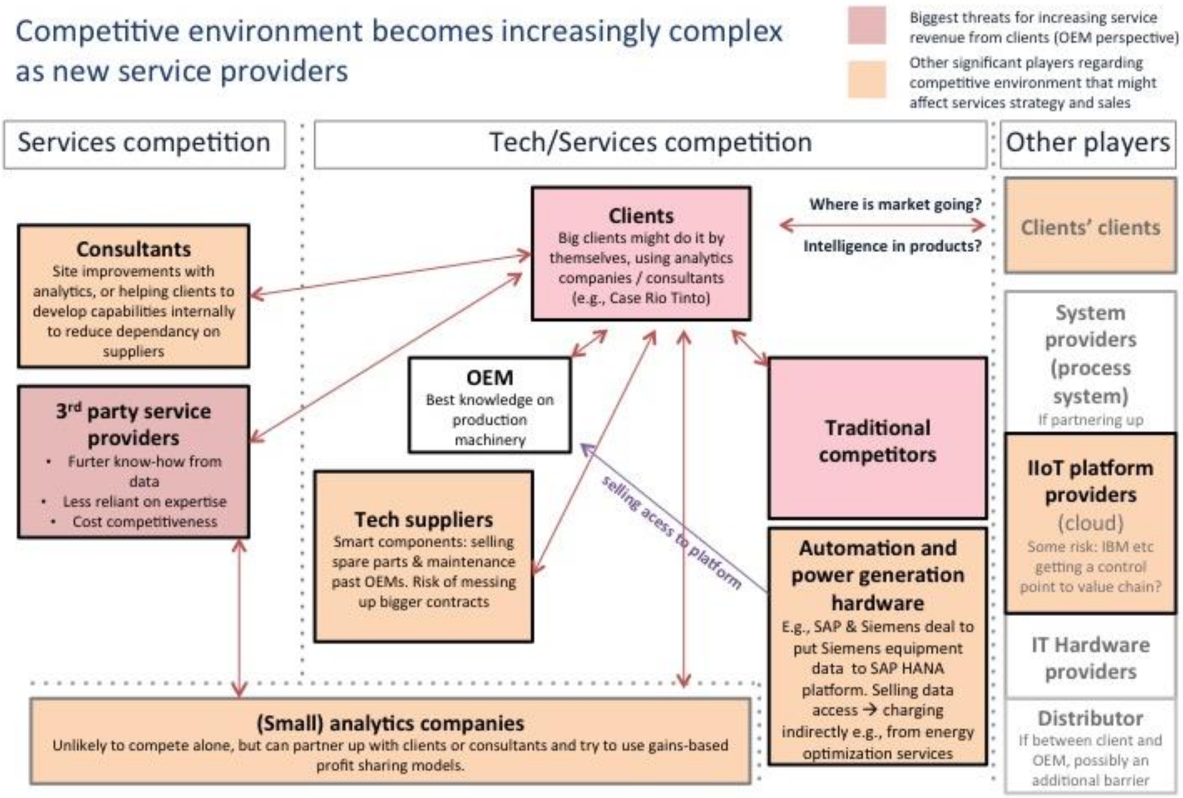


Figure 20: Competitive environment

Cloud-based data platforms might bring new value exchanges to the industrial sector. For example, big power and automation hardware providers are planning to offer their hardware-produced data on a cloud platform and to charge for data access. While OEMs and manufacturers should be able to collect the same data themselves, simply buying data access might be the most cost-efficient solution due to the effects of scale involved in these huge power and automation hardware companies implementing IoT platforms. Similarly, employing the same reasoning, some OEMs might be able to build an internal knowledge base that can be monetized.

7.1.3 RQ3: How does information intensity influence service business strategy and services sales?

Based on findings related to RQ1, increasing information intensity provides opportunities for vertical integration with respect to client core processes, thereby increasing potential market size. Interviews at Case OEM and its clients revealed that opportunities for new stand-alone services enabled by analytics might be scarce or difficult to commercialize. Consequently, it was proposed that, instead of commercializing new capabilities separately, these services be bundled with an existing solution offering. Consequently, the value promise associated with OEMs would strengthen relative to those of third party service providers or clients' internal service organizations, thereby helping OEMs to win valuable long-term contracts.

The competitive threat posed by third party service providers has traditionally been their lower cost. With analytics capabilities, third party service providers might also strengthen their position in advanced services solutions. Efficient usage of installed base data has been recognized as improving service delivery efficiency (Ala-Risku, 2009). Enriching this data with machine data and setting virtual service operations centers might further improve OEM capabilities in executing service delivery. Cost competitiveness could be further improved by using third party service providers in hybrid arrangements (Kowalkowski et al., 2011). With analytics providers adopting a partnership role, the appeal of service provision partner networks is increasing in appeal.

Applying Teece's (2007) terminology, industrial service providers should at least sense opportunities regarding new competencies and service development based on higher information intensity. Advanced analytics and installed base data play a distinct role in advanced solutions offering. Many issues regarding service development, such as data access, need to be solved, but without a company-wide approach and targets, seizing such opportunities might prove difficult. Because information seems transformative for service offerings and delivery, companies need to also reconfigure their organization and processes. Due to the likely segmentation of clients into those that will not be offered anything new and those that will, an ambidextrous approach is likely to be required, another option being to abandon one of the segments.

From a sales perspective, the service development phase is especially challenging because, for sectors with small development budgets, existing value arguments might not be strong enough to attract pilot customers. Therefore, deciding on a service development approach–

internally or in collaboration with a client–should be carefully considered in advance. Proposed bundling of new competencies with existing services portfolio prompts questions on the provision and pricing of these add-on elements, both with respect to internal KPI and the client’s perspective.

Client procurement also provides an interesting perspective. If an industrial service provider improves its quality perspective, it is more likely to be considered as a potential strategic partner instead of a commoditized service provider that will be purchased services, cost being the still the primary KPI. Unfavorable positioning on Krajlic’s (1983) matrix might be another important factor either supporting or constraining advanced solutions sales.

7.1.4 Additional findings

During the abductive reasoning process, other interesting findings were uncovered. Firstly, information intensity was identified as explaining the transition to advanced services to a large extent. The analytical frame based on information intensity was found to be more suitable than the big data framework to justify this explanation, because the latter typically does not take into account forms of information other than data.

Secondly, the literature review on Industrial Internet and Industrie 4.0 revealed that these two discourses hardly overlap due to their relative orientations to either “things” or “systems”. This finding was further elaborated by presenting technological perspectives and business perspectives that explain the weak overlap. It was found that many manufacturing sectors have been able to use machine data for decades because of hardwired systems, whereas in the case of distributed machine units, only remote connections enable use of comparable analysis and control mechanisms. Therefore, in many industries, the development into Industrie 4.0 can be seen as a continuum beginning with the development of digital control systems, but in distributed systems the transition was more radical, as many authors within the Industrial Internet context suggest. Because many industrial production sites have achieved high OEE during the past decades, the potential of advanced analytics is smaller than in some other industrial sectors.

7.2 Synthesis of findings

Part 7.1 gave concise answers to the research questions based on the literature and empirical results uncovered in the study and also presented some key findings. However, due to the breadth of the work, many different findings could be reported, and many conclusions or propositions could be drawn. Thus, this section will give a synthesis of most of the findings. To aid the reader, the findings are formatted in bullet-point style, presented as proposition, and organized with respect to thematic entities. Part 7.3 will elaborate further on the findings presented in parts 7.1 and 7.2 in the form of discussion.

7.2.1 Market maturity fosters information capability-based competition

Process manufacturing industries that have reached market saturation seem to offer fewer opportunities for information-intense advanced service provision than those that are still growing. This is likely to be generalizable outside the process manufacturing context also.

- Process-related services: High process efficiency rates have typically been achieved, leaving less room for further OEE increases. Opportunities are in client core process –related services that help improving cost performance (energy, raw materials, quality costs, employee costs etc)
- Product-related services: Declining industries struggling with overcapacity issues might regress with respect to maintenance sophistication
    - If all capacity cannot be utilized due to low demand, there is no need to minimize downtime. Therefore companies may step back from condition-based maintenance to reactive maintenance.
    - However, if cost performance during production shifts can be improved with condition-based management, avoiding, e.g., unplanned downtime, market potential for advanced services related to industrial assets exists.
- In cases where tradeoffs between benefits and costs are positive, organization-related barriers related to value-based sales might exist:
    - Fixed and tight maintenance budgets may restrict trying out new services
    - If factory managers have high independence and company top management does not view operations as core process, larger firm-wide contracts might be difficult to sell

7.2.2 Growth of information-based business builds on contextual expertise

Companies aiming to grow their service business through higher information intensity should be looking at client core processes and beyond basic after-market services, thus leading to vertical expansion.

- In many cases, after-market services have limited client-relevant improvement potential, whereas process-related cost reductions in energy, raw materials, employees, or quality may be more significant. Also in growing industries capacity maximization and quality improvements may have significant potential.
    - Through continuous learning from client processes, industrial service providers might develop capabilities with respect to client production process outsourcing services. This trend may be further aggregated by industry consolidation and private equity owners, aiming to fix costs.
- After-market services delivery (internal execution) benefits from higher information intensity but also requires a functional installed base data.
- New services might be possible to develop beyond current product- or process-supporting services, but their potential is assumed to be relatively low as long as the client's processes are directed to producing physical output.
- Many new functionalities that higher information intensity enables are likely to have most potential when bundled with existing service offering
    - The marginal benefit from higher information intensity seems to be decreasing, the turning point varying by industry and by industry application

7.2.3 The ways in which digitalization enables information intensive business opportunities vary by industry

Enabling technologies and unit type (e.g., component, unit, product…) in focus seem to explain many sectorial differences

- Tracking technologies such as GPS and RFID have the most potential in logistics-related processes.
- Remote connections are most beneficial when connecting previously isolated units into an interconnected system.
- Physically wired production systems have enabled relatively high information intensity since the 1990s.

- Also hybrid systems exist, incorporating elements of geographically centralized and decentralized systems
- The more complex the unit in focus (component, unit, product, system…) is, the more difficult it becomes to optimize
    - Components and separate units are relatively simple and produce manageable (big) data masses, whereas complex systems may surpass technical limits and be costly to implement.

7.2.4 Information intensity leads to encapsulated networks and ecosystem-level competition

Competitive environment and value networks are becoming more complex with higher information intensity. Non-traditional competitors arise as threat.

- Third party service providers may minimize their lack of machine-related knowledge with machine learning algorithms.
- Horizontal suppliers such as automation and power hardware suppliers are attempting to build data platforms with IT providers.
- Clients with satisfactory internal resources and capabilities may realize most of the benefits of higher information intensity with an analytics partner and possibly other partners. However, this is likely to be reasonable only for the largest manufacturers, and an OEM’s tacit expert knowledge cannot be replaced completely with analytics.
- IT companies are not regarded as a significant threat to OEMs’ industrial service provision, as long as the processes are complex enough to require expert knowledge. They can, however, partner with other value network companies. Risk of obtaining a control point to value networks seems unlikely as long as platforms do not have very high lock-in effects.
- Role in supply chain impacts opportunities for service provision: The closer the technology supplier or OEM is to the client, the higher the opportunities are to develop new service offerings. Many companies may offer services simultaneously, orchestrated by the main service partner or client. A possible distributor between OEM and client can be a barrier to advanced services provision.

7.2.5 Basic services become commoditized and consumerized across industries

Due to increasing competition, basic services such as basic maintenance operations are likely to be commoditized.

- Hybrid arrangements (orchestrating a network of third party service providers) constitute an opportunity for OEMs, if information is effectively used in support of this.
- Also information utilization capabilities are likely to commoditize: dynamic capabilities are needed

Based on the findings given above, high information intensity services seem to have highest potential in industries where the following are true:

- Industrial assets have not been connected with each other due to existence of high OEE improvement potential.
- Market growth enables investments, and clients are willing to outsource their processes.
- Decision-making is centralized, enabling company-wide solutions.
- The service provider has direct contact with the client and is considered to be a key supplier or partner.
- Industrial asset lifecycle is reasonably short; the installed base is renewed in a reasonable timeframe.

7.3 Implications for research and practice

Previous chapters present concrete evidence on the impact of digitization and increasing information intensity in industrial services. By combining various literature sources and empirical material, a holistic representation of the phenomenon has been created to the extent that current literature and empirical world feasibly enables. This can be considered as one of the contributions of the thesis, revealing the converging discourses on the phenomenon from various research areas, and thus helping future researchers to link their research to other relevant discourses with additional viewpoints and insights.

7.3.1 Call for research agenda: A multidisciplinary approach to digitization in industrial services

It was found that, as Industrial Internet and Industrie 4.0 publications suggest, information is transforming industrial sectors and processes and consequently also industrial services provision. The importance of industrial services in the realization of the new industrial revolution has been proposed here to be essential. Although many players are likely to participate in these increasingly complex value networks and, on their part, aggregate change, servitizing OEMs were found to have unique capabilities in realizing the benefits of information, when working together with a client. By learning from these joint efforts, OEMs may develop their process-related competencies, consequently leading to vertical expansion and possibly changing industry logic on core competencies related to operational processes. Adoption of higher information intensity in industrial service provision was proposed to be strongly linked to advanced services provision, where production process outsourcing services may emerge as a new opportunity. Digitization also changes the competitive environment of industrial service providers and adds complexity to value networks. Based on these findings, two implications on future research can be deduced.

The role of information seems transformative for industrial service provision, and it should thus be raised to the servitization and services infusion research agenda. Besides information, the role of digital infrastructures in industrial services provision has not been awarded sufficient attention in the servitization literature. The role of such structures seems to be becoming increasingly essential in industrial services provision, and in line with Information Systems researchers (Tilson et al., 2010; Yoo et al., 2012), digitization and digital infrastructures are strongly suggested as deserving of increased attention in the future. Although a few articles, such as Kowalkowski et al. (2013), Grubic (2014), and Opresnik and Taisch (2015), have already contributed to the topic, its importance and the aforementioned articles' limited focus and some shortcomings in setting the scene leave room both for holistic perspectives and more focused research on the topic.

Moreover, it would be beneficial for future servitization research on industrial digitization to adopt a common terminology, or at least to better acknowledge the relevant discourses related to the phenomenon within other management and engineering communities. The complexity of the topic seems to challenge industrial service providers to such an extent that very few informants seemed to understand the phenomenon or its implications well. Therefore, researchers of the topic should preferably have strong industry contextual knowledge and technological understanding, particularly to ensure the validity of findings based on qualitative material or of propositions based on quantitative material. Facilitating this would be a cross-disciplinary approach to the phenomenon, acknowledging and adopting the various terminologies and viewpoints from the managerial Industrie 4.0 (e.g., Kagermann et al., 2013) and Industrial Internet (e.g., Porter & Heppelmann, 2014) discourses, as well as from the more technical academic publications on the enabling technologies and sector-specific solutions.

Future research should also acknowledge the two findings derived from this study’s broad literature review: (1) thing- vs. system-centric views of IoT in industrial settings and (2) the non-disruptive, long-term trend of increasing information intensity in system-centric industrial settings in contrast to the more radical change evident in thing-centric settings. Along with servitization, adoption of this thing-system division would be beneficial in other Industrial Internet-related management and technical discourses also.

7.3.2 Theoretical and practical implications of increasing information intensity on servitization

Increasing information intensity adds new perspectives to maturity model-type service offering categorizations (e.g., Baines & Lightfoot, 2013; Gebauer et al., 2013; Neff et al., 2014; Kohtamäki & Helo, 2015). Based on the findings of this study, information intensity is to a great extent the enabler for higher value offerings. This is not a completely novel finding; Neff et al. (2014) built a maturity model for service offerings reflecting underlying technological enablers such as remote monitoring, and Ulaga & Reinartz (2011) identified the role of various data sources as enablers for services provision. However, the model of Neff et al, (2014) does not include considerations on information intensity, and it is based on the assumption of a centralized service center that uses remotely transferred data. This study shows that Neff et al.’s (2014) categorization is not normative but only one possible solution among other possible configurations. In process automation, remote monitoring was found not to be a necessity for advanced solutions provision as high information intensity services can also be produced locally–the largest clients having relatively good opportunities of doing it even without the aid of an OEM or of orchestrating the supplier network. It seems logical that commercialization or industrialization (Kowalkowski et al., 2015) of new advanced solutions may benefit from centralization, but in industries with low levels of standardization and high data volumes, either decentralized or hybrid local-global arrangements may constitute a more suitable service delivery configuration.

Consequently, advanced solutions may be fruitful to analyze from the perspective of information intensity. Also industry dynamics in terms of industry lifecycle and client approaches to outsourcing (Baines & Lightfoot, 2013) should be better acknowledged, offering opportunities for an integrated advanced solutions maturity model, or at least additional lenses that academicians and industry practitioners could apply.

Traditional product-centric after-market services such as spare parts and maintenance have a value proposition based essentially on providing asset availability with reduced lifecycle cost. Maintenance strategies ranging from reactive levels to preventive and predictive levels require increasing levels of information intensity and enable incremental improvements with respect to value creation. In addition to installed base data at the preventive level, predictive level maintenance strategies require machine data. However, within the predictive maintenance approach, multiple technical steps enable increasing information intensity usage, each enabling further levels of optimization: (1) analytical models based only on machine and installed base data, (2) analytical models using various other sources also, and (3) analytical models using machine learning algorithms (see Figure 21). Additionally, expert opinion might be needed to correctly interpret the results, thereby involving consultative services.

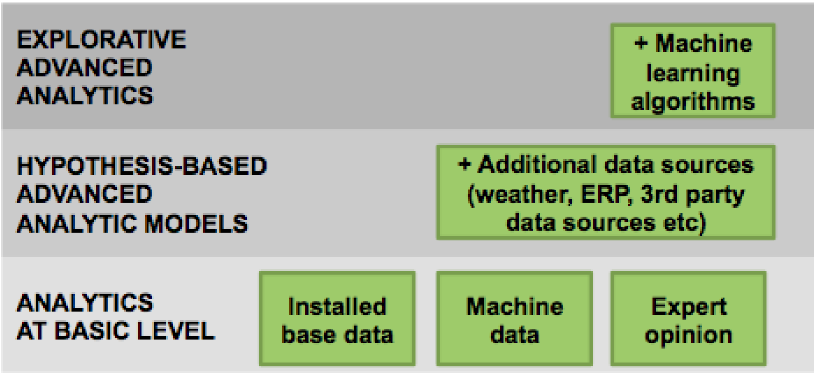
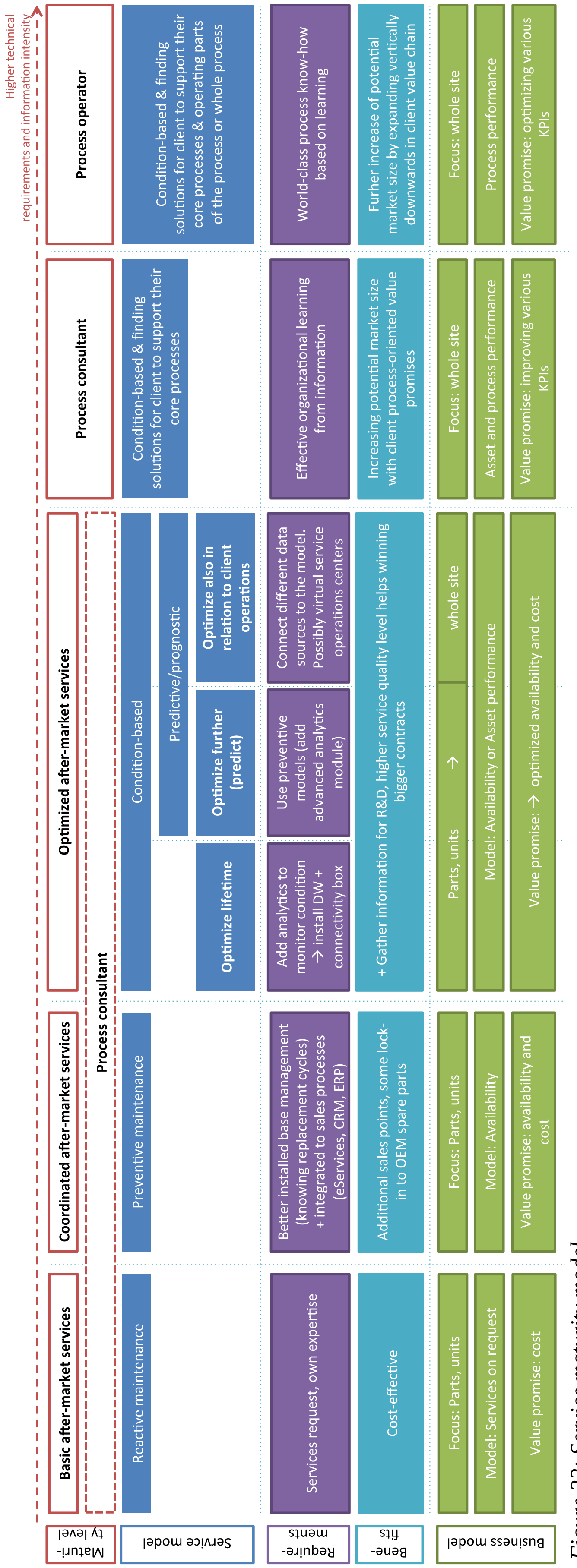


Figure 21: Categorization of analytics

Servitization scholars classify client process-oriented services in various ways and in various quadrants, such as the distinction between transactional and relational services or Oliva and Kallenberg (2003). In maturity models, it would be tempting to see process-supporting services as advanced solutions, but in many cases these can be one-off process improvement cases based on OEM expert knowledge. But as Ala-Risku (2009) or Ulaga and Reinartz (2011), for instance, propose, by learning from client data, OEMs can deepen their knowledge base. Therefore, with efficient after-market services provision on a high information intensity level, service providers can learn more from client core processes and move further in a linearly thought maturity model. It seems that Kowalkowski et al.'s (2015) point on non-linear service transformation does not work well on a service offering conceptualization based on a Gebauer et al. (2013) type perspective to vertical expansion to client processes. That is, after all, what ultimately may result from learning driven by high information intensity.

Based on the literature analysis and empirical findings, it seems that new and additional services beyond traditional product and process-supporting services (e.g., Mathieu, 2001) have limited potential. Most immaterial services based on data and information either replace current after-market services (e.g., 3D CAD models for spare parts) or support client processes (e.g., dashboards). A viewpoint expressed earlier that information-based services, such as those offering weather service instead of measurement equipment, is fundamentally about process outsourcing, likewise to any other process outsourcing service, in the form of outsourced operations or output-as-a-service. Because practically all OEM services offered to current clients can be seen either as a product or a process-supporting service, the only truly new business based on increased information intensity seems to originate either from new client segments or from the current value network through the selling of data, information, or analytics as a service, following Delen & Demirkan's (2012) classification. Therefore, those new services not supporting client processes or products should be viewed as horizontal expansion. They are not included in the service maturity model presented on the next page (Figure 22), which categorizes service offerings based on the technological maturity required to produce that service type. While following typical categorizations (e.g., Baines & Lightfoot, 2013; Kohtamäki & Helo, 2015) on services maturity, Case OEM demonstrated that industry-specific issues such as overproduction might lead to situations where many clients demand basic services while the service provider had the capability to deliver more sophisticated services. Therefore service providers may have capabilities that exceed most clients' demands, offering still mostly cost-optimized basic services for many clients while being able to deliver advanced solutions for the segment that perceives benefit from purchasing these higher value offerings but has not built organizational barriers to buy value-creating services, such as applying tight, fixed budgeting that does not take into account possible other savings.



Maturity level	Basic after-market services	Coordinated after-market services	Optimized after-market services	Process consultant	Process operator
Service model	Reactive maintenance	Preventive maintenance	Condition-based Predictive/prognostic **Optimize lifetime** **Optimize further (predict)** **Optimize also in relation to client operations**	Condition-based & finding solutions for client to support their core processes	Condition-based & finding solutions for client to support their core processes & operating parts of the process or whole process
Requirements	Services request, own expertise	Better installed base management (knowing replacement cycles) + integrated to sales processes (eServices, CRM, ERP)	Add analytics to monitor condition → install DW + connectivity box Use preventive models (add advanced analytics module) Connect different data sources to the model. Possibly virtual service operations centers	Effective organizational learning from information	World-class process know-how based on learning
Benefits	Cost-effective	Additional sales points, some lock-in to OEM spare parts	+ Gather information for R&D, higher service quality level helps winning bigger contracts	Increasing potential market size with client process-oriented value promises	Furher increase of potential market size by expanding vertically downwards in client value chain
Business model	Focus: Parts, units Model: Services on request Value promise: cost	Focus: Parts, units Model: Availability Value promise: availability and cost	Parts, units → whole site Model: Availability or Asset performance Value promise: → optimized availability and cost	Focus: whole site Asset and process performance Value promise: improving various KPIs	Focus: whole site Process performance Value promise: optimizing various KPIs

Figure 22: Service maturity model

Research findings also implied that a dual approach might be needed in advanced solutions provision. Long lifecycles of industrial assets in many manufacturing sectors, combined with a potentially high investment cost to modernize them, might require service providers to segment their client base into those that are offered high information intensity services and those that are not. Also client size and client approaches to core competencies were recognized as additional valid segmentation factors. Therefore, besides a services transition-related viewpoint to exploration and exploitation (O'Reilly & Tushman, 2008), a perspective on a segmentation-based dual approach might be worth of investigating with respect to servitization.

This study proposed many variables that affect the transition to higher information intensity -enabled service offerings. Industry evolution has been recognized as one interesting explaining factor (Cusumano et al., 2015), and this study found further evidence that industry evolution, when measured by process efficiency or OEE, is also important managerially. When very high efficiency rates have been achieved, additional value derived from increased information intensity levels is relatively small, and therefore in some cases a no-go decision with respect to developing advanced solution offerings might be well justified, with segmentation and dual approaches offering yet another option. It was also proposed that in the cases where very high OEE has been achieved without typical IoT technologies, relatively high information intensity has likely been available locally, supporting the validity of the analytical framework and suggesting that information intensity is the underlying factor creating (most) of the value.

Besides a perspective based on process effectiveness and industry maturity, market maturity seems to be another relevant lens for service providers to look at service offerings. Case OEM suffers from overcapacity in a market where demand is constantly decreasing. Since all capacity has not been in use, manufacturers regress with respect to maintenance, transitioning from condition-based to reactive maintenance. While the market is likely to balance itself at some point as firms react by closing facilities, long asset lifecycle could extend this balancing process over decades. A saturated market therefore seems to provide a challenge for advanced service solutions, at least with respect to goods-centric services. With higher recycling rates and saturating or even declining demand for such raw materials as steel (Pauliuk et al., 2013) over the long run, cost efficiency sooner or later becomes the dominant determinant of industrial production. This is a challenge but also an opportunity for OEMs and their service provision; with maturing markets and a low level of differentiation, all factory operations are likely to commoditize as long as the market has enough competition. OEMs could therefore end up abandoning basic service operations to escape the service trap, but with a streamlined service organization they could expand vertically to process outsourcing, which might offer tempting profit margins based on several assumptions. If economies of scale and machinery-related know-how enable more efficient process operations, the market could offer interesting opportunities during the phase when the entire industry is increasingly adopting this higher cost competitiveness level. Classic economic theory on competition and equilibrium work predict that, over the long term, all capabilities could be expected to commoditize as the industry matures, leaving only asset ownership or access to capital as sources of competitive advantage, pushing towards ongoing consolidation as long as institutions do not interfere. On the goods side, shifting focus to recycled materials might open up opportunities for new machinery sales directed at recycling or applying the logic of a circular economy to OEMs themselves; refurbished or remanufactured industrial assets might become more common, changing industry logic (e.g., Seitz, 2007) and also affecting service provisions by creating secondary markets for products that have not yet reached the ends of their lifecycle. This would also speed up renewal of installed bases at the most sophisticated clients, resulting in a quicker adoption of new services, if old technology is considered to be a constraint with respect to advanced services adoption by clients. To be able to offer effective refurbishing of industrial goods, OEMs would need records on machine usage history on their installed base. Therefore, service models driven by high information intensity could open up new business model opportunities, and increase the clock speed of industry evolution and renewal.

Findings from empirical materials also support the Baines and Lightfoot (2013) proposition that client approaches to outsourcing affect industrial service providers' opportunities to adopt advanced solutions. It was proposed that type of ownership of the company might affect this approach, private equity owners being more likely to outsource operations than traditional companies. Another interesting perspective worthy of study in the future is the effect the position of the OEM within the client's value chain has on its ability to offer high information intensity-enabled services. Empirical evidence from this study is not sufficient to make well-argued propositions as to how OEM positioning in the client value chain as supplier affects its opportunities for effective advanced solutions sales, but three interesting variables were identified for further evaluation: (1) The positioning of the OEM in the client value chain either as a component, unit, or system supplier and integrator, with a relatively higher role offering greater opportunities to move from product- to process-directed services; (2) The position as supplier in Krajlic's (1983) matrix, reflecting client core competencies and outsourcing approaches (vs. Baines & Lightfoot, 2013); and (3) The role of a possible distributor as a barrier between OEM and client for OEM's advanced solutions provision.

Based on the reflections above, it seems that as Opresnik and Taisch (2015) suggest, information processing capabilities can open up new opportunities and decrease costs associated with service delivery. However, based on the literature analysis and empirical materials, it seems that big data-type capabilities will quickly become a commodity and, contrary to what Opresnik and Taisch (2015) propose, provide competitive advantage only for a limited time for the first-movers. Also, high information intensity is regarded as supportive of advanced solutions, not as an important source for completely new service concepts and types. With that view, higher information intensity is analogous to the adoption of management information systems in the 1990s, which have since become standard IT solutions rather than differentiating digital infrastructures. Consequently, rather than IT being in and of itself a source of competitive advantage, the capabilities of managing IT investments and the infrastructure are likely to constitute possible success factors within the industrial context, following Weill and Aral's (2006) findings.

Higher information intensity in industrial services is likely to grow the potential market for OEMs, but the questions of (1) who will participate in the division of it and (2) how to do that efficiently should be interesting both to practitioners and researchers. Complexity of value networks seems to increase with newly entering players such as analytics service providers. Third party service providers might become a major threat with their typically higher cost competitiveness and possibly improved capabilities for higher value services. Hybrid arrangements (Kowalkowski et al., 2011) may become an interesting option for OEMs willing to improve their cost competitiveness in commoditizing service categories. Non-traditional competitors such as automation and power hardware suppliers or IT providers may attempt to obtain a control point in the value networks with data platforms (Eisenmann et al., 2006; Cusumano, 2013). The increasing complexity and data sharing options also opens up questions on organizational boundaries. Jonsson et al. (2009) deserves praise for introducing the issue within the context of industrial services, but their work could be further elaborated from the mostly dyadic perspective they employ to complex service delivery configurations.

Research findings also have practical and theoretical contributions for industrial selling. It was proposed that new services are likely to have limited potential if offered solely and therefore should be bundled with existing service offerings. Other propositions were made concerning segmentation of clients and an ambidextrous approach to exploitation. Many informants also highlighted the importance of arguing the value propositions with quantified benefits. But because overcapacity seems to lead to unwillingness to participate in new service development, requirements for value quantification easily become a chicken-egg problem that needs to be surmounted. Internal sales KPIs and client billing based on new capabilities are also concrete problems that industrial services providers need to solve.

Outside the pure servitization context, several further findings are worthy of note. Current taxonomy for smart or intelligent products was found to be blurry and a source of confusion. A conceptualization taking into account thing- and system-centricity was proposed. This conceptualization needs further validation.

Data access challenges were brought up in the interviews, but these did not seem to offer much new to the existing understanding on the issue (e.g., Porter & Heppelmann, 2014), and they were mostly left out from Chapter 6’s description of the study’s empirical material. However, new perspectives aroused from data volumes that seem to have at least practical implications for industries producing more data than can be practically collected. Relevant considerations in addition to Porter and Heppelmann’s (2014) list of ten questions for Industrial Internet seem to be, at least with respect to the process automation context: (1) level of local or fog computing required to address constraints related to data connection speed; (2) data velocity and quality of service (reliability of connection) requirements if processes are self-adjusting so as to manage risks, and; and (3) requirements for system- and process-wise response times between different layers of the ISA-95 model.

7.3.3 Practical implications and recommendations for the Case OEM

Due to the confidential nature of the Case OEM interviews, most practical recommendations regarding strategic decisions, implications, and service development opportunities have been excluded from the thesis. The previous section on theoretical and practical recommendations includes some of these considerations. However, a few general recommendations can be highlighted here also, as they are most likely relevant to other industrial service providers.

First, increasing availability of information in industrial services seems to have a transformative effect on services strategy. Case OEM has not yet formulated a company-wide strategy with respect to digitization, which is highly recommended. Second, it seems that new services should not be offered separately but bundled with current offerings and aimed at boosting large, continuing service deals. Therefore, internal KPIs should be designed in a way that supports new information-enabled services development. Value propositions and goals should also be focused on providing value-creating solutions to client core processes. Third, Case OEM should develop a new organizational approach to service development to ensure that different initiatives across organizational silos converge. Fourth, the company should try to build a stronger internal base database. That would be likely to result in greater efficiency in sales, and improve services quality and cost competitiveness. Virtual service operations centers could provide a possible means of leveraging that knowledge base, also providing an opportunity to further outsource low-margin services to third party service providers while maintaining control of quality. Finally, data access issues need to be addressed, one recommendable action being to develop a standard contract for data sharing. Lastly, Case OEM should approach digitization with an open mind, assuming that the failure at the turn of the 2000s to commercialize remote monitoring was caused primarily by immature and, at the time, overly costly technologies.

7.4 Limitations and ethical issues

No study is free from limitations. The major limitations of this work are related to the scope of the thesis, empirical material, and topicality of the target phenomenon.

This thesis is wide in scope. Although research questions have been answered and the target phenomenon has now been positioned academically, more work will be needed to bring digitization to the servitization research agenda. Many different topics have been covered to a satisfactory depth in the literature review, but some viewpoints may not have been identified or others that could be beneficial to study in more depth have been ignored. For example, Information Systems research could be given more focus to position topics such as the strategic role of IT or profitability of IT investments in the industrial services context. Also, various other servitization topics beyond service offerings and service strategy could be addressed, data sharing and organizational boundaries being clearly one topic that has not been covered sufficiently here. However, covering all possible aspects in one study was impossible, and this thesis has primarily focused on providing an introduction to the emerging phenomenon.

Restricting this study to one case company is another limitation. Following Eisenhardt's (1989) recommendation, covering at least four to six case companies at a similar depth as was done here with Case OEM could further validate findings and the analytical frame of information intensity. This thesis also used secondary materials in triangulation, but the material had been provided by the companies for branding and marketing purposes and thus cannot be trusted in the same way as primary material. Secondary material also does not often give perspectives on the development of the new services or the enabling technologies. Still, the novelty value of Case OEM is considered high, and, with supporting materials and literature sources used, the validity of findings should not be a concern. Most contributions were descriptive, focusing on the phenomenon, and findings related to servitization are based on Case OEM, which is described with transparency in materials and findings.

Novelty of the topic is a clear limitation. It is still impossible to evaluate many of the findings in hindsight, which is the typical approach for most academic research. Along with the adoption of higher levels of information intensity, companies will gain experiences that are real, but subjective instead of the more technology-focused realist nature findings in this thesis. The role of information in service strategy and service offerings should be reviewed and possibly revised after several years, by which time profitability issues will be possible to assess.

Ethical considerations regarding the research approach also deserve space here. High ethical standards are needed when using Dubois and Gadde’s (2002) abductive research methods: although the methodology section described thoroughly the research process, the actual reasoning process is practically impossible to describe in a traditional research report format (Subbady, 2006). Based on the experiences of this research project, two suggestions could be given. Firstly, methodology should explain step-by-step the different decisions that were made along the research process and so provide a fair picture of the flow of the research process. Secondly, findings that do not have extensive empirical material on the background should be written with transparency and modesty, giving the reader an opportunity to make his/her own assessment of the findings.

Besides research methodology, some important ethical considerations concern the research topic. In the coming decades, digitization will most likely automate even many white-collar jobs (Brynjolfsson & McAfee, 2014). The extent of this change can be radical for masses of individuals, posing important questions regarding future social structures and the state’s role in controlling digitization. If only a fraction of current jobs will be required, income and social gaps will likely widen further with most citizens ending up in labor-intensive and low-productivity positions. Therefore, researchers covering the topic should at least acknowledge the destructive forces of artificial intelligence and digitization. Research ethics might conflict with socially motivated ethics, and researchers may argue that ethical considerations on social impacts conflict with their integrity. However, the severity of the consequences of the possible mass-destruction of jobs with respect to individuals’ future well-being is so high that future researchers should at least go through the cognitive process of considering their position with respect to ethical considerations concerning digitization and society.

References

Agostini, A. & Berghiolli, S. (2014). Condition Based Maintenance in the Paper industry. Maintworld, September 7, 2014, 1-14.

Ala-Risku, T. (2007). Installed base information management with industrial service operations. Proceedings from POMS 18th Annual Conference. Dallas, Texas.

Ala-Risku, T. (2009). Installed base information: Ensuring Customer Value and Profitability after the Sale. Doctoral dissertation. Helsinki University of Technology. Espoo, 2009.

Allmendinger, G. & Lombreglia, R. (2005). Four Strategies for the Age of Smart Services. *Harvard Business Review*, 83(Oct), 131-145.

ANSI/ISA-95.00.01-2010 (IEC 62264-1 Mod). (2010). Enterprise-Control System Integration - Part 1: Models and Terminology.

Antioco, M., Moenaert, R.K., Lindgreen, A. and Wetzels, M.G.M. (2008). Organizational antecedents to and consequences of service business orientations in manufacturing companies. *Journal of the Academy of Marketing Science*, 36(3), 337-358.

Armistead, C., & Clark, G. (1991). A framework for formulating after-sales support strategy. *International Journal of Operations & Production Management*, 11(3), 111-124.

Arrow, K. (1984). The Economics of Information. Belknap Press of Harvard University Press, Cambridge, MA.

Artto, K., Valtakoski, A., & Kärki, H. (2015). Organizing for solutions: How project-based firms integrate project and service businesses. *Industrial Marketing Management*, 45(2), 70-83.

Ashton, K. (2009). That ‘internet of things’ thing. *RFiD Journal*, 22(7), 97-114.

Atzori, L., Lera, A. & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*, 54(15), 2787–2805

Baines, T. S., Lightfoot, H. W., Benedettini, O., & Kay, J. M. (2009). The servitization of manufacturing: A review of literature and reflection on future challenges. *Journal of Manufacturing Technology Management*, 20(5), 547-567.

Baines, T., & W. Lightfoot, H. (2013). Servitization of the manufacturing firm: Exploring the operations practices and technologies that deliver advanced services. *International Journal of Operations & Production Management*, 34(1), 2-35.

Bandyopadhyay, S., Sengupta, M., Maiti, S., & Dutta, S. (2011). Role of middleware for internet of things: A study. *International Journal of Computer Science & Engineering Survey* (IJCSES), 2(3), 94-105.

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of management*, 17(1), 99-120.

Barton, D., & Court, D. (2012). Making advanced analytics work for you. *Harvard business review*, 90(10), 78-83.

Benkler, Y. (2003). Freedom in the commons: Towards a political economy of information. *Duke Law Journal*, 1245-1276.

Boisot, M., & Canals, A. (2004). Data, information and knowledge: have we got it right? *Journal of Evolutionary Economics*, 14(1), 43-67.

Bonomi, F., Milito, R., Zhu, J., & Addepalli, S. (2012). Fog computing and its role in the internet of things. Proceedings of ACM: first edition of the MCC workshop on Mobile cloud computing, 13-16

Brax, S. (2005). A manufacturer becoming service provider-challenges and a paradox. *Managing Service Quality: An International Journal*, 15(2), 142-155.

Brax, S. & Jonsson, K. (2009). Developing integrated solution offerings for remote diagnostics: a comparative case study of two manufacturers. *International Journal of Operations & Production Management*, 29(5), 539-560.

Brynjolfsson, E., & McAfee, A. (2012). Race against the machine: How the digital revolution is accelerating innovation, driving productivity, and irreversibly transforming employment and the economy. Brynjolfsson and McAfee.

Brynjolfsson, E., & McAfee, A. (2014). The second machine age: work, progress, and prosperity in a time of brilliant technologies. WW Norton & Company.

Burmeister, C., Luettgens, D., & Piller, F. T. (2015). Business Model Innovation for Industrie 4.0: Why the ‘Industrial Internet’ mandates a New Perspective. RWTH-TIM Working Paper. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2571033

Castells, M. (2011). The rise of the network society: The information age: Economy, society, and culture. John Wiley & Sons.

Chen, H., Chiang, R. & Storey, V. (2012). Business Intelligence and Analytics: From Big Data to Big Impact. *MIS quarterly*, 36(4), 1165-1188.

Colombo, A. W., Karnouskos, S., & Bangemann, T. (2014). Towards the Next Generation of Industrial Cyber-Physical Systems. In Industrial cloud-based cyber-physical systems (pp. 1-22). Springer International Publishing.

Cusumano, M., Kahl, S. & Suarez, F. (2015). Services, industry evolution, and the competitive strategies of product firms. *Strategic management journal*, 36(4), 559-575.

Davenport, T. (2006). Competing on analytics. *Harvard business review*, 84(1), 98.

Dean, J., & Ghemawat, S. (2004). MapReduce: Simplified data processing on large clusters. Proceedings of the 6th conference on symposium on operating systems design and implementation. San Francisco.

Delen, D., & Demirkan, H. (2013). Data, information and analytics as services. *Decision Support Systems*, 55(1), 359-363.

Dijcks, J.-P., (2013). Oracle: Big Data for the Enterprise. Redwood Shores, Oracle

Drath, R., & Horch, A. (2014). Industrie 4.0: Hit or Hype? *Industrial Electronics Magazine*, IEEE, 8(2), 56-58.

Dubois, A. & Gadde, L.-E. (2002). Systematic combining: an abductive approach to case research. *Journal of Business Research*, 55(7), 553-560

Easton, G. (2010). Critical realism in case study research. Industrial Marketing Management, 39(1), 118-128.

Eisenhardt, K. & Martin, J. (2000). Dynamic capabilities: what are they? *Strategic Management Journal* 21(10-11), 1105–1121.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, 14(4), 532−550.

Eisenmann T., Parker G. & van Alstyne M. (2006). Strategies for two-sided Markets, *Harvard Business Review* 84(10), 92-101

Eloranta, V., & Turunen, T. (2015). Seeking competitive advantage with service infusion: a systematic literature review. *Journal of Service Management*, 26(3), 394-425.

Engle, R., Kane, M. & Tuholski, S. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. Models of working memory: Mechanisms of active maintenance and executive control, 102-134.

Evans, P. & Annunziata, M. (2012). Industrial internet: Pushing the boundaries of minds and machines. General Electric.

The Federation of Finnish Technology Industries. (2015). Teknologiateollisuuden / Suomen taloustilanne ja näkymät. March 2015. The Federation of Finnish Technology Industries.

Ferrer, G., Dew, N. & Apte, U. (2010). When is RFID right for your service? *International Journal of Production Economics*, 124(2), 414-425.

Gaiardelli, P., Resta, B., Martinez, V., Pinto, R., & Albores, P. (2014). A classification model for product-service offerings. *Journal of cleaner production*, 66, 507-519.

Gandomi, A., & Haider, M. (2015). Beyond the hype: Big data concepts, methods, and analytics. *International Journal of Information Management*, 35(2), 137-144.

Gebauer, H., Edvardsson, B., Gustafsson, A., & Witell, L. (2010). Match or mismatch: strategy-structure configurations in the service business of manufacturing companies. *Journal of Service Research*, 13(2), 198-215

Gebauer, H., Fleisch, E., & Friedli, T. (2005). Overcoming the service paradox in manufacturing companies. *European Management Journal*, 23(1), 14-26.

Gebauer, H., Paiola, M. & Saccani, N. (2013). Characterizing service networks for moving from products to solutions. *Industrial Marketing Management*, vol. 42, 31-46.

Gibson, C., & Birkinshaw, J. (2004). The antecedents, consequences, and mediating role of organizational ambidexterity. *Academy of management Journal*, 47(2), 209-226.

Glaser, B., & Strauss, A. (1967). The discovery grounded theory: strategies for qualitative inquiry. Aldin, Chicago.

Grover, V. & Kohli, R. (2012). Cocreating IT value: New capabilities and metrics for multifirm environments. *MIS Quarterly*, 36(1), 225—232.

Grubic, T. (2014). Servitization and remote monitoring technology: A literature review and research agenda. *Journal of Manufacturing Technology Management*, 25(1), 100-124.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, 29(7), 1645-1660.

Hagiu, A. (2014). Strategic Decisions for Multisided Markets. *MIT Sloan Management Review*, 55(2), 71-81

Hakanen, E. (2015). Intelligent materials and structural holes and enablers for new business models in steel industry networks. Master's thesis. Aalto University, 2015.

Halinen, A., & Törnroos, J. Å. (2005). Using case methods in the study of contemporary business networks. Journal of Business Research, 58(9), 1285-1297.

Harjunkoski, I., & Bauer, R. (2014). Sharing data for production scheduling using the ISA-95 standard. *Frontiers in Energy Research*, 2, 44.

Hartley, R. (1928). Transmission of information. *Bell System Technical Journal*, *1928* 535-563

Helander, A. & Möller, K. (2007). System supplier's customer strategy. *Industrial Marketing Management*, 36(6), 719-730.

Henderson, J. C., & Venkatraman, N. (1993). Strategic alignment: Leveraging information technology for transforming organizations. *IBM systems journal*, 32(1), 4-16.

Hidalgo, C. (2015). Why Information Grows: The Evolution of Order, from Atoms to Economies. Basic Books.

Hitzler, P., & Janowicz, K. (2013). Linked Data, Big Data, and the 4th Paradigm.*Semantic Web*, 4(3), 233-235

Holmberg, K., Siilasto, R., Laitinen, T., Andersson, P., & Jäsberg, A. (2013). Global energy consumption due to friction in paper machines. *Tribology International*, 62, 58-77.

Holmström, J., Främling, K. & Ala-Risku, T. (2010). The uses of tracking in operations management: Synthesis of a research program. *International Journal of Production Economics*, 126(2), 267-275.

Iansiti, M., & Lakhani, K. (2014). Digital Ubiquity: How Connections, Sensors, and Data Are Revolutionizing Business. *Harvard Business Review*, 92(11), 91-99

ITU-T. (2012). Ubiquitous Sensor Networks (USN). ITU-T Technology Watch Briefing Report Series, No.4

Ives, B. & Vitale, M. (1988), After the Sale: Leveraging Maintenance with Information Technology. *MIS Quarterly*, 12(11), 7-21

Jacobs, A. (2009). The pathologies of big data. *Communications of the ACM*, 52(8), 36-44.

Järvensivu, T., & Törnroos, J. Å. (2010). Case study research with moderate constructionism: Conceptualization and practical illustration. *Industrial Marketing Management*, *39*(1), 100-108.

Jonsson, K. (2006). The embedded panopticon: visibility issues of remote diagnostics surveillance. *Scandinavian Journal of Information Systems*, 18(2), 3.

Jonsson, K., Holmström, J., & Lyytinen, K. (2009). Turn to the material: Remote diagnostics systems and new forms of boundary-spanning. *Information and Organization*, 19(4), 233-252.

Juuso, E. K., & Lahdelma, S. (2013). Intelligent performance measures for condition-based maintenance. *Journal of Quality in Maintenance Engineering*, 19(3), 278-294.

Kagermann, H., Helbig, J., Hellinger, A., & Wahlster, W. (2013). Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry; Final Report of the Industrie 4.0 Working Group. Forschungsunion.

Kaplan, S., & Sawhney, M. (2000). E-hubs: the new B2B marketplaces. *Harvard business review*, 78(3), 97-106.

Karnouskos, S., & Colombo, A. (2011). Architecting the next generation of service-based SCADA/DCS system of systems. Proceedings of IEEE: IECON 2011-37th Annual Conference, 359-364

Kim, S. H., Cohen, M. A., & Netessine, S. (2007). Performance contracting in after-sales service supply chains. *Management Science*, 53(12), 1843-1858.

Kindström, D. & Kowalkowski, C. (2014). Service innovation in product-centric firms: A multidimensional business model perspective. *Journal of Business & Industrial Marketing*, 29(2), 96-111.

Kohtamäki, M. & Helo, P. (2015). Industrial services – the solution provider's stairway to heaven or highway to hell? *Benchmarking: An International Journal*, 22(2), 170-185

Kowalkowski, C., Kindström, D. & Gebauer, H. (2013). ICT as a catalyst for service business orientation. *Journal of Business & Industrial Marketing* 28(6), 506–513

Kowalkowski, C., Kindström, D., & Witell, L. (2011). Internalisation or externalisation? Examining organisational arrangements for industrial services. *Managing Service Quality: An International Journal*, 21(4), 373-391.

Kowalkowski, C., Windahl, C., Kindström, D., & Gebauer, H. (2015). What service transition? Rethinking established assumptions about manufacturers' service-led growth strategies. *Industrial Marketing Management*, 45, 59-69.

Kumar, A., Øvsthus, K., & Kristensen, L. (2014). An industrial perspective on wireless sensor networks—a survey of requirements, protocols, and challenges. *Communications Surveys & Tutorials*, IEEE, 16(3), 1391-1412.

Laney, D. (2001). 3-D data management: Controlling data volume, velocity and variety. Application Delivery Strategies by META Group Inc. Retrieved from http://blogs.gartner.com/doug-laney/files/2012/01/ad949-3D-Data-Management-Controlling-Data-Volume-Velocity-and-Variety.pdf

Lano, J. (2015). Strategies for deploying Information Services Offering in the B2B capital goods industry. Master's thesis. Aalto University, 2015.

Lapworth. L. (2015). Practical Challenges of Data Analytics. 2nd UCL Workshop on the Theory of Big Data. January 7th, 2015.

LaValle, S., Lesser, E., Shockley, R., Hopkins, M. S., & Kruschwitz, N. (2011). Big data, analytics and the path from insights to value. *MIT Sloan management review*, 52(2), 21-31

Lee, E. (2008). Cyber physical systems: Design challenges. In Object Oriented Real-Time Distributed Computing. ISORC 11th IEEE International Symposium, 363-369

Lee, J. (1998). Teleservice engineering in manufacturing: challenges and opportunities. *International Journal of Machine Tools and Manufacture*, 38(8), 901-910.

Lee, J., Bagheri, B., & Kao, H. A. (2015). A cyber-physical systems architecture for industry 4.0-based manufacturing systems. *Manufacturing Letters*, 3, 18-23.

Lee, J., Kao, H. A., & Yang, S. (2014b). Service innovation and smart analytics for industry 4.0 and big data environment. *Procedia CIRP*, 16, 3-8.

Lee, J., Ni, J., Djurdjanovic, D., Qiu, H., & Liao, H. (2006). Intelligent prognostics tools and e-maintenance. *Computers in industry*, 57(6), 476-489.

Lee, J., Wu, F., Zhao, W., Ghaffari, M., Liao, L., & Siegel, D. (2014a). Prognostics and health management design for rotary machinery systems—Reviews, methodology and applications. Mechanical Systems and Signal Processing, 42(1), 314-334.

Lightfoot, H., Baines, T., & Smart, P. (2013). The servitization of manufacturing: A systematic literature review of interdependent trends. *International Journal of Operations & Production Management*, 33(11-12), 1408-1434.

Lustig, I., Dietrich, B., Johnson, C. & Dziekan, C. (2010). The analytics journey. Analytics Magazine, Analytics Magazine, INFORMS, Atlanta, GA (November/December 2010), 11–18

Maglio, P. (2015). Editorial—Smart Service Systems, Human-Centered Service Systems, and the Mission of Service Science. *Service Science*, 7(2), ii-iii.

Maniyka, J., Chui, M., Bisson, P., Woetzel, J., Dobbs, R., Bughin, J. & Aharon, D. (2015). The Internet of Things: Mapping the value beyond the hype. McKinsey Global Institute. June 2015.

Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J., & Ghalsasi, A. (2011). Cloud computing—The business perspective. *Decision Support Systems*, 51(1), 176-189.

Mathieu, V. (2001). Product services: from a service supporting the product to a service supporting the client. *Journal of Business & Industrial Marketing*, 16(1), 39-58.

McAfee, A., Brynjolfsson, E., Davenport, T. H., Patil, D. J., & Barton, D. (2012). Big data. The management revolution. *Harvard Business Review*, 90(10), 61-67.

McFarlane, D., Sarma, S., Chirn, J., Wong, C. & Ashton, K. (2003). Auto ID systems and intelligent manufacturing control. *Engineering Applications of Artificial Intelligence* 16 (4), 365–376.

Medina-Borja, A. (2015). Editorial Column—Smart Things as Service Providers: A Call for Convergence of Disciplines to Build a Research Agenda for the Service Systems of the Future. *Service Science,* 7(1), ii-v.

Mell, P. & Grance, T. (2011). The NIST definition of cloud computing.

Meyer, G. G., Främling, K., & Holmström, J. (2009). Intelligent products: A survey. *Computers in industry*, 60(3), 137-148.

Meyer, G., Buijs, P., B. Szirbik, N., & Wortmann, J. (2014). Intelligent products for enhancing the utilization of tracking technology in transportation. *International Journal of Operations & Production Management*, 34(4), 422-446.

Miller, H. & Mork, P. (2013). From data to decisions: a value chain for big data. *IT Professional*, 15(1), 57-59.

Modell, S. (2009). In defence of triangulation: a critical realist approach to mixed methods research in management accounting. Management Accounting Research, 20(3), 208-221.

Monostori, L. (2014). Cyber-physical production systems: Roots, expectations and R&D challenges. *Procedia CIRP*, 17, 9-13.

Mortenson, M. J., Doherty, N. F., & Robinson, S. (2015). Operational research from Taylorism to Terabytes: A research agenda for the analytics age. *European Journal of Operational Research*, 241(3), 583-595.

Neely, A. (2008). Exploring the financial consequences of the servitization of manufacturing. *Operations Management Research*, 1(2), 103-118.

Neely, A., Benedettini, O., & Visnjic, I. (2011). The servitization of manufacturing: Further evidence. 18th European operations management association conference, Cambridge, 3-6

Neff, A., Hamel, F., Herz, T., Uebernickel, F., Brenner, W. & Vom Brocke, J. (2014). Developing a maturity model for service systems in heavy equipment manufacturing enterprises. *Information & Management,* 51(7), 895-911.

Nikolaus, K. (2015). RFID-Tags: Rewriting the Rules of Logistics. Siemens. Siemens website. Retrieved from https://www.siemens.com/innovation/en/home/pictures-of-the-future/industry-and-automation/digitale-fabrik-rfid-in-industry.html on June 6, 2015.

Nonaka, I. (1994). A dynamic theory of organizational knowledge creation. *Organization science*, 5(1), 14-37.

Nonaka, I., & Takeuchi, H. (1995). The knowledge creation company: how Japanese companies create the dynamics of innovation. Oxford university press.

Nyquist, H. (1924). Certain factors affecting telegraph speed. *Bell System Technical Journal* April 1924, 324-346

O’Reilly, C. & Tushman, M. (2008), Ambidexterity as a dynamic capability: resolving the innovator's dilemma. *Research in organizational behavior*, 28, 185-206.

Oliva, R. & Kallenberg, R. (2003). Managing the transition from products to services. *International Journal of Service Industry Management*, 14(2), 160-172.

Opresnik, D., & Taisch, M. (2015). The value of Big Data in servitization. International *Journal of Production Economics*, 165, 174-184.

Orkoneva, L. (2015). Gaining competitive advantage with platforms in a context of manufacturers’ service infusion. Master’s thesis. Aalto University, 2015.

Pagani, M. (2013). Digital business strategy and value creation: framing the dynamic cycle of control points. *MIS Quarterly*, 37(2), 617-632.

Parasuraman, R., Sheridan, T. & Wickens, C. (2000). A model for types and levels of human interaction with automation. Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions, 30(3), 286-297

Patton, M. (1990). Qualitative evaluation and research methods (2nd edition). Thousand Oaks, CA, CA, US: Sage Publications, Inc.

Pauliuk, S., Milford, R. L., Müller, D. B., & Allwood, J. M. (2013). The steel scrap age. *Environmental science & technology*, 47(7), 3448-3454.

Perrons, R. K., & Jensen, J. W. (2015). Data as an asset: What the oil and gas sector can learn from other industries about “Big Data”. *Energy Policy*, 81, 117-121.

Porat, M.V., & Rubin, M. (1977). The information economy: Definition and measurement (OT Special publication, 1, 77–120). Washington DC: Office of Telecommunications, U.S. Department of Commerce.

Porter, M. (1980). Competitive strategy: Techniques for analyzing industries and competition. New York.

Porter, M., & Heppelmann, J. (2014). How smart, connected products are transforming competition. *Harvard Business Review*, 92(11), 11-64.

Provost, F. & Fawcett, T. (2013). Data Science and Its Relationship to Big Data and Data-Driven Decision Making. *Big Data* 1(1), 51–59.

Qin, S. J. (2014). Process data analytics in the era of big data. *AIChE Journal*, 60(9), 3092-3100.

Rajkumar, R., Lee, I., Sha, L. & Stankovic, J. (2010). Cyber-physical systems: The next computing revolution, Proceedings of ACM: 47th Design Automation Conf. (DAC'10). New York, NY. 731–736.

Rifkin, J. (2011). The third industrial revolution: how lateral power is transforming energy, the economy, and the world. Macmillan.

Ross, J., Beath, C. & Quaadgras, A. (2013). You may not need big data after all. *Harvard Business Review*, 91(12)

Ruiz-Garcia, L., & Lunadei, L. (2011). The role of RFID in agriculture: Applications, limitations and challenges. *Computers and Electronics in Agriculture*, 79(1), 42-50.

Sampson, S. E., & Froehle, C. M. (2006). Foundations and implications of a proposed unified services theory. *Production and Operations Management*, 15(2), 329-343.

Seitz, M. A. (2007). A critical assessment of motives for product recovery: the case of engine remanufacturing. *Journal of Cleaner Production*, 15(11), 1147-1157.

Shannon, C. (1948). The Mathematical Theory of Communication. *Bell System Technical Journal*, 27, 379-423 & 623-656

Shvachko, K., Kuang, H., Radia, S., & Chansler, R. (2010). The hadoop distributed file system. In Mass Storage Systems and Technologies (MSST), 2010 IEEE 26th Symposium, 1-10

Sievers, H. (2015). Dominant designs in complex technological systems. A longitudinal case study of a telecom company 1980-2010. Doctoral dissertation, Aalto University, 2015.

Sjölander, A., Thomasson, J., Sui, R. & Ge, Y. (2011). Wireless tracking of cotton modules. Part 2: Automatic machine identification and system testing. *Computers and Electronics in Agriculture*, 75 (1), 34–43.

Sørensen, C., & Bochtis, D. (2010). Conceptual model of fleet management in agriculture. *Biosystems Engineering*, 105(1), 41-50.

Spohrer, J. & Demirkan, H. (2015). Introduction to the Smart Service Systems: Analytics, Cognition, and Innovation Minitrack. Proceedings of IEEE: System Sciences (HICSS), 48th Hawaii International Conference, 1442-1442

Spring, M., & Araujo, L. (2013). Beyond the service factory: Service innovation in manufacturing supply networks. *Industrial marketing management*, 42(1), 59-70.

Stabell, C. & Fjeldstad, O. (1998). Configuring value for competitive Advantage: on chains, shops, and networks. *Strategic Management Journal*, 19(5), 413–437

Storås, N. (2015). Netti pelastaa teollisuuden. Tivi, January 2015, 36-38

Storbacka, K., & Pennanen, R. (2014). Solution business: Building a platform for organic growth. Springer Science & Business Media.

Suddaby, R. (2006). From the editors: What grounded theory is not. *Academy of management journal*, 49(4), 633-642.

Swanson, L. (2001). Linking maintenance strategies to performance. *International journal of production economics,* 70(3), 237-244.

Teece, D. (2007). Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal*, 28(13), 1319-1350.

Teece, D., Pisano, G. & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, 18(7), 509–533.

Tekiner, F. & Keane, J.. (2013). Big data framework, Proceedings of IEEE: International Conference on Systems, Man, and Cybernetics, 2013. 1494–1499.

Thoben, K. & Wortmann, J. (2013). The Role of IT for Extended Products' Evolution into Product Service Ecosystems. Advances in Production Management Systems. Competitive Manufacturing for Innovative Products and Services, 399-406. Springer Berlin Heidelberg.

Thomas, J. & Cover, T. (2006). Elements of information theory, 2nd edition. New York: Wiley.

Töytäri, P. (2015). Managing value-based exchange in industrial markets: An organizational capability perspective. Doctoral dissertation. Aalto University, 2015

Tsang, A. H. (2002). Strategic dimensions of maintenance management. *Journal of Quality in Maintenance Engineering*, 8(1), 7-39.

Turber, S., Smiela, C. (2014). A Business Model Type for the Internet of Things. Proceedings of the 22nd European Conference on Information Systems, Tel Aviv, Israel, 1-10.

Ulaga, W. & Reinartz, W. J. (2011). Hybrid offerings: how manufacturing firms combine goods and services successfully. *Journal of Marketing*, 75(6), 5-23

Van Ostaeyen, J. (2014). Analysis of the business potential of product-service systems for investment goods. Doctoral Dissertation. KU Leuven, 2014.

Waller, M. & Fawcett, S. (2013). Data science, predictive analytics, and big data: a revolution that will transform supply chain design and management. *Journal of Business Logistics*, 34(2), 77-84.

Wang, G., Liu, W., Zhao, X., Yang, J. & Yuan, Q. (2011). Development and application of equipment maintenance and safety integrity management system. *Journal of Loss Prevention in the Process Industries,* 24(4), 321-332.

Weill, P., & Aral, S. (2006). Generating premium returns on your IT investments. *MIT Sloan Management Review,* 47(2), 39.

Westergren, U. (2011). Opening up innovation: the impact of contextual factors on the co-creation of IT-enabled value adding services within the manufacturing industry. *Information Systems and e-Business Management*, 9(2), 223-245.

Wilbanks, G. W. (1996). 50 years of progress in measuring and controlling industrial processes. *Control Systems, IEEE*, 16(1), 62-64.

Williams, T. (1994). The Purdue enterprise reference architecture. *Computers in industry*, 24(2), 141-158.

Windahl, C., & Lakemond, N. (2010). Integrated solutions from a service-centered perspective: Applicability and limitations in the capital goods industry. *Industrial Marketing Management*, 39(8), 1278-1290.

Wise, R. & Baumgartner, P. (1999). Go downstream, the new profit imperative in manufacturing. *Harvard Business Review*, 77(5), 133–141

Witell, L., Myhrén, P., Edvardsson, B., Gustafsson, A., & Löfberg, N. (2014). Servitization of Capital Equipment Providers in the Pulp and Paper Industry. Servitization in Industry, 151-164. Springer International Publishing.

World Economic Forum Working Group (WEF). (2015). Industrial Internet of Things: Unleashing the potential of connected products and services. World Economic Forum. January, 2015.

Wu, X., Kumar, V., Quinlan, J. R., Ghosh, J., Yang, Q., Motoda, H., ... & Steinberg, D. (2008). Top 10 algorithms in data mining. *Knowledge and Information Systems*, 14(1), 1-37

Wärtsilä. (2015). CMD investor material. Available at www.wartsila.com.

Xu, L., He, W., & Li, S. (2014). Internet of Things in industries: A survey. *Industrial Informatics, IEEE Transactions*, 10(4), 2233-2243.

Yang, X., Moore, P., & Chong, S. (2009). Intelligent products: From lifecycle data acquisition to enabling product-related services. *Computers in Industry*, 60(3), 184-194.

Yin, R. (2009). Case Study Research: Design and Methods. 4th edition. SAGE Publications, Thousand Oaks, CA.

Yin, S., Li, X., Gao, H., & Kaynak, O. (2015). Data-based techniques focused on modern industry: an overview. *Industrial Electronics, IEEE Transactions*, 62(1), 657-667.

Yoo, Y., Boland, R., Lyytinen, K., & Majchrzak, A. (2012). Organizing for innovation in the digitized world. *Organization Science*, 23(5), 1398-1408.

Yu, J. (2012). Local and global principal component analysis for process monitoring. *Journal of Process Control*, 22(7), 1358-1373.

Zins, C. (2007). Conceptual approaches for defining data, information, and knowledge. *Journal of the American society for information science and technology*, 58(4), 479-493.

Zuboff, S. (1988). In the Age of the Smart Machine: The Future of Work and Power. Basic Books.

Appendix

Interview questions

Please describe briefly your background. Please also describe possible topics that you are knowledgeable of on a level that is rare in your company, and that could be insightful regarding the topic of this interview.

Perspectives and context

- How information usage in services provision has changed over decades?

  (If required, explain that information can represent e.g., tacit knowledge, machine data, process data, installed base data etc.)
- What sort of services are currently offered, that benefit highly from data / information?
- What sort of business / service models have been taken in usage, benefiting from the data/information.
- How is information (services data, sensors, weather etc) currently managed and used?
- What challenges are related to e.g., storing, retrieving, processing, analyzing and using this information?

Value of data

- What sort of data/information could be gathered in the future, that might have value for the client? How rapidly this is happening and how big the change could be? Please share thoughts also from technical aspects regarding your own area of expertise on practical issues.
- What potential applications for data in improving/creating services and business offering might be in the near – and more distant – future?
- Which ones have the highest value creation potential from client point-of-view?
- Do you think there is a way to classify somehow these opportunities?

- Are there challenges in selling new data-enabled services? What sort of?

Competitive environment

- Who has best competences in developing analytics and intelligence on the data? Why? What are the roles of different participants in the network?
- Are clients likely to develop these capabilities?
- How IT-companies are likely to be involved? Is there a scenario where they would become a risk for taking an important control point for value capture?
- Do you think different clients take different perspectives to new services? Could there be distinct client segments?
- Is it likely that there will be shared standards and data platforms in your industry? Who could create that?

Practical implications and back to strategic perspectives

- If analytics capabilities are built in-house, how should these capabilities be shared in the organization?
- How should possible new services or capabilities be conceptualized and sold?
- What role analytics capabilities might have on your business in the long term? How far in the client value stream you might be able to go?
- In your opinion, what should your company do on the topic?
- Is there anything else you might want to add, question I should ask or a person I should talk to?