Tampere University

KARAN MENON

Industrial Internet Enabled Value Creation for Manufacturing Companies

A data and information management perspective

Tampere University Dissertations 310

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ACADEMIC DISSERTATION
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Responsible supervisor and Custos	Professor Hannu Kärkkäinen Tampere University Finland	
Pre-examiners	Professor Abdelaziz Bouras Qatar University Qatar	Professor Shaun West Lucerne University of Applied Sciences and Arts Switzerland
Opponent	Professor Jens Pöppelbuss Ruhr-Universität Bochum Germany	

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karmany-evādhikāras te mā phaleshu kadāchana

You have a right to perform your prescribed duties, but you are not entitled to the fruits of your actions.

Bhagavad Gita Chapter 2, Verse 47 (First half of the verse)

PREFACE

First things first, if planned well, the dissertation process is not as frustrating as it seems. Officially, all this started in the summer of 2015, when the Faculty of Management and Business agreed to have me as a doctoral student in the then Department of Information Management and Logistics (now, Unit of Information and Knowledge Management). In reality, it started somewhere in 2014, when I bumped into Professor Hannu Kärkkäinen in the department's coffee room. For a chemical- and materials science engineer, transitioning towards management studies took some effort. This transition process was made easy by a number of fantastic people whom I met during my journey. They helped me evolve into a young scientist and a better person. Hence, the end of the process is a very critical milestone both in my professional as well as personal life.

One person, who always had trust and confidence in my dissertation, sometimes even more than me, was Professor Hannu Kärkkäinen. If it were not for Hannu, I would not be writing this preface after finishing one of the most important manuscripts in a young scientist's life. From that coffee room chat in 2014 until last Friday (11th September 2020), Hannu has taught me everything I know in the field of research. Hannu, I am really grateful and lucky to have a supervisor and friend like you. Thank you for pushing me to achieve better things in my research and teaching me the finer nuances of research. I am delighted that our partnership will continue to flourish in the coming years.

I was honored to have two experienced scientists act as the pre-examiners to my dissertation. Professor Dr. Abdelaziz Bouras (Qatar University, Qatar) and Professor Dr. Shaun West (Lucerne University of Applied Sciences and Arts, Switzerland) invested their valuable time into evaluating my work, and provided me with some very insightful comments. Their feedback improved this dissertation significantly. This being an article-based dissertation, I am also grateful to the anonymous reviewers of my articles, and to the editors of the journals and conference proceedings that

published my research.

I wish to thank all the funders who have supported my research during the last few years. The dissertation was supported by Business Finland projects (VALIT, SPEED), Academy of Finland project (COBWEB), European regional development fund project (Välkky). The following parties supported my dissertation project with research grants: Finnish Cultural Foundation, The Jenny and Antti Wihuri Foundation and the Finnish Foundation for Technology Promotion. This dissertation has resulted into two wonderful and big Business Finland funded projects, namely, SNOBI and FutureSpaces. I would like to thank all the companies and researchers involved in these projects. This will help me take the research forward.

Assistant Professor Thorsten Wuest (West Virginia University (WVU), USA) has been a guide and a friend during this journey, and has helped me grown into a better researcher. We have co-authored four (out of five) of my dissertation articles. I was honoured to work with Thorsten in his lab at WVU as part of a research exchange visit and mingle with amazing minds. I would like to thank Dr. Sameer Mittal, Dr. Muztoba Khan and Dr. Jürgen Lenz to make my stay and research at WVU so fruitful. We will be continuing our collaboration in the coming years.

In addition to WVU, I was lucky to have some amazing collaborations with inspiring people. I am thankful to Professor Ravi Vatrapu (Ryerson University, Canada), Associate Professor Raghava Mukkamala (Copenhagen Business School, Denmark), Associate Professor Lester Lasrado (Kristiania University College, Norway) and Professor of Practice Timo Seppälä (Aalto University, Finland) for helping me out in achieving my goals in this dissertation.

I have been lucky to have some amazing colleagues, who have helped me in every way of my journey. Mikko (Mikko Uuskoski), I am really grateful to have spent so many hours discussing about our research and having a wonderful time enjoying some of the crazy Beckhoff parties. Thank you for everything and let us continue to have this in the coming years. I would like to thank Professor Nina Helander and Professor Samuli Pekkola to support my work as unit heads. Thank you Jayesh, for being an amazing office mate and friend. Our discussions in the office have been useful and stress relieving. Jari (Dr. Jari Jussila, HAMK), I guess there are not enough words to thank you for being my guide and friend throughout my dissertation process. Thank you to the Unit colleagues, Pasi, Ilona, Jukka, Henri, Hongxiu, Jussi, Prashanth, Osku, Maija, Annamaija and Ira for amazing outings, christmas parties and coffee/cake sessions. Apart from research colleagues, I am lucky to have some amazing administrative colleagues such as, Irmeli, Heidi, Marita, Harri and Sari. Thank you for making the administrative process simple for me.

Working on a long project, such as a dissertation, can be a bit exhausting at times. Luckily, I have many great friends, who have not only been interested in my research, but have also helped me to get my mind out of the work zone. There has been no shortage of laughter and joy in my life thanks to you all. Thank you Sarang, Narayan, Pooja, Anusha, Tero, Alberto, Siiri, Anubhuti, Abhishek, Praveen, Rohan, Robert, Igor, Helena and all my floorball, cricket and volleyball friends.

I have been lucky to have supportive, caring and loving family. Thank you Maa and Paa for always believing me and cheering me up when things were not working exactly. Thank you my second set of parents (my wife's parents) to be so happy with my success and for pushing me to achieve wonderful things in life. Siddharth, although he is my wife's brother, he has always stood by me like my brother and I am really grateful to have a brother like him. Munkki and Sauna are always waiting for you in Tampere, Siddharth!

Finally, the love of my life, the support who held my hand and guided me whenever I was lost, the best life partner anyone can ever get, Sheba. Sheba, your arrival in my life has brought me joy, luck and happiness that I cherish and thank you for. You have celebrated my success but most importantly, you have stood by me like a rock during my failures. I do say it a lot but I don't mind saying it again, I love you, Sheba, and thank you for sharing your life with me.

Writing this on a Sunday evening in Hervanta, the best place in Tampere, on 13th September 2020

Karan Menon

ABSTRACT

The "*Industrial Internet*" creates a situation where the smart and connected products create up-to-date information on their status as well as conditions from within the customer's real-time environment. The basic idea behind *industrial internet* enabled technologies is that they provide a digital identifier that uses the internet to relay data to the different actors of the delivery and value chains as well as creates new opportunities to earn for the manufacturing companies.

Like many other novel technologies, industrial internet enabled technologies also pose several challenges to the manufacturing companies, such as, increased investments, disruption in the business models, effective data and information management, and employees' fear to be replaced to name a few. These challenges hinder the manufacturing companies from creating value via the industrial internet enabled technologies. This dissertation addresses some of the challenges that these technologies bring, especially from data and information management perspective.

The aim of this dissertation is to increase the understanding of the impact industrial internet enabled data and information management on value creation for business - to - business (B2B) manufacturing companies. There is growing interest in value creation through industrial internet enabled technologies for manufacturing companies, but the impact of related data and information management is relatively less researched. Hence, this dissertation raises the following question: How to create value from industrial internet enabled data and information management for manufacturing companies? This dissertation considers the viewpoint of B2B manufacturing companies while investigating the above-mentioned research question.

In addition to this introduction, this article-based dissertation is comprised of five academic articles (two journal articles and three conference articles). The research design took the qualitative research approach to answer the research questions. Depending on the study, the primary research data were interviews or qualitative surveys or literature-based cases. The dissertation studied various manufacturing

companies and platform companies to create a concrete understanding towards the impact of industrial internet enabled data and information management on value creation for the manufacturing companies.

The results of this dissertation are illustrated in a manner that first we understand the process of creating a systematic and step-by-step maturity model for industrial internet enabled technologies through detailed design guidelines to create the maturity model. Subsequently, we address the critical issue of data and information management through platforms and related openness. This platform openness brings up various long-term impacts such as switching costs, lock-in to name a few. These long-term impacts, especially the impacts related to switching costs, are studied in detail. Finally, the impact of industrial internet enabled data and information on advanced business models is studied using a morphological box framework.

This research makes various contributions to earlier research. This dissertation furthers the academic understanding by formulating design guidelines to create a maturity framework which can divide tasks into different categories and steps, and simplify the complex steps of implementing industrial internet in a step-by-step manner resulting into the potential for increasingly more advanced business value creation. This dissertation increased the understanding of the role of industrial internet enabled data and information through a multidimensional platform openness framework. This dissertation creates a deeper understanding in analyzing short-and long-term impacts of platform openness, such as security issues, application developer's reliability and quality, and others that in turn impact industrial internet enabled value creation. This dissertation increased the understanding of increased platform openness impacts, especially long-term impacts such as switching costs, lock-in, and others by using a multidimensional framework. Finally, this dissertation furthers the understanding to the impact of industrial internet based technologies as well as related data and information management on nonownership business models by using morphological box framework.

CONTENTS

ORIGINAL PUBLICATIONS

Publication I	Menon, K., Kärkkäinen, H. and Lasrado, L. A. (2016). Towards a maturity modeling approach for the implementation of industrial internet. *PACIS 16 Proceedings*. Ed. by D. T.-P. Liang and D. S.-Y. Hung.
Publication II	Menon, K., Kärkkäinen, H., Wuest, T. and Gupta, J. P. (2019a). Industrial internet platforms: A conceptual evaluation from a product lifecycle management perspective. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 233.5, 1390–1401. DOI: 10.1177/0954405418760651.
Publication III	Menon, K., Kärkkäinen, H. and Wuest, T. (2020a). Industrial internet platform provider and end-user perceptions of platform openness impacts. *Industry and Innovation* 27.4, 363–389. DOI: 10.1080/13662716.2019.1673150.
Publication IV	Menon, K., Kärkkäinen, H., Wuest, T. and Seppälä, T. (2018a). Is Openness Really Free? A Critical Analysis of Switching Costs for Industrial Internet Platforms. *IFIP International Conference on Product Lifecycle Management*. Ed. by P. Chiabert, A. Bouras, F. Noël and J. Ríos, 215–226. DOI: 10.1007/978-3-030-01614-2_20.
Publication V	Menon, K., Kärkkäinen, H., Mittal, S. and Wuest, T. (2019a). Impact of IIoT Based Technologies on Characteristic Features and Related Options of Nonownership Business Models. *IFIP International Conference on Product Lifecycle Management*. Ed. by C. Fortin, L. Rivest, A. Bernard and A. Bouras, 302–312. DOI: 10.1007/978-3-030-42250-9_29.

Author's contribution to the co-authored publications

Publication I — In Publication 1, I led the development of the idea for the research with the other two co-authors. I carried out the literature review of industrial internet technologies and implementation, wrote the methodology section, and presented the analysis. I discussed and wrote the findings of the paper with the team. Based on the anonymous reviewer comments, I led the response process, and eventually, presented the paper in PACIS 2016 conference.

Publication II — Along with the other authors, I led the development of the idea for the research presented in Publication 2. I reviewed the literature and wrote the sections, industrial internet platforms, industrial internet platform openness, and PLM. I wrote the methodology section and the result section. The discussion and conclusions section was planned amongst the team members and written by me. Once we received feedback from peer-reviewers, I was responsible to lead the process of making suitable changes with the help of other co-authors and prepare the final version of the article.

Publication III — In the preparation of Publication 3, I, under the guidance of team members, was responsible for designing the empirical study, collecting the interview data, and conducting the data analysis. All three co-authors reviewed the literature. I was the primary person responsible for the sections related to industrial internet platform openness. I wrote the discussion section with guidance from the other team members. I presented a preliminary version of this article at the PLM 17 conference. A fully developed version was submitted to a journal for publication based on the feedback we received from the conference reviewers and participants. The author's team prepared a revised version of the article based on the feedback given by the journal's anonymous reviewers.

Publication IV — In the preparation of Publication 4, I, under the guidance of team members, was responsible for designing the empirical study, collecting the interview data, and conducting the data analysis. I wrote the literature sections related to industrial internet platforms as well as related openness and switching costs. I, under the guidance of the team members, wrote the discussion and conclusions section. I took the lead in improving the article based on anonymous peer-reviews and presented it in PLM 18 conference.

Publication V

For publication 5, I set out the research idea and the goals of the study. I collected relevant case studies from the literature to carry out a literature review and analyze the impact of industrial internet based technologies on advanced business models such as the non-ownership business models. I, under the guidance of the team, wrote the discussion and conclusions section. Once we received feedback from peer-reviewers, I was responsible for making suitable changes with the help of other co-authors and preparing the final version of the article. I presented this article at PLM 19 conference.

1 INTRODUCTION

The "*Industrial Internet*" is portion of a broader digitalisation that has slowly influenced the economy and industry dating back to the 1950s (Ehret and Wirtz 2017; Evans and Annunziata 2012). Industry 4.0 is based on the establishment of smart factories, smart products and smart services embedded in industrial internet (Kagermann, Wahlster and Helbig 2013). Nowadays, at the center of the the most recent wave of development we can see progressively smart, connected products and services that create up-to-date information on their status and highlights within the customer's real-time environment (Kagermann, Wahlster and Helbig 2013; Porter and Heppelmann 2014). In addition, industrial internet enabled new technologies provide real-time monitoring and optimization of customers processes and machines (Ehret and Wirtz 2017; Evans and Annunziata 2012). Focus will shift from the (one-time) delivery of products and services to customers to the optimisation of their (continuous) use in the customer's real-time environment. This digitalisation of the products and services is rapidly shaping traditional business models, breaking the prevailing sector boundaries in business life and the public sector alike (Ardolino et al. 2018; Bock and Wiener 2018; Grubic and Jennions 2018).

With the industrial internet, sensors, machines, processes and services continuously produce information that can be refined to anticipate and automate work (Ehret and Wirtz 2017; Evans and Annunziata 2012). This requires that all things related to the production and service process have a digital identifier that uses the internet to relay data to the different actors of the delivery and value chains but also creates new business models (Ardolino et al. 2018; Arnold, Kiel and Voigt 2016; Ehret and Wirtz 2017).

Industrial internet based technologies are expected to pose several challenges to existing companies including high investments, disrupted existing business models, effective data and information management and employees' fear to be replaced (Kiel, Müller et al. 2017). These challenges are harmful for both large companies as well as small and medium-sized enterprises (SMEs) (Müller, Buliga and Voigt 2018). In essence, this dissertation addresses the research topic of overcoming the data and information management related challenges brought in by industrial internet based technologies that hinder business value creation for manufacturing companies and their customers. In response to technological developments, such as industrial internet, companies need to correspondingly adapt their business model, fostering opportunities and meeting challenges that arise (I. Lee and K. Lee 2015; J. Lee, Kao and Yang 2014). The topic of new or changed business models that are enabled or challenged through industrial internet based data and information management remains a relatively new topic that few studies have investigated so far (Ardolino et al. 2018; Arnold, Kiel and Voigt 2016; Ehret and Wirtz 2017; Grubic and Jennions 2018; Kiel, Arnold et al. 2016).

Earlier studies mentioned above, highlight the fact that industrial internet technologies can provide value to manufacturing companies through novel business models but do not address the issues that industrial internet enabled data and information management bring for the aforementioned value creation. From technological standpoint, there are many platforms that are capable of handling industrial internet enabled data and information, for e.g., PTC ThingWorx, Microsoft Azure, IBM Watson, GE Predix etc. (Menon, Kärkkäinen, Wuest and Gupta 2019b). Previous research sheds some light on how to use platforms to effectively manage data and information flow in order to create value for business to consumer (B2C) firms (Garcia-Swartz and Garcia-Vicente 2015; Hagiu and Wright 2015; Lan, Liu and Dong 2019). Via their virtual interconnection on digital platforms, several entities are combined on one single space for gathering, processing and managing data. So-called multi-sided platforms combine customers, suppliers, and partners on one single platform, serving all stakeholders' interests (Gawer 2009; Hagiu and Wright 2015; Henten and Windekilde 2016). By engaging in platforms, stakeholders lay the foundation for new forms of interaction between stakeholders inaugurating new ecosystems. In the consumer industry, platform providers already have radically transformed traditional businesses, e.g., Airbnb, Amazon, and Alibaba (Hagiu and Wright 2015; Henten and Windekilde 2016). So far, the usage of digital platforms for effective data and information management in the industrial sector (manufacturing companies) is yet to grow due to some unsolved theoretical and practical issues (Menon, Kärkkäinen, Wuest and Gupta 2019b).

It remains unclear which potentials digital platforms imply for the industrial sector, as developments unfolding in B2C markets might have different effects in the business to business (B2B) context (Köhler, Wörner and Wortmann 2014; McIntyre and Srinivasan 2017; G. G. Parker, M. W. Van Alstyne and Choudary 2016). Further, there are challenges caused by issues, for instance, data ownership, management and control of platforms, and relationships between the entities (Gawer and Cusumano 2014; Menon, Kärkkäinen and Gupta 2016; G. G. Parker, M. W. Van Alstyne and Choudary 2016). Addressing these questions and solving these issues is of high importance, as digital platforms are expected to generate large potential for industrial value creation (Gawer 2009; Gawer and Cusumano 2014). Given its importance for value creation, research has lately begun to turn its focus on platforms. So far, most academic studies so far almost exclusively examine platforms of non-industrial contexts, neglecting digital platforms in industrial contexts and their potential and challenges respectively (Garcia-Swartz and Garcia-Vicente 2015; Köhler, Wörner and Wortmann 2014; Lan, Liu and Dong 2019; McIntyre and Srinivasan 2017). Digital platforms in the context of managing data and information via industrial internet enabled technologies are scarcely understood. Hence, there is a need to develop a comprehensive understanding of short and long term impacts of using platforms to manage industrial internet enabled data and information because the extant of literature in this topic is quite sparse (Kiel, Müller et al. 2017; Soto Setzke et al. 2018). For instance, majority of the papers examine digital platforms for manufacturing companies from an overall benefit perspective, especially short-term benefits (such as interoperability, better & faster connectivity) without going into the depth of long-term impacts (such as increased switching costs, lock-in) (Lan, Liu and Dong 2019; G. G. Parker, M. W. Van Alstyne and Choudary 2016; Rajala et al. 2018).

Furthermore, there is little research that explores the value and benefits of industrial internet enabled data and information management on novel advanced business models such as pay-per-use, pay-per-output and pay-per-outcome (Ehret and Wirtz 2017; Gebauer et al. 2017; Grubic and Jennions 2018). There is significant research to study the impact of data and information management on pay-per-use, pay-per-output and pay-per-outcome type business models in the software industry, B2C (Xerox for example), utilities (electricity, internet) but very little research in the context of manufacturing companies (Gebauer et al. 2017; Grubic and Jennions 2018; Müller, Buliga and Voigt 2018). Manufacturing companies encounter set of unique

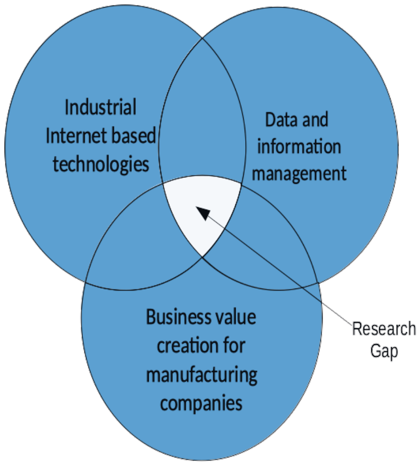

Figure 1.1 Targeted contribution of the dissertation

challenges while implementing these novel business models, especially challenges related to data and information management, for e.g., analytics, interoperability, long-term platform related impacts such as lock-in and others. These challenges are not studies studied in detail in existing literature (Fraile et al. 2018; Pedone and Mezgár 2018; Soto Setzke et al. 2018).

The aim of this dissertation is to increase the understanding of the impact of industrial internet enabled data and information management on value creation for manufacturing companies (B2B).

In summary, the contribution of this thesis concerns the interaction of industrial internet based technologies, business value creation for manufacturing companies as well as data & information management (Figure 3.1). There is some research on overall impact of industrial internet based technologies on business value creation for manufacturing companies and business models, especially using the business model canvas framework (Ehret and Wirtz 2017; Kiel, Arnold et al. 2016; Müller, Buliga and Voigt 2018). There exists research in the technical forums on the industrial internet based technologies and related data & information management (I. Lee and K. Lee 2015; J. Lee, Bagheri and Kao 2015; J. Lee, Kao and Yang 2014). There is some research on how manufacturing companies can create value using automation systems and related data and information management. Therefore this dissertation focuses on the triple intersection of all the three topics mentioned above and in Figure 1.1.

On the basis of the above research gap description this dissertation addresses the following overall research question and more detailed sub-questions.

Overall research question:

RQ: How to create value from industrial internet enabled data and information management for manufacturing companies?

More detailed sub-research questions:

RQ1: What is the role of data and information management in industrial internet enabled value creation for manufacturing companies?

RQ2: How can data and information management impact industrial internet enabled value creation and related risks in manufacturing companies?

RQ3: How does the industrial internet enabled data and information management impact advanced business models for manufacturing companies?

The thesis is structured as follows: In the second chapter, the background of the thesis is introduced, including industrial internet enabled value creation for manufacturing companies, industrial internet based data and information management for manufacturing companies and impact of industrial internet enabled data and information management on advanced business models for manufacturing companies.

In the third chapter, the research strategy and design are presented, including the aims and scope of the research, the research questions, and the research strategy.

In the fourth chapter, a summary of the individual publications and their major results is presented. The main content and the major results of each publication are presented and their links described.

Finally, in the fifth chapter, how the research results provide answers to the research questions and contribute to new understanding to the concepts presented in Figure 1.1. The fifth chapter includes managerial contributions, an evaluation of the study, the limitations of the study, and suggestions for future research.

2 THEORETICAL BACKGROUND

2.1 Industrial internet enabled value creation for manufacturing companies

Internet of things (IoT) is the umbrella term defined as a network of physical objects - devices, vehicles, buildings, home appliances and other items embedded with sensors, electronics and network connectivity that enables these objects or things to collect and exchange data (Munirathinam 2020). Cyber physical systems (CPS) unlike the IoT that basically connects a network of things, connects and integrates the physical processes, computation and networking. IoT in the industrial world is Industrial IoT or IIoT. This IIoT drives the fourth industrial revolution where industries compete through new capabilities and business models enabled by the IIoT based technologies. This fourth industrial revolution is called Industry 4.0 (Kagermann, Wahlster and Helbig 2013).

General Electric (GE) coined the term “Industrial Internet” in 2012 (Evans and Annunziata 2012). The term points towards the meshing of the digital and machine worlds. According to (Evans and Annunziata 2012), industrial internet can be defined as the integration of three elements:

- Intelligent machines: i.e. connecting the worlds’ machines and fleet of machines with advanced sensors, controls and software applications.
- Advanced analytics: Combination of physics-based advanced analytics, predictive algorithms, automation and domain expertise
- People at work: Connecting people at work or on the move, anytime, to support “more intelligent design, operations, maintenance and higher service quality and safety”.

This dissertation mainly focuses on the first two aspects of industrial internet;

i.e., intelligent machines and advanced analytics.

1. Sensors - data collection purposes
2. Actuators - control systems
3. Connectivity - internet and communication protocols and related middleware
4. Analytics and intelligence - IT-driven services (big data analytics, artificial intelligence & human intelligence)

The Industrial Internet provides a way to get better visibility and insight into the company's processes and assets through integration of machine sensors, actuators, connectivity as well as analytics and intelligence. Therefore, it provides a method of transforming business operational processes through the interaction between large data sets via analytics (Jeschke et al. 2017; Wang et al. 2016). Internet of things (IoT) has enabled many Business to consumer (B2C) companies to provide value to their end customers, for e.g., washing machine manufacturers use IoT to provide information related to optimal usage of detergent and other washing products to increase the efficiency of the machine and eventually reduce the cost of washing for the end-customer (customers of the washing machine manufacturing companies), indoor lighting management companies use IoT to optimize the usage of lights in the house (Golovatchev et al. 2016; I. Lee and K. Lee 2015). For these B2C companies investing in the IoT technologies and solutions becomes feasible because of the number of equipment and appliances they sell. For manufacturing companies that operate in the business-to-business (B2B) environment the situation is different (Gebauer et al. 2017; Grubic and Jennions 2018; J. Lee, Bagheri and Kao 2015). These B2B manufacturing companies do not sell as many equipment as the B2C companies and the machines they manufacture are high in investment. Moreover, the B2B manufacturing sector is a very traditional sector where changes and upgrades in technologies are relatively slow, when compared to the B2C sector. This means that the implementation of any new technology requires heavy investment, step-by-step planning of implementation and customer's willingness to pay more for the upgrade. Implementation of IoT is also encountered by these challenges in the manufacturing sector (Gebauer et al. 2017; Grubic and Jennions 2018; J. Lee, Bagheri and Kao 2015; Menon, Kärkkäinen and Gupta 2016). To differentiate between commercial (B2C) IoT and industrial (B2B) IoT the term industrial internet was coined (Evans and Annunziata 2012).

The industrial internet based technologies combine business and engineering processes to improve the production efficiency, robustness as well as to produce high quality products at lower costs (Jeschke et al. 2017; Wang et al. 2016). Regarding such benefits, in general, industrial internet based technologies have been demonstrated e.g. to enable decreases in transaction costs (such as, maintenance related transaction costs, operations related transaction costs etc.) between companies in various manners (Ehret and Wirtz 2017), while increasing transparency in collaboration through increases in the quantity and quality of data and information (e.g. (Ardolino et al. 2018)). These benefits can lead to value creation for the customers in terms of increased performance or efficiency of the machine and/or decreased cost of buying in long-term because of optimized machine usage.

Based on the above described benefits of industrial internet based technologies for the manufacturing companies, we define value creation in the following manner: "Value can be created by differentiation along every step of the value chain, through activities resulting in products and services that lower buyers' costs or raise buyers' performance (Amit and Zott 2001). Industrial internet based technologies enable industrial value creation by harnessing entirely digitized, connected, smart and decentralized value chains (Kagermann, Wahlster and Helbig 2013; Kiel, Arnold et al. 2016). Industrial internet enabled technologies are expected to address key issues for manufacturing companies, e.g., shortened technology and innovation cycles, increasing customisation, and enhanced demand volatility (Kiel, Arnold et al. 2016). Industrial internet based technologies create value for the customers of the manufacturing companies by increasing efficiency and flexibility. These technologies also allow the manufacturing companies to implement complex business models such as pay-per-use, pay-per-output and pay-per-outcome business models. This in turn reduce the customer's buying cost of the machines as well as operational risks (Arnold, Kiel and Voigt 2016; Kagermann, Wahlster and Helbig 2013; Kiel, Arnold et al. 2016; Menon, Kärkkäinen, Wuest and Gupta 2019b).

2.2 Industrial internet based data and information management for manufacturing companies

Industrial internet based technologies create a smart and connected product environment for the customers (Porter and Heppelmann 2014). In order to achieve this smart and connected product environment manufacturing companies need to build and support a novel technological infrastructure. As described by (Porter and Heppelmann 2014) this "technology stack" comprises of multiple layers, including new machines (product hardware), embedded software, connectivity, machine's digital twin running on remote servers (product cloud), data and information security tools, gateway (preferably open) for other information sources (weather, energy prices, geo-mapping), and integration with enterprise business systems. Figure 2.1 demonstrates this technology stack as explained by (Porter and Heppelmann 2014). This technology stack integrated data and information from various systems that are related to the machine creating a system of systems for the manufacturing companies (Porter and Heppelmann 2014). Industrial internet platforms (Menon, Kärkkäinen, Wuest and Gupta 2019b; Menon, Kärkkäinen, Wuest and Seppälä 2018b) such as Microsoft Azure, PTC ThingWorx, IBM Watson IoT and others provide all the above mentioned functionalities that are described in the technology stack. These platforms enable the manufacturing companies to effectively manage all the machine related data and information effectively, resulting into business value creation for customers, suppliers and subcontractors of the manufacturing companies (Alexopoulos et al. 2018; Lenz, Wuest and Westkämper 2018).

These industrial internet platforms are able to store and create access to the collected data using unified architecture and databases, either in dedicated in-house servers or in the cloud (Eckhardt, Ciuchta and Carpenter 2018; Evans and Annunziata 2012; I. Lee and K. Lee 2015; Zheng et al. 2019). This data gets used for predictive, preventive, and prescriptive analytics of machines and operations which can improve the end-customers performance in turn create value for the end-customer (Amit and Zott 2001). For example, technicians, workers, and engineers can remotely monitor the condition of the machines without physically being present (Lesjak et al. 2014). They can make informed decisions by running the data through machine-learning algorithms to predict the health condition of a machine. This is how the next level of

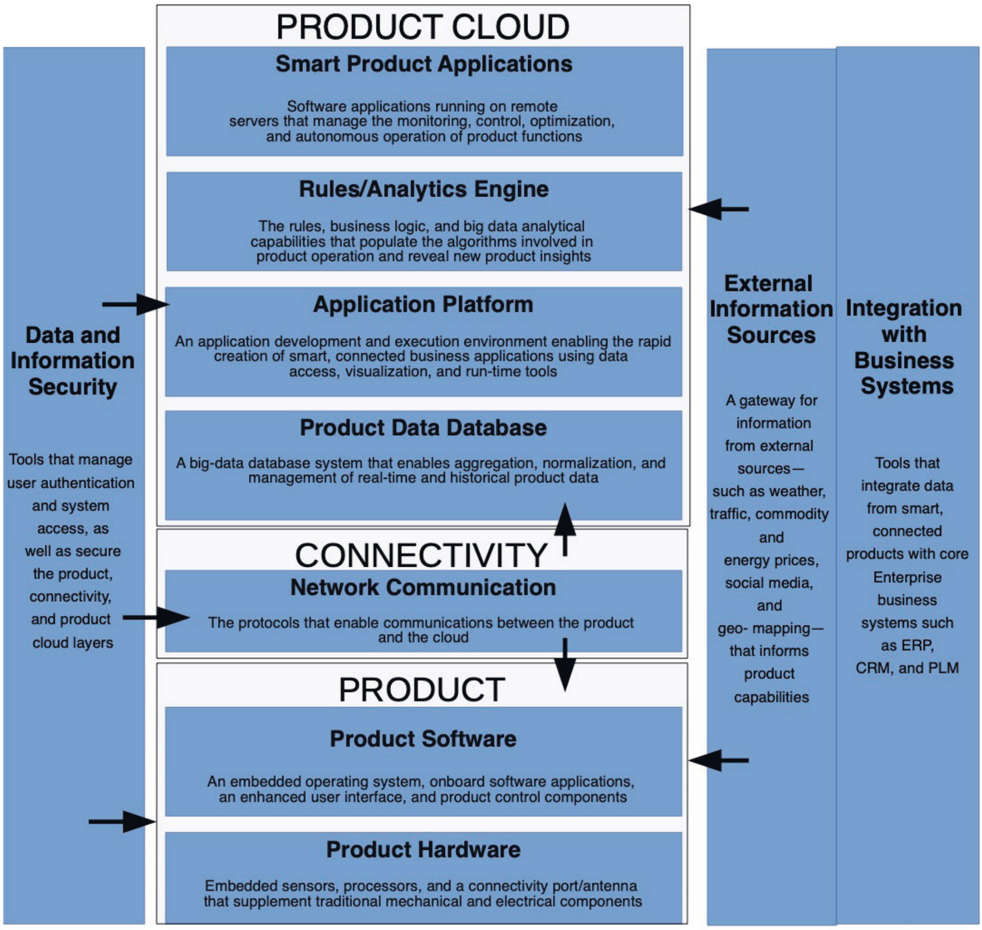

Figure 2.1 Technology stack for industrial internet enabled machines (Porter and Heppelmann 2014)

machine maintenance is now carried out using industrial internet based technologies and platforms.

In general platforms and platform economy has been of increasing academic and industrial interest, both in general as well as in the specific context of industrial internet. Some of the topics under platform research studied in the literature include, platform business models (Hagiu and Wright 2015; Rochet and Tirole 2006), platform related network effects (G. G. Parker and M. W. Van Alstyne 2005; Rochet and Tirole 2006), platform openness (Gawer 2009; Ghazawneh and Henfridsson 2013), platform related interoperability, platform lock-in (Opara-Martins, Sahandi and Tian 2016), to name few. In the manufacturing companies' context, platform related openness is considered very important for technology implementation and creating business value (Benlian, Hilkert and Hess 2015; Eisenmann 2008; Menon, Kärkkäinen and Wuest 2017; G. Parker and M. Van Alstyne 2018). Industrial internet platform openness has many short-term benefits for manufacturing companies such as, enhanced interoperability with different machines because of open standards, diverse and high end applications made by core as well as third party developers. Long-term impacts, especially downsides of platforms for manufacturing companies are relatively less studied. Literature primarily discusses about the downsides or risks of platform openness from the platform supplier or provider perspective and not from the platform end-user (manufacturing companies that purchase the rights to use the platforms) perspective (Benlian, Hilkert and Hess 2015; Eisenmann 2008; McIntyre and Srinivasan 2017; G. G. Parker, M. W. Van Alstyne and Choudary 2016; G. Parker and M. Van Alstyne 2018).

Lock-in, which is understood to be one of the long-term downside of openness, can be a result of multiple factors including increased switching costs. (Blut et al. 2016) define switching costs as "the customer's perception of the magnitude of additional costs required to conclude the current relationship, and secure an alternative supplier." However relatively little is known about the impact of switching costs for an industrial internet platform end-user in a B2B context. Furthermore the impact of increased openness on switching costs is also not studied well. One challenge with the proper understanding of the role of switching costs, as well as the impact of openness to switching costs is related to the nature of switching costs developing and often increasing in the course of time (Blut et al. 2016). Furthermore, due to common difficulty of anticipating future switching costs, as well as the many- dimensionality of both openness and switching cost concepts, it may be difficult for a platform user to identify the multitude and the importance of different impacts of openness to switching costs, especially in the long run.

2.3 Impact of industrial internet enabled data and information management on advanced business models for manufacturing companies

Industrial Internet platforms enable effective management of data and information created by machines powered by industrial internet based technologies. This allows the manufacturing companies to collect, store and process more data in real-time or near real-time that is more accurate. These platforms allow the manufacturing companies to create value of this data and information in a manner that they can improve the efficiency of the machines for their customers or offer the customers completely new business models that reduce the buying cost for the customer but increase the overall earnings for the manufacturing companies. In either case, increased efficiency of the machines or new business models, the manufacturing companies have an impact on their own overall business.

In the framework created by (Kohtamäki et al. 2019), the authors have described how different characteristics of the industrial internet technologies' enabled product impact various advanced business models that are derived from servitization literature. In this model, as shown in figure 2.2, Customization, digitalization and pricing are the three dimensions that can be maneuvered in order to achieve the most suitable advanced business model. The reason why these resulting business models are considered as advanced business models is the complexity the exhibit in terms of implementation and the reliance on advanced industrial internet enabled technologies. A change in any one of the dimensions or two dimensions or all the three dimensions can result into different business models with different complexities. The business models tend to become more complex and advanced as well as the need for more data (quantity), relevant and precise data increases as you go from origo to the top right corner because of the increase in the level of customization, digitalization and pricing. For example, if more precise and relevant data is available then the manufacturer can promise optimization in case of solution digitalization dimension as well as a more customized solution in solution customization dimension, resulting into an advanced business model which can be either availability oriented or outcome-oriented.

These complex and advanced industrial internet business models can be planned

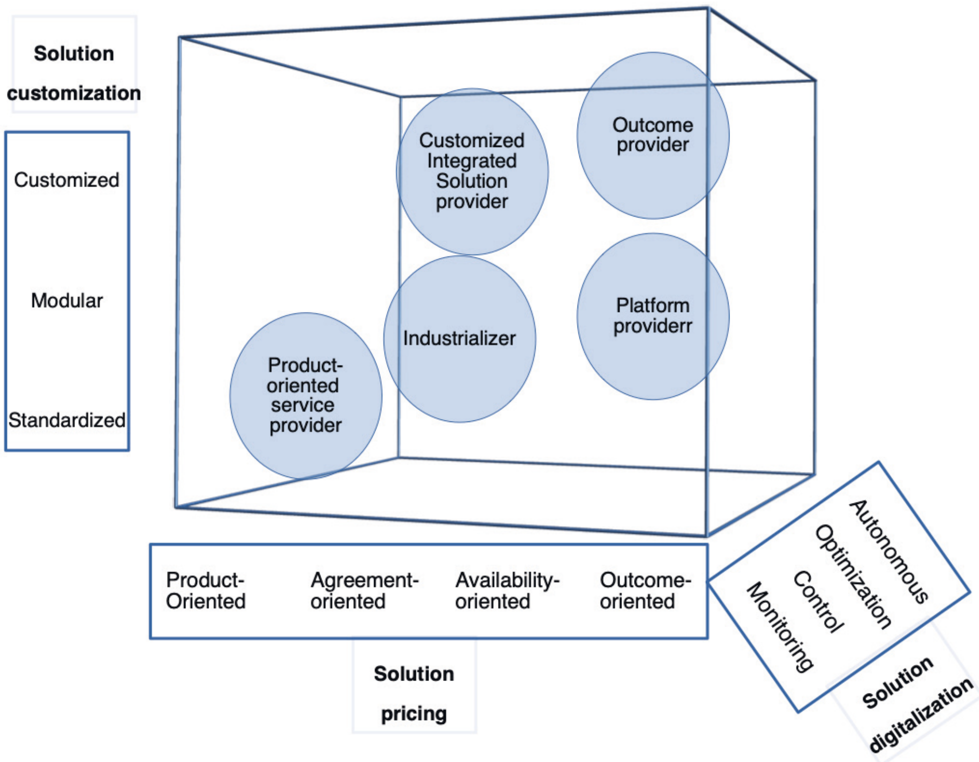

Figure 2.2 Impact of customization, prizing and digitization on advanced business models (Kohtamäki et al. 2019)

using a maturity approach wherein a step-by-step implementation approach can help effective implementation of these advanced business models. Previously, businesses often had to implement large and complex intra- and inter-organizational change processes such as those occasioned by Product Lifecycle Management (e.g. (Vezzetti, Violante and Marcolin 2014), Supply Chain Management (Wendler 2012) or major investments in IT or technological solutions. In such cases, the technology can drive the implementation process forward too rapidly, in that the human workforce's skills and motivation lag behind the technological/organisational progress. The industrial internet is still a new phenomenon so many companies lack a comprehensive understanding about its purpose and the solutions it can offer. Therefore, companies have to experiment to learn how to proceed. However, many of these experiments fail as they have not been designed to maximize learning and thus increase the acceptance of the new innovations by the workers. Businesses need a coordinated and systematic approach to the concept behind the industrial internet in order to increase its penetration into modern industrial production. Maturity models provide this kind of a systematic and coordinated approach towards implementation of industrial internet based technologies (Bertolini et al. 2019; Ganzarain and Errasti 2016; Gökalp, Şener and Eren 2017; Schumacher, Erol and Sihn 2016).

3 RESEARCH DESIGN

The main purpose of this dissertation is to understand in an in-depth manner how value can be created from industrial internet enabled data and information for manufacturing companies. Drawing from the focus of the dissertation, we explain in this section, the decisions made to conduct this research and the methodological and method-related options selected to answer the research questions suitably.

3.1 Research questions

By the analogy of geography, this research inquiry does not target an island that is unconnected to other islands in the relevant literature. Instead industrial internet based technologies, business value creation for manufacturing companies and data & information management are perceived as the mainland studied by others (figure 3.1). The aim of any dissertation could be perceived as an investigation of previously unknown area(s) and new peninsula(s) that are connected to the mainland. The researcher can choose to study either one unknown area very deeply or several unknown areas in order to widen the understanding of the phenomena from multiple perspectives and possibly open new, interesting areas for further research. The latter strategy was chosen to guide the selection of suitable research approaches and methods, as well as an appropriate research design.

In this dissertation the primary research problem concerns the understanding of value creation from industrial internet enabled data and information. Therefore, this dissertation addresses the following research questions:

Overall research question:

RQ: How to create value from industrial internet enabled data and information management for manufacturing companies?

More detailed questions:

RQ1: What is the role of data and information management in industrial internet

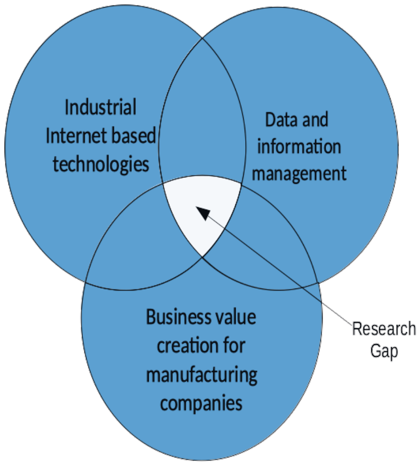

Figure 3.1 Venn Diagram - Research Gap

enabled value creation for manufacturing companies?

RQ2: How can data and information management impact industrial internet enabled value creation and related risks in manufacturing companies?

RQ3: How does the industrial internet enabled data and information management impact advanced business models for manufacturing companies?

This dissertation and the research questions consider the *intelligent machines and advanced analytics* perspective from the industrial internet definition by (Evans and Annunziata 2012; Jeschke et al. 2017; Wang et al. 2016). All the research questions above follow the definition of value creation provided by (Amit and Zott 2001), where customers can create value from novel technologies such as *industrial internet*, either by improving the performance or by getting the machines at reduced prices (using novel business models such as pay-per-use for example). The research questions take the platform perspective to get a better understanding of data and information management related issues (Eisenmann, G. Parker and M. W. Van Alstyne 2008; Gawer and Cusumano 2014; G. G. Parker, M. W. Van Alstyne and Choudary 2016).

3.2 Research strategy

This section clarifies the research approaches taken in this dissertation. It also describes the factors that have most affected the choices of the research approaches and methods. The main data sources used in the publications are also described. There are numerous methods and approaches that can help conduct business research. Research questions and existing knowledge of the topic affect the selection of the research approach and method.

In order to device a research strategy, especially from the methodological and methods perspective, we have used the research onion as presented by (Saunders, Lewis and Thornhill 1996). Industrial internet technologies were very new and upcoming, when this dissertation began and it still is very novel for most of the manufacturing companies. This dissertation intends to go into the depth of the issues industrial internet technologies bring when it comes to creating value for the manufacturing companies. We wanted to take an approach which was somewhere in between interpretivism (where understanding is seen as a value) and pragmatism (understanding the phenomena and investigating the impact on human actions). We wanted to understand the fundamentals behind the issues industrial internet related data and information management bring for manufacturing companies as well as the actions that managers can take in order to extract maximum value of industrial internet based technologies. Further, we use the inductive approach which is commonly used for qualitative research for example, interviews are carried out concerning specific phenomena and then the data may be examined for patterns between respondents (Saunders, Lewis and Thornhill 1996).

This dissertation uses the case study methodology to investigate the various epistemological issues, such as industrial internet platform related openness and its impact in long and short term on the business of manufacturing companies as well as the role of industrial internet technologies in value creation through advanced data and information based business models such as pay-per-use, output and outcome models. The case study methodology is particularly suitable when the nature of the problem is complex, theory development is low, and the problem is studied in a natural context (Bonoma 1985). The case study is used to investigate the topic comprehensively by using multiple methods and data sources (Yin 2015) that appropriately reflect the research problem. Potential data sources for the case study may include, but are not limited to, documentation (e.g. white paper reports), archival records, interviews, physical artifacts, direct observations, and participant observations (Baxter and Jack 2008). (Yin 2015) proposed a rough categorization of four different case study designs: single-case and multiple-case designs, both having either a single (holistic) or multiple (embedded) units of analysis. Multiple-case study design is considered appropriate when the researcher seeks exemplary outcomes (i.e., literal replications) or contrasting results for predictive reasons (i.e., theoretical replication) in relation to a specific theory (Yin, 2003). Multiple-case study design is relatively flexible, but it requires the justification of each case chosen for the research. There is no upper or lower limit regarding the number of cases that can be included in a study (Ghauri, Grønhaug and Strange 2020). To conduct case studies, (Yin 2015) suggested carefully planning the case design, justifying the selected cases by their reflection of the research problem, and using multiple methods and multiple sources of evidence when collecting the data. An important aspect of case studies is their flexibility. (Yin 2015) argued that case studies often evolve be-cause new information is discovered during the data collection, which may lead to altering or modifying the original design.

3.3 Data collection and analysis

In order to understand how industrial internet enabled data and information can create value for manufacturing companies, this dissertation was divided into two streams, industrial internet platforms and related openness as well as industrial internet enabled advanced business models. Publication 1 used literature to formalize the dimensions and stages critical to understand the maturity in the implementation of industrial internet enabled technologies and business models for the manufacturing companies. Qualitative case study methodology was used in the rest of the publications (publication 2 to 5). The case study approach used in this dissertation had two objectives. The first was to understand how value can be created by understanding the impact of industrial internet platform openness on platform end-users' business and subsequent switching costs. Publication 2, 3 and Publication 4 focused on this objective. The second objective was to understand value creation because of industrial internet enabled technologies by implementing novel and advanced business models (such as pay-per-X type business models). Publication 5 focused on this objective.

Table 3.1 Data sources and methods

Publication	1	2	3	4	5
Title	Towards a maturity modeling approach for the implementation of industrial internet	Role of Industrial Internet platforms in the management of product lifecycle related information and knowledge	Industrial internet platform provider and end-user perceptions of platform openness impacts	Is Openness really free? A critical analysis of switching costs for Industrial Internet Platforms	Impact of IIoT based technologies on characteristic features and related options of non-ownership business models
Research questions addressed	RQ 1, RQ 2	RQ 1, RQ 2	RQ 2, RQ 3	RQ 2, RQ 3	RQ 1 and RQ 3
Methodology	Literature review	Case studies from literature and web-based sources (white papers, websites)	Literature and Case Study	Literature and Case Study	Case studies from literature
Methods	Literature review	collection of cases from literature and web-based sources (white papers, websites	Multiple interviews with pioneering platforms and manufacturing companies	Qualitative survey and Multiple interviews with pioneering manufacturing companies	Case studies from Literature
Data	Maturity model design guide-lines related articles to formulate industrial internet maturity model design guidelines	Multiple platform case studies for analysing and developing industrial internet platform openness framework	10 hours of intense interview data of 4 industrial internet platforms and 2 manufacturing companies that use industrial internet platforms.	Qualitative survey data of 9 equipment manufacturing companies that created the foundation and selection. 8 hours of intense interview data of the same 9 manufacturing companies to investigate the impact of platform openness on switching costs	Academic articles that consisted of multiple case studies of manufacturing companies that have implemented the advanced business models.

Publication 2 used literature and secondary data to extract relevant cases related to platforms in order to analyse the impact of platform openness on manufacturing companies' business. Publication 5 did a systematic literature review of qualitative case study papers to extract relevant cases that can enable the analysis of industrial internet based technologies' impact on advanced business models such as the pay-per-use, output and outcome business models. Publication 3 and Publication 4 used multiple case study approach to conduct the exploratory research strategy, which made it possible for an in-depth investigation towards the impacts of openness on industrial internet platform selection and related switching costs for the manufacturing companies.

Case selection strategy was clearly defined in all the 4 publications (publications 2 to 4). In case of platform companies, only those platforms were selected that were leading, pioneering and experienced in catering to manufacturing companies and solving their data and information management issues related to industrial internet based technologies. These experienced platforms allowed us to enforce credibility in our findings and transferability also becomes relatively simpler, because the selected platforms are international platforms and are world leaders in the field of industrial internet or IoT data and information management. Similarly, in case of manufacturing companies, pioneering and experienced with industrial internet based technologies were selected. It was important these manufacturing companies had used one or more of the above selected platforms, to make the results credible. We selected B2B manufacturing companies, that manufactured machines. Primary reason to make this selection was to focus on specific problems (interoperability, security, connectivity) that these machine manufacturing companies can encounter because of industrial internet based technologies. We had to avoid companies that did not have any real industrial internet implementation but mentioned industrial internet on their web pages and marketing materials, based on initial screening and discussions with these companies. Table 3.1 provides the details of data collected for all the publications in this dissertation.

In all the articles, a qualitative content analysis approach was followed to carry out the data analysis (Hsieh and Shannon 2005). The content analysis was carried out systematically through coding and categorizing the obtained data. Content or data was obtained from four different sources across all the five articles, previous academic literature, qualitative interviews, qualitative survey, web-based sources (white paper and websites). The data analysis was inductive in all the five articles. Article 1 systematically analysed maturity model literature and combined the findings with industrial internet literature in order to extract the guidelines to create an industrial internet maturity model. Article 2 took into account previous literature as well as data from the web pages as well as white papers of leading platform providers in order to create a list of appropriate industrial internet platforms. From a large pool of platforms four platforms were selected for detailed openness related analysis in the context of industrial internet platforms. This analysis was carried out using the openness framework presented in table 4.2. Article 3 analysed the interview data inductively in order to create an understanding of the impact of industrial internet platform openness on the business of manufacturing companies and platform providers. This analysis was done in a manner that, first preliminary analysis was done by two of the team members (including the author of this dissertation) and then it was discussed and re-analysed with the third co-author to create a final inductive analysis. Article 4 went through two step analysis process. First step analysed the data obtained through qualitative survey inductively to understand the relevance of industrial internet platforms in the interviewees' business. Second step was to analyse the interview data systematically and inductively to understand the priority of the impact of increased openness on switching costs. Article 5 systematically categorized the case-study data obtained from literature in a manner that all the characteristic features and related options could be analysed. The coding of these case studies were inductively done corresponding to every characteristic feature and option to extract the changes needed in all of them.

4 SUMMARY OF INDIVIDUAL PUBLICATIONS AND THEIR MAJOR RESULTS

In this section the most important results that are related to the research questions of the dissertation are put together. The contribution of the publications and the whole dissertation, as well as the limitations and future research are discussed in the following section 5.

4.1 Step-by-step implementation of industrial internet technologies

Publication 1 systematically defined industrial internet, a definition which is used consistently in the entire thesis. Industrial internet is a phenomenon that brings together the digital world with the physical world of machines. It combines industrial systems with the power of advanced computing, low-cost sensing, data analytics and innovative connectivity using the internet. The concept of industrial internet involves collecting large amounts of data by embedding sensors and advanced instrumentation in machines, which is analyzed to offer real-time intelligence. (Burmeister, Lüttgens and Piller 2016) argue that the industrial internet, is mainly about business model innovations in manufacturing industries. Business model innovations require certain skills and competences for their development (Foss and Saebi 2018) and the early identification of such skills and competencies helps in creating a roadmap to implement increasingly sophisticated and complex business models.

This paper also investigated the need to understand the maturity of different manufacturing companies if the full potential of industrial internet had to be extracted. The implementation and gradual adoption of industrial internet and related business models can be a very complex and extensive process of change. It requires the coordinated development of a large number of versatile individual and organizational skills and competencies. Furthermore, one important challenge is that it requires the collaboration of various individuals, business functions, and even various organizations, since the business models often evolve from departmental and factory-level models to inter-organizational and even ecosystem-level business models. Due to the complexity and the extent of the concept, the implementation and adoption of industrial internet can be slow, it is often not very systematic, and decisions and investments are often made that are not optimal from the whole company's point of view.

The industrial internet is still a new phenomenon so many companies lack a comprehensive understanding about its purpose and the solutions it can offer. Therefore, companies have to experiment to learn how to proceed. However, many of these experiments fail as they have not been designed to maximize learning and thus increase the acceptance of the new innovations by the workers. Businesses need a coordinated and systematic approach to the concept behind the industrial internet in order to increase its penetration into modern industrial production. Maturity models provide this kind of a coordinated and systematic approach. The advantages of maturity models in the adoption of particularly complex systems include:

- Serving as a basis for building a longer-term road-map for investment decisions or the development of required novel competencies
- Providing a structured checklist for the implementation, and the management of competencies in the implementation process
- Making the complex adoption process faster and more efficient
- Helping to assess the current situation of an implementation in terms of various critical management areas.
- Determining the desired future outcome in an optimal way (Batenburg, Helms and Versendaal 2006; Jussila, Kärkkäinen and Lyytikkä 2011; Kärkkäinen et al. 2014; Neff et al. 2014; Wendler 2012).
- Time and again, the adoption of complex systems has been significantly slower and less efficient than was expected due to inadequate coordination (Batenburg, Helms and Versendaal 2006; Wognum and Drongelen 2005) which results in unplanned and unexpected bottle-necks in certain management areas.

Table 4.1 Design guidelines for industrial internet maturity model

Phase	Decision Parameters	Characteristics	Examples	Design Guidelines /Recommendation
Define Scope	Focus/Breadth	Generic Model	Industrial Internet as a phenomenon can be the scope	Industrial Internet as a phenomenon can result in a broad maturity model for a company to use.
		Specific Model	Industry Specific, i.e. manufacturing industry (heavy equipment manufacturing industry), IT industry (data analytics, data visualization) Manufacturing-techniques specific i.e. mass manufacturing, engineering to other kinds of manufacturing	A heavy equipment manufacturing company, for example, needs a design based on processes, people and object-related outputs. The maturity model can be based on mass manufacturing, project-oriented manufacturing or engineering for designer manufacturing.
	Audience	Both, Management -oriented and technology-oriented audience	Industrial internet is a phenomenon, which involves intelligent machines, advanced analytics and people working together. Hence, it is important to have both technological as well as management-oriented needs.	To find out the needs and roles of management and technology personnel in the area of industrial internet in order to keep the context directed at the target audience.
Design Model	Maturity Definition	Combination of Process, people and object-focused parameters/dimensions	Industrial internet maturity can be defined keeping intelligent machines' maturity, advanced analytics' maturity and people's skills and competences in mind.	Optimization of system of systems involving people and people's capabilities and a multitude of business processes & technologies, including IT and sensors
	Goal Function	Multi-Dimensional	Connectivity (sensor related) and the spread of connectivity over different business units can be examples of two dimensions	Complex processes like the industrial internet require more than one dimension to understand the benefits of their adoption.
	Design Process	Literature and Practitioner Based	PLM, Supply Chain Management, Service System related maturity models	Take analogous models from literature (Table 1) and discuss the pros and cons with industry practitioners.
	Application Method	Self-Assessment or Third Party certified professional	Self-assessment if industry professional is designing the model for the same industry evaluation	Depending on the audience and respondents the model should be applied either by the industry or by third party professionals
	Respondents	Combination of internal (staff and administration) and external (Business partners)		If model is applied internally, Management & Staff are respondents and if it is applied externally to an industrial ecosystem, then the business partners are the respondents

Any Industrial Internet implementation demands a specific technological and strategic implementation in a company's business process. In order to fully understand the effects of the implementation of industrial internet, a more specific (industry specific, domain specific, production method specific) maturity model is required to define the breadth of the model. The Industrial Internet is of particular significance to manufacturing industries and Information Technology (IT). The goods and equipment that are produced by the heavy equipment manufacturing industry are characterized as long-lasting and highly productive. Hence, processes such as maintenance, repair and change operations are very important capabilities for these industries to have in order to achieve and maintain high profit margins (Neff et al. 2014). Based on the maturity model design framework (Mettler 2009) for decision-making parameters during the development of a maturity model, development, Table 4.1 defines the scope and presents the design guidelines for maturity models in an industrial internet context.

4.2 Industrial internet platforms - management of data and information

Publication 2 primarily focuses on understanding the value of data-information-knowledge derived from industrial internet platforms for manufacturing companies. Machines generate the data related to processes and operations. This data is translated into useful information using analytical frameworks. Operators and other personnel translate this information into actionable knowledge which can be used to improve the processes or operations or functioning of the machines based on their experience and expertise.

Product lifecycle management (PLM) can be defined as a systematic and controlled concept for managing product-related information and products throughout the whole product lifecycle. Fundamentally, PLM is focused on data, information and knowledge (D-I-K) and how to use those to properly serve a company's business and product development, as well as to create value for the customer (Ardolino et al. 2018).

The flow of real-time data from the various sensors across the value chain will enable for the first time the chance to observe the entire value chain instantly. This allows the optimization of the entire value chain rather than just selected parts of it. Hence, the Industrial Internet will go way beyond the traditional factory automation and will reduce the transaction costs for every transaction in the value chain.

This paper also defines industrial internet platforms and this definition is used consistently throughout the dissertation. Industrial internet platform is basically an Industry Platform (industry platforms are defined as products, services or technologies developed by one or more firms, and which serve as foundations upon which a larger number of firms can build further complementary innovations and potentially generate network effects. (Gawer and Cusumano 2014)) that has an input of data from industrial internet based technologies.

Industrial internet platforms are critical in creating value of industrial internet enabled data for manufacturing companies. The industrial internet platforms can access data from different sensors, actuators, enterprise systems, social media and other novel data sources (Porter and Heppelmann 2014). The industrial internet platform is able to aggregate data into a single database which can be stored, either in dedicated in-house servers or with other third party cloud storage providers (Evans and Annunziata 2012; J. Lee, Kao and Yang 2014). This organized data can be used, for example, by technicians to remotely monitor the condition of machines without physically being present (Lesjak et al. 2014), the data can also be run through machine learning algorithms to predict the health condition of a machine and notify the concerned technician to make an informed decision about the need for machine maintenance (J. Lee, Kao and Yang 2014).

Industrial companies need to select the platforms based on optimal levels of openness because of their requirement to use the platforms with various different actors (for example: suppliers, customers, designers). *A platform is "open", as long as, 1) no restrictions are placed on participation in its development, commercialization or use; or 2) any restrictions-for example, requirements to conform with technical standards or pay licensing gees-are reasonable and non-discriminatory, that is, they are applies to all the potential platform participants.*

4.3 Industrial internet platform openness

Publication 3 investigated the impact of industrial internet platform openness (allowing better exchange of data) on industrial internet platform provider and end-user's

Table 4.2 Dimensions and sub-dimensions of platform openness

Dimensions of Openness	Detailed Sub-Dimensions of Openness	Definitions
Demand-Side User (End User)	Access to information	Level of access to information on interfaces to link to the platform or utilize its capabilities (Gawer and Cusumano 2014).
	Cost of access	Cost of access as in patent or licensing fees(Gawer and Cusumano 2014).
	Control in terms of rules to use the platform	Types of rules governing use of the platform(Gawer and Cusumano 2014).
Supply-side User (Application Developer)	Core Developers	They are developers employed by the platform management company itself. They develop tools and applications which allows the users to use the platform effectively(G. G. Parker, M. W. Van Alstyne and Choudary 2016).
	Extension Developers	They are outside parties or 3rd party developers who add features (applications) and value to the platform to enhance the functionality of the platform(G. G. Parker, M. W. Van Alstyne and Choudary 2016).
	Data Aggregators	Data aggregators collect different interaction based data and re-sell it to the companies (as per the platform laws), who then can target advertisements etc to the users(G. G. Parker, M. W. Van Alstyne and Choudary 2016).
Platform Provider and Sponsor related openness	Proprietary Model	A single firm plays both provider and sponsor role(Eisenmann, G. Parker and M. W. Van Alstyne 2008).
	Licensing Model	A single firm sponsors the platform then licences to multiple providers(Eisenmann, G. Parker and M. W. Van Alstyne 2008).
	Joint Venture Model	Multiple sponsors jointly sponsor the platform but a single firm serves as its sole provider(Eisenmann, G. Parker and M. W. Van Alstyne 2008).
	Shared Model	Multiple sponsors collaborate to develop the platform's technology and then compete with each other to provide differentiated but compatible versions to the users(Eisenmann, G. Parker and M. W. Van Alstyne 2008).

business. Four major platform providers and two manufacturing companies that use these industrial internet platforms were interviewed. Both the platform providers and the end-users had a very different perspective towards industrial internet platform openness. To understand the impact of platform openness the framework created in publication 2 was used (see Table 4.2).

The results related to industrial internet platform openness strategies by both platform providers and end-users are presented in Table 4.3. Kaa-IoT, which is an open-source platform, considers openness to be one of the critical factors in the company's development strategy. For commercial platforms such as PTC-ThingWorx, Microsoft Azure, and IBM Watson IoT, openness allows the platform to be more extensible, i.e., ability to connect with different devices and different actors which is different from being open source. All the platforms raised one point in unison:

Table 4.3 Findings from II platform providers based on openness dimensions

Platform openness dimensions		Details of openness for every subdimension			
Primary openness dimensions	Detailed subdimensions	Kaa-IoT	PTC ThingWorx	Microsoft Azure	IBM Watson IoT
Demand-side user openness (platform user)	Access to information (openness standards)	Apache 2.0, latest industry standards, security standards	Apache 2.0, Java application that works on a browser, connectivity agnostic, works as middleware	Open standards—HTTPS, MQTT, OPC UA, Hadoop, Storm, Kafka, Java, ASP.Net, etc.	Communication protocols such as MQTT, application protocols such as HTTP, but does not support industrial payload protocol and legacy protocols for industrial automation
	Cost of access	No cost of access	Three payment models: standard, enterprise, and professional	Pay-per-use model	Pay-per-use model
	Control in terms of rules to use the platform	User decides the rules	User decides the rules	N/A	N/A
Supply-side user openness (application developer)	Core developers	No difference in terms of access to data for core or third-party developers. Data aggregation is not allowed	No core developers for application development; applications are made by third-party developers only. Data aggregation is not allowed	Difference between core and third-party developers' access but with open standards this is reducing. Data aggregation is not allowed	No difference in terms of access to data for core or third-party developers. Data aggregation is not allowed
	Extension (third-party) developers				
	Data aggregators				
Platform provider and sponsor-related openness	Proprietary model	Current and future model—shared model	Current and future model—shared model	Current model—licensing. Future model—with partnerships, moving toward shared model	Current model—combination of proprietary and licensing. Future model—shared model, but proprietary will still exist for core development
	Licensing model				
	Joint-venture model				
	Shared model				

openness allows the industrial end-user to avoid lock-in. *"Customers, especially industrial customers, are worried that if the platform stops development or changes the development focus, then it impacts their business if they're locked into the platform. Openness allows them to move to another platform if the above- mentioned scenario occurs." (IBM Watson IoT employee)*

The above table 4.3 enables managers to select the right kind of platform and right kind of openness based on the kind of business model they have with their customers.

4.4 Long-term impacts of industrial internet platform openness

Publication 4 takes the concept of industrial internet platform openness further using switching costs. Switching costs are defined as the customer's perception of the magnitude of additional costs required to conclude the current relationship, and se-

Table 4.4 Platform openness (Menon, Kärkkäinen and Wuest 2017) and switching cost framework (Blut et al. 2016)

			Switching Costs							
			Procedural				Financial		Relational	
			Uncertainty costs	Search costs	Training costs	Setup costs	Sunk costs	Lost performance costs	Brand relationship and psychological costs	Personal relationship and psychological costs
Openness Dimensions	End-user related openness	Access to information								
		Cost of access								
		Control in terms of rules to use the platform								
	Application developer related openness	Core developers								
		Extension or 3rd party developers								
		Data aggregators								
	Provider or sponsor related openness	Proprietary model								
		Licensing model								
		Joint venture model								
		Shared model								

cure an alternative supplier (Blut et al. 2016). Manufacturing companies usually see the benefits of platform openness because of the various benefits but have a tendency to fail to anticipate the impact of future switching costs, while having a preference of minimizing immediate costs, and thus, this leading to lock-in. Publication 4 creates a framework of increased openness impacts on switching costs (4.4)

The empirical material for this paper stems from a qualitative questionnaire, training and workshop of eleven manufacturing and service companies. The participants and respondents were all senior production and/or supply chain related directors as well as managers. Table 4.5

It is important to understand that increased access to data, better control over the use of the platform and increase in the number of applications can increase the switching costs significantly in long term. One of the various findings of this study was that increased openness for access to information was commonly perceived to increase the switching costs related to training and setup costs. This means access to more data and information, which can result into investments in infrastructure as well as training the personnel. None of the respondents consider increased openness towards cost of access, i.e. cost of the platform usage reduces, will impact the relational switching costs. This means that for industrial manufacturing companies

Table 4.5 Impact of switching costs on openness dimensions

			Switching Costs								Total
			Procedural				Financial		Relational		
			Uncertainty costs	Search costs	Training costs	Setup costs	Sunk costs	Lost performance costs	Brand relationship and psychological costs	Personal relationship and psychological costs	
Openness Dimensions	End-user related openness	Access to information	4	5	9 (four +H)	10 (five +H)	3	6	3	2	42
		Cost of access	1 (one +H)	5	3	4 (one +H)	2	1			16
		Control in terms of rules to use the platform	2	2	8 (two +H)	2	2	1 (one +H)	3 (one +H)	2	22
	Application developer related openness	Core developers		4 (one +H)	5 (one +H)	5 (one +H)	4	2 (one +H)	4	2	26
		Extension or 3rd party developers	3	2 (one +H)	5	5 (one +H)		4	5	3	27
		Data aggregators	2	4 (one +H)	2 (one +H)	2 (one +H)			2	3	15
	Provider or sponsor related openness	Proprietary model	1	1	1	2	1	1	1		8
		Licensing model	1	3	1	1 (one +H)	2	1	4 (one +H)	1	14
		Joint venture model		1	2		1		1	1	6
		Shared model		1	1		1			1 (one +H)	4

Ranked 1 in High Impact on business responses
Ranked 2 in High Impact on business responses
Ranked 1 in responses to openness dimensions
Ranked 2 in responses to openness dimensions
Ranked 3 in responses to openness dimensions
No responses

it is the access to data and information that is more vital when compared to the cost of access to the platform. Another interesting finding of the study was that if the openness towards 3rd party developers would increase then some of the perceived procedural costs will have a significant impact. The is because it is the 3rd party developers or application developers, in general, that create business opportunities for the platform end-users by developing novel applications. Hence, if the openness increases for 3rd party developers then more applications will be developed on the platform motivating the end-user to stay on the platform for a long time and therefore, increasing the switching costs. This is similar to what Apple or Google have done on their mobile phone application platforms. They have facilitated the inclusion of various 3rd party developers to develop applications that make it difficult for the end-user of the platform to switch from one mobile phone operation system to another. This is can be replicated by B2B platforms such as the industrial internet platforms as well.

Table 4.6 Impact of IIoT based technologies on characteristic features of advanced business models

Characteristic Features			Impact of IIoT based technologies	References
A	Ownership	During the phase of use	Ownership of Data associated with the process of manufacturing and condition of the machine	[(Ardolino et al. 2018; Bock and Wiener 2018; Bock, Wiener et al. 2019; Hypko, Tilebein and Gleich 2010)]
		After the phase of use		
B	Personnel	Manufacturing	Adaptive control using predictive analytics of the machine impacts the Personnel activities. Predictive maintenance impacts overall maintenance activities.	[(Bock, Wiener et al. 2019; Ehret and Wirtz 2017; Grubic and Jennions 2018; Kleemann and Essig 2013)]
		Maintenance		
C	Location of operation		Condition monitoring gives more freedom when it comes to selecting the location of operation	[(Ardolino et al. 2018; Grubic and Jennions 2018; Liinamaa et al. 2016)]
D	Single/multiple customer operation		Real-time or near-real time monitoring allows multiple customer operations with ease.	[(Bock and Wiener 2018; Bock, Wiener et al. 2019)]
E	Payment model		IIoT based technologies enable flexible and smart contracts	[(Bahga and Madisetti 2016)]

4.5 Industrial internet based data and information - impact on business models

Publication 5 defines advanced data enabled business models for manufacturing companies under the terminology of non-ownership business models (NOBM). While recognizing the uncertainties related to the realization of business benefits from IIoT, the novel types of Non-ownership Business Models (NOBMs) enable collaborating companies to share both opportunities and downsides of IIoT for mutual benefit, thus creating novel networked value creation opportunities. Regarding such benefits, in general, IIoT has been demonstrated e.g. to enable decreases in transaction costs between companies in various manners, while increasing transparency in collaboration through increases in the quantity and quality of data and information.

In this paper, the main focus was on companies that not only produce products for other companies, but more specifically, on companies the products (machines or machine components) of which are used as part of the other companies' manufacturing processes, and mostly, are capital-intensive in nature, i.e. B2B companies. Thus, for instance, the risk aspect, associated to all NOBMs which transfer product ownership from customers to suppliers, is emphasized, while e.g. failures in products or product components can cause even significant interruptions in the whole pro-

Table 4.7 Impact of IIoT based technologies on the options related to characteristic features of advanced business models

C.F.*	Options				Impact of IIoT based technologies
A	Equipment producer	Leasing bank	Operating joint venture	Customer	Condition Monitoring and Predictive Maintenance enables the equipment producer to take more risk in ownership
	Equipment producer	Leasing bank	Operating joint venture	Customer	
B	Equipment producer	Operating joint venture	Customer		Adaptive control allows the equipment producer to take control of the manufacturing process and maintenance
	Equipment producer	Operating joint venture	Customer		
C	Equipment producer's establishment	Establishment "fence to fence" to the customer	Customer's establishment		Optimization, prediction and geo-localization allows the equipment producer to operate the machine at any location
D	In parallel operation for multiple customers	Operation for a single customer			Usage monitoring, intensity assessment and condition monitoring allows the equipment producer to serve multiple customers with the same machine.
E	Pay per unit	Pay for availability	Fixed rate	Pay for equipment	Smart contracts based on all the IIoT based capabilities allows flexibility in payment contracts.
*** C.F. – Characteristic Features as in Table 4.6**					

duction process, and thus, the supplier has significantly higher responsibility of such risks. The information interoperability possible because of IIoT has wholly changed the relationships between the customers, manufacturers and the suppliers, and thus modifying the business models of the manufacturing companies.

Non-ownership model can be defined as "service in which customers acquire some property rights to an asset and are offered a certain degree of freedom in using this asset for a specified period of time while the burdens of ownership remain with the owner". Renting and leasing are also considered as non-ownership models but in this study we focus on advanced IIoT enabled non-ownership models. They are advanced because they require machine data and analytics as well as collaboration with various partners to provide added value to the customer in order to make the earnings more dynamic. To take the manufacturer's point of view into consideration, the earning logic of non-ownership business models must be described. This can be done by dividing the non-ownership model into pay-per- use, pay-per-output and pay-per-outcome models. Pay-per-use type non-ownership model implies that the customer pays for the use of the machine and every other aspect related to the machine, i.e. ownership, installation, maintenance, upgradation, recycling is taken care of by the manufacturer. Pay-per-output type non-ownership model focuses on the result of the machine use, which is usually quantified in monetary terms. Pay- per-outcome type non-ownership model focuses on the value derived by the customer after using the machine provided by the manufacturer.

Advanced business models that enable manufacturing companies to transition from sales-based revenue to a more continuous, service-based revenue generation are very appealing for a myriad of reasons, including closer customer relations, lock-in, more control of complex assets, and access to the system's operational data for the manufacturer. Lay et al.'s ((Lay, Schroeter and Biege 2009)) morphological box depicts five different characteristic features, owner-ship, personnel, location of operation, single/multiple customer operation, and payment model."Characteristic features" are the central features of novel manufacturing business-to-business product-related business models, which are typical, as well as centrally differentiate the different types of novel business models from each other, and thus can be used for identifying the variety of options in the case of novel business models. Table 4.6 presents the impact of industrial internet based technologies on the characteristic features of the morphological box presented by (Lay, Schroeter and Biege 2009). Table 4.7 presents the impact of industrial internet based technologies on the options of the above mentioned characteristic features of the morphological box presented by (Lay, Schroeter and Biege 2009).

After embedding IIoT based technologies with the machines and the equipment, it is possible to collect data of processes and the condition of the machine. This collected data on further analysis can enable process optimization, wear and tear prediction and new product design with better optimization for the manufacturer. IIoT technologies create a connected environment for the machines via cloud, which enables the machine operator to remotely control the machine from another location.

5 CONCLUSIONS

This section presents the discussion and conclusion of the dissertation. First, the academic contributions of the publications to answering the research questions are summarized . The contribution to each research question is then discussed in detail. Second, contributions of the dissertation to management are outlined. Third, the dissertation project is evaluated against the criteria of qualitative research. Finally, the limitations of the study are discussed and suggestions for further research are provided.

5.1 Academic contributions of the publications to the research questions

The contribution of this dissertation project to answering the research questions is summarized in this section. All publications in the dissertation project contributed to the intersection of business value creation for manufacturing companies, data and information management and industrial internet based technologies as shown in figure 3.1.

Table 5.1 presents the major contributions of the dissertation in correspondence with the research questions of the dissertation. More detailed contributions are presented in the following parts of this sub-section.

Publication 1. The implementation and gradual adoption of industrial internet and related business models can be a very complex and extensive process of change. It requires the coordinated development of a large number of versatile individual and organizational skills and competencies. Due to the complexity and the extent of the concept, the implementation and adoption of industrial internet can be slow, it is often not very systematic, and decisions and investments are often made that are not optimal from the whole company's point of view. The maturity modelling approach

Table 5.1 Major academic contributions of the publications towards the research questions of dissertation

Research Questions	Main academic contributions of the publications towards the research questions (for more detail related to contribution to earlier research, see text below this table)
RQ 1 - What is the role of data and information management in industrial internet enabled value creation for manufacturing companies?	Publication 1 furthers the academic understanding by formulating design guidelines to create a maturity framework, that can divide tasks into different categories and steps, and simplify the complex steps of implementing industrial internet in a step-by-step manner resulting into the potential for increasingly more advanced business value creation. Publication 2 increased the understanding of role of industrial internet enabled data and information through a multi-dimensional platform openness framework. Publication 5 furthers the understanding to the impact of industrial internet based technologies as well as related data and information management on non-ownership business models by using morphological box framework
RQ2: How can data and information management impact industrial internet enabled value creation and related risks in manufacturing companies?	Platform openness allow manufacturing companies to create value for themselves and their customers (e.g. enhanced interoperability, advanced analytics etc.). Potential risks especially long-term risks of industrial internet platform openness are scarcely studied. Publication 3 creates a deeper understanding in analyzing short and long-term impacts of platform openness, such as security issues, application developer's reliability and quality and others that in turn impact industrial internet enabled value creation. Publication 4 increased the understanding of increased platform openness impacts, especially long term impacts such as switching costs, lock-in and others by using a multidimensional framework.
RQ3: How does the industrial internet enabled data and information management impact advanced business models for manufacturing companies?	Publications 3 and 4 analyze the long term impacts of industrial internet platform openness for end-customers businesses. Publication 5 deepens the understanding on industrial internet enabled technologies' impact on non-ownership business models by studying the impact of industrial internet enabled technologies on every characteristic feature and related options of the morphological box

(Pöppelbuß Maximilian Röglinger 2011) is fast being recognized as a useful approach to this problem. Since as long ago as 1993, maturity models have commonly been associated with Capability Maturity Models (CMM). This has resulted in the development of Capability Maturity Model Integration (CMMI) as espoused by Wendler (2012). Over the course of three studies, (Wendler 2012) shows a total of 20 application domains and 18 application areas in a variety of industries such as IT, manufacturing and services. Even in the adoption and implementation of hugely complex, inter-organizational, multi-process applications, such as those incurred in, for example, Product Lifecycle Management (PLM) (Vezzetti, Alemanni and Macheda 2015), Supply Chain Management (SCM) ((Netland, Alfnes and Fauske 2007)), Social Media ((Geyer and Krumay 2015)) and Product-Service Systems ((Neff et al. 2014)) maturity modelling approach has proved to be useful. Thus, it seems reasonable that similar benefits would also be gained in the context of potential maturity models designed for the adoption and implementation of the processes involved with Industrial Internet applications. It is an extremely complex process because of the related development of completely new types of business ecosystems ((Evans and Annunziata 2012; Kagermann, Wahlster and Helbig 2013; Posada et al. 2015)), very novel types of business models and value creation models (Bruner 2013; Posada et al. 2015).

Publication 1 furthers the understanding to create a framework, which can be a maturity framework, that can simplify the complex steps of implementing industrial internet in a step-by-step manner resulting into business value creation (RQ 1). Publication 1 covers the maturity model literature and combines the understanding with industrial internet based technological complexities to create detailed guidelines that can create an exhaustive maturity model for industrial internet based technological implementation. Based on the maturity model design framework (Mettler 2009) for decision-making parameters during the development of a maturity model, development, table 4.1 defines the scope and presents the design guidelines for maturity models in an industrial internet context. (Mettler 2009) emphasizes that it is important to define the focus of the phenomenon to be studied using an appropriate maturity model. Any Industrial Internet implementation demands a specific technological and strategic implementation in a company's business process. In order to fully understand the effects of the implementation of industrial internet, a more specific (industry specific, domain specific, production method specific) maturity model is required to define the breadth of the model. The Industrial Internet is of particular significance to manufacturing industries and related data and information management. This allows us to tailor the maturity model for the implementation of industrial internet towards the manufacturing industries, especially heavy equipment manufacturing. Global companies like GE, Siemens and Konecranes Oyj, which are active in the heavy equipment manufacturing sector, and IT and IT-service companies like Intel, Cisco and AT&T would all benefit from a maturity model fashioned according to industrial internet design guidelines (Agarwal and Brem 2015; Bruner 2013; Neff et al. 2014). The goods and equipment that are produced by the heavy equipment manufacturing industry are characterized as long-lasting and highly productive. Hence, processes such as maintenance, repair and change operations are very important capabilities for these industries to have in order to achieve and maintain high profit margins (Neff et al. 2014). The design guidelines in Table 4.1 provide steps to create a model that can take into account the aforementioned capabilities that allow the manufacturing companies to capture value from industrial internet based data and information management (RQ2).

Publications 2 and 3. Industrial internet enabled technologies (such as) can offer novel and important solutions to the management of data and information for the entire life cycle of the machine. The flow of real-time data from various sensors across the value chain will enable for the first time the chance to observe the entire value chain instantly (Buda et al. 2015). Hence, the industrial internet technologies will go beyond traditional factory automation and has the ability to reduce the transaction cost for every transaction in the value chain. Yet, partly due to very recent maturation of the industrial internet based technologies and its implementation there is relatively little research in management of industrial internet enabled data and information, especially in the context of business value creation. It has been understood from previous studies that platforms in general can provide new ways to access and accelerate the value capture from data and information extracted from various systems (Gawer and Cusumano 2014). This value capture from industrial internet enabled technologies and related data and information through platforms is relatively less researched. Platform openness is essential to the understanding of how platforms can facilitate interoperability between platform end-users (industrial companies in case of II-platforms) and their respective information systems. Platform openness related impacts, both short-term and long-term, can vary for B2C and B2B platforms. Most of the previous studies address the platform openness impacts (both short- and long-term) from a B2C perspective, but in Publication 3, the issue of openness impacts from industrial platforms is addressed (Livares and Ood 2004; Ondrus, Gannamaneni and Lyytinen 2015; Tiwana 2014; Wessel, Thies and Benlian 2017).

Publications 2 and 3 increased the understanding on the role of data and information management (RQ1) as well as the role of industrial internet platforms in managing data and information (RQ2) that impact the implementation of novel advanced business models for the manufacturing companies (RQ3). Publication 2 identified key functionalities related to data and information management (such as data access and collection, data aggregation, storage, analytics, sharing and sense making) that impact platform selection and provided a funnel type approach of narrowing down from a plethora of available to platforms to industrial internet platforms that address the above mentioned key functionalities. Publication 2 also increased the understanding in the role of platform openness through various openness related dimensions and sub-dimensions (Table 4.3). Publication 3 contributed to understanding the impact (both short and long-term impacts) of platform openness, discussed in Publication 2, for both industrial internet platform providers (platform companies such as Kaa-Iot, PTC-Thingworx, Microsoft Azure and IBM Watson IoT) as well as platform end-users (manufacturing companies). Publication 3 goes deeper than previous research especially, in analyzing long-term impacts of platform openness related decisions for both platform providers' (platform companies) and platform end-users' (manufacturing companies) businesses.

Publication 2 furthers the understanding on data and information management related challenges for manufacturing companies using product lifecycle management (PLM) as a framework. Publication 2 contributes to previous studies by (G. G. Parker, M. W. Van Alstyne and Choudary 2016; Terzi et al. 2010) By specifically studying the issues of interoperability of information systems using openness related dimensions and sub-dimensions. Publication 2 creates a multi-dimensional platform openness framework derived from the studies by (Eisenmann, G. Parker and M. W. Van Alstyne 2008; Gawer and Cusumano 2014; G. G. Parker, M. W. Van Alstyne and Choudary 2016). This framework combines various dimensions and sub-dimensions described by (Eisenmann, G. Parker and M. W. Van Alstyne 2008; Gawer and Cusumano 2014; G. G. Parker, M. W. Van Alstyne and Choudary 2016) Table 4.2. Academically, Publication 3 contributes to the concept of platform openness and the related dimensions (Demand Side End-User, Supply Side End-User, and Platform Sponsor/Owner dimensions) for platform end-users. We add to the understanding of various dimensions of openness from the specific viewpoint of industrial platforms or B2B platforms. The detailed results are in table 4.3.

Publication 4. Various Industrial internet or industry 4.0 platforms allow the manufacturing companies to manage data and information efficiently in order to implement IoT related technologies to enhance their business and create value for the customers (Ehret and Wirtz 2017; Kotiranta et al. 2017; Menon, Kärkkäinen and Wuest 2017). In the manufacturing companies' context, platform related openness is considered very important for technology implementation and creating business value (Benlian, Hilkert and Hess 2015; Eisenmann 2008; G. G. Parker, M. W. Van Alstyne and Choudary 2016). This requirement from the industrial end-users also enforces platform providers to make critical decisions on platform openness (Benlian, Hilkert and Hess 2015; Eisenmann 2008; Kotiranta et al. 2017; Menon, Kärkkäinen and Wuest 2017; G. G. Parker, M. W. Van Alstyne and Choudary 2016). Lock-in, which is understood to be one of the long-term downside of openness, can be a result of multiple factors including increased switching costs. However, previous to this publication (publication 4), relatively little was known about the impact of switching costs in a B2B context and the impact of increased openness on switching costs.

Publication 4 increased the understanding on platform openness impacts, especially long-term impacts (such as lock-in, switching costs, transaction costs etc.). Publication 4 goes into the depth of industrial internet platform's increased openness impacts on platform switching costs for platform end-users (manufacturing companies). (Blut et al. 2016) state that relatively little is known about the relevance of switching costs, yet, particularly in industrial and B2B markets. Furthermore, switching costs should be seen in B2B-context as a multi- faceted construct (Blut et al. 2016). Thus, part of the novelty of this study is derived from the use of multidimensional switching cost concept, and reflecting the importance of platform openness from the perspective of individual switching cost components in the relatively little studied industrial B2B context, as well as the little studied perspective of industrial internet platform use, and the platform user perceptions on the impact of openness to switching costs. Publication 4 furthers this impact by creating a multidimensional framework that combines the platform openness framework created by (Menon, Kärkkäinen and Gupta 2016) and switching cost framework created by (Blut et al. 2016). This framework is presented in Table 4.4 (result section table). Publication 4 goes in depth of the increased openness impact on switching costs for industrial internet platform end-users empirically and demonstrates the impact on manufacturing companies' businesses (RQ3). Publication 4 concludes that increased openness in terms of industrial internet enabled data and information management through platforms has significant long-term impacts on switching costs such as increased training costs, increased setup costs, increased costs related to application development and others. Some of these long-term impacts may seem to be very unintuitive, and hard to detect and understand without presented types of systematic frameworks, which can result into lock-in for the manufacturing companies (RQ2) in the selection of e.g., IIoT platforms table 4.5.

Publication 5. The academia and managers are currently having high expectations on the potential of the industrial internet based technologies (Ehret and Wirtz 2017). However, these benefits are not very apparent and easy to realize. While recognizing the uncertainties related to the realization of business benefits from IIoT, the novel types of Non-ownership Business Models (NOBMs) enable collaborating companies to share both opportunities and downsides of industrial internet based technologies for mutual benefit, thus creating novel networked value creation opportunities. Regarding such benefits, in general, IIoT has been demonstrated e.g. to enable decreases in transaction costs between companies in various manners (Ehret and Wirtz 2017), while increasing transparency in collaboration through increases in the quantity and quality of data and information (e.g. (Ardolino et al. 2018)). Currently there is limited understanding in academic literature about the value and benefits of industrial internet based technologies to business and novel business models (Arnold, Kiel and Voigt 2016). Literature has previously studied non-ownership business models from various sectors; such as software industry (Blut et al. 2016), B2C product manufacturers such as washing machine manufacturers, manufactured products such as copier and printer (Ardolino et al. 2018). However, there is very little research on the impact of IIoT technologies on NOBM's, which research gap we aim to address here. B2B manufacturers that make equipment or machines that are critical in customers process, such as the air-compressors or jet engines (critical components for an airplane manufacturer) have a very different risk profile when it comes to these non-ownership models when compared to the above-mentioned products. There are some authors that discuss the risk profile for these kind of manufacturing companies (Gebauer et al. 2017). Some of the authors (Ardolino et al. 2018; Bock and Wiener 2018; Gebauer et al. 2017), discuss the impact of IIoT on the business models of the manufacturing companies using the business model framework. They do not discuss the impact of IIoT on specific non-ownership business models, such as the pay-per-use, pay-per-output and the pay-per-outcome models in a manner that the companies can define the value proposition for every individual model.

Publication 5 furthers the understanding to the impact of industrial internet based technologies as well as related data and information management on non-ownership business models (RQ1 and RQ 3) by using morphological box framework created by (Lay, Schroeter and Biege 2009). Publication 5 deepens the understanding on industrial internet enabled technologies' impact on non-ownership business models by studying the impact of industrial internet enabled technologies on every characteristic feature and related options of the morphological box presented by (Lay, Schroeter and Biege 2009). Publication 5 creates an in-depth analysis of the impact of industrial internet based technologies on characteristic features such as ownership, where in addition to the ownership of the machine (mentioned by (Lay, Schroeter and Biege 2009)), one of the key additions to the morphological box framework is the ownership of data extracted by industrial internet based technologies. It also furthers the understanding in exploring the needed novel characteristic features (such as machine utilization level analysis, ownership of data, raw materials and utilities used based on the data and information available because of industrial internet based technologies) and related options. These results are presented in the table 4.6 and table 4.7.

5.2 Managerial Implications

Industrial internet implementation brings in new challenges from data and information perspective as well as related advanced business models perspective for the managers of manufacturing companies. These challenges and needs can be systematically understood using a maturity approach, where the managers can in a step-by-step manner use the design guidelines presented in Publication 1 to understand their current situation and also create a few scenarios of what they would like to achieve in future through the industrial internet enabled implementations. Maturity models help the managers pinpoint certain bottle necks and issues. They can discuss and negotiate these issues with personnel from other departments, who can then reflect on the decisions that can impact the overall strategy of the company.

Industrial internet implementations usually lead to challenges related to management of data and information that the machines generate using these technologies. Publications 2 and 3 help the managers to make an informed decision on what kind of industrial internet platform to select based on the kind of openness that suits their business. For instance, in high-security organizations, such as the military, airplane industry or the energy sector, managers should not prefer the platform that is open in all aspects, but consider the significance of the implications of openness to information security or the quality control of applications for their business. Publication 4 furthers this decision making process related to selection of appropriate platform by giving an in depth analysis using various case studies in the short and long term impacts of platform related openness. Managers can use the switching cost versus openness framework created in publication 4 to understand the impact of increased openness of the platforms that they decide to use for their processes on switching costs in long term. This impact can lead to a situation where they are locked in with the platform and give away a lot of bargaining power to platform providers.

Finally, publication 5 demonstrates a variety of NOBMs and their characteristic features as well as options that the managers can select from to create an NOBM for their own business. The upgraded morphological box takes into account the impact of industrial internet based data and information. This gives managers a variety of options from pay-per-use to pay-per-output to pay-per-outcome type business models. Overall, the thesis provides tools to strategize their industrial internet implementation and related data and information management keeping value creation for the customer in mind.

5.3 Evaluation of the study

In order to evaluate this study it is important to understand the different research paradigms (Guba 1990).

1. Positivism - the main assumption is that one true reality exists and it can be discovered using scientific methods. Quantitative methods are applied in this

approach

2. Post-positivism - the main assumption is that reality exists but it is difficult or impossible to completely determine if a true reality has been found. Both qualitative and quantitative methods are applied in this approach
3. Constructivism - knowledge consists of those constructions about which there is relative consensus. Qualitative methods are used to capture various consensus
4. Critical theory - knowledge consists of a series of structural/historical insights that will be transformed as time passes. Like in constructivism approach, even in this qualitative methods are used to capture various consensus.

This dissertation explores the impact of industrial internet enabled data and information management on creating value for manufacturing companies. As mentioned in the methodology section, various aspects of this dissertation, namely, the guidelines for industrial internet maturity model, industrial internet platform openness as well as switching costs framework and morphological box analysis of industrial internet based data and information, all have been evaluated and studied using qualitative methods. Hence, the evaluation of these results in the dissertation fall under the constructivism paradigm. In order to evaluate these results criteria developed (Guba 1990) is used. These authors (Guba 1990) claim that the overall criterion for qualitative research is trustworthiness. The criteria they suggested were: credibility, dependability, confirmability and transferability. Following sub-sections evaluate the results of this dissertation using this criteria as described by (Guba, Egon and Y. S. Lincoln 1998)

5.3.1 Credibility

Credibility is similar to internal validity in quantitative research and it is concerned with the value of the truth in the research. Credibility establishes whether the research findings represent plausible information drawn from the participants' original data and is a correct interpretation of the participants' original views (Guba 1990). There are 4 main strategies to evaluate credibility;

1. Prolonged engagement - Lasting presence during observation of long interviews or long-lasting engagement in the field with participants. Investing suf-

ficient time to become familiar with the setting and context, to test for misinformation, to build trust, and to get to know the data to get rich data (Guba 1990). Several distinct categories of questions were asked regarding topics in discussion such as openness of industrial internet platforms, openness impact on switching costs of industrial internet platforms (Publication 2, 3 and 4). Participants were encouraged to support their statements with examples, and the interviewer asked follow-up questions. The researchers studied the data from their raw interview material until an understanding emerged to provide them with the scope of the phenomena under study.

2. Persistent observation - Identifying those characteristics and elements that are most relevant to the problem or issue under study, on which you will focus in detail (Guba 1990). In both publications 3 and 4, the focus of the study was platform openness as well as increased switching costs impact on both manufacturing companies and platform providers. The interview questionnaire had all the categories focusing on various elements of these issues (openness and switching costs). Hence, the focus was on the impacts of these two concepts (openness and switching costs) on the businesses of both manufacturing companies and platform providers. The researchers studied the data until the final theory provided the intended depth of insight

3. Triangulation - Using different data sources, investigators and methods of data collection.

   - Data triangulation refers to using multiple data sources in time (gathering data in different times of the day or at different times in a year), space (collecting data on the same phenomenon in multiples sites or test for cross-site consistency) and person (gathering data from different types or level of people e.g. individuals, their family members and clinicians). Publications 2, 3 and 4 were able to secure data triangulation by using various data sets that emerged from, literature, detailed qualitative interviews, detailed qualitative survey and workshops.
   - Investigator triangulation is concerned with using two researchers to make coding, analysis and interpretation decisions. A total of four researchers were involved in collecting the data (via literature, qualitative interviews, qualitative survey and workshop) as well as analysis and coding of the col-

lected data. Interviews were usually conducted by two researchers and they discussed the impacts and conclusions with the whole team to eventually achieve investigator triangulation.

- Method triangulation means using multiple methods of data collection(Sim and Sharp 1998). Methodological triangulation was used by gathering data by means of different data collection methods such as in-depth interviews, qualitative survey, workshop and researcher notes.

4. Member check - Feeding back data, analytical categories, interpretations and conclusions to members of those groups from whom the data were originally obtained. It strengthens the data, especially because researcher and respondents look at the data with different eyes (Crozier, Denzin and Y. Lincoln 1994). A total of four researchers were involved in various publications. All the four researchers had regular meetings and discussions to formulate the questionnaire, simulate the results of the interview and discuss the findings. This allowed rigorous triangulation from the investigator point of view for all the papers. This allowed us to look at the data and its implication from different perspectives.

5.3.2 Dependability

Dependability acknowledges that similar results may not be obtained but emphasizes the need for the researcher to account for the ever-changing context within which the research occurs, as well as any changes in the design of the study that were needed to obtain a better understanding of the context. The main purpose of dependability is to produce findings that are stable and dependable (Guba 1990). Hence, there is a need to develop an audit trail through which derived findings are as explicit and repeatable as possible (Morrow 2005). According to (Guba 1990) dependability can be evaluated in two steps, 1) overlapping methods, where two or more methods are put together in a manner that weaknesses of one is compensated by the strengths of the other method; and 2) step-wise replication or audit trail, in which two separate research teams (original team can be split into two teams) deal separately with data sources that have also been divided into halves.

Publication 4 used overlapping methods of in-depth qualitative interviews, qualitative survey and workshop discussion to understand the impact of industrial internet platform openness on platform switching costs. It was difficult to estimate the impact of platform openness on switching costs with one method because of the long-term impact that switching costs bring in, hence, multiple overlapping methods were used to understand the phenomena in detail.

As far as the second step is concerned, publications 2, 3 and 4 provide a detailed account of the case selection criteria, questionnaire formulation strategy for in-depth interviews as well as details on the type of people (and their positions) interviewed. Two researchers were responsible to conduct the interviews, workshops and distribute, explain as well collect the qualitative survey questionnaire. The interpretation of the results to formulate discussion pointers as well as conclusions was done within the team of four researchers, in a manner that the other two researchers (who were not involved in the data collection process) acted as auditors for the data while formulating interpretations.

5.3.3 Confirmability

Confirmability refers to the degree to which the results could be confirmed by others. The main objective of confirmability is to produce findings that are free from investigator bias (Guba 1990). Confirmability can be increased by the following measures (Shenton 2004); 1) triangulation to reduce effort of investigator bias; 2) admission of researcher's beliefs and assumptions; 3) recognition of shortcomings in study's methods and their potential effects; 4) in-depth methodological description to allow integrity of research results to be scrutinized; and (e) use of diagrams to demonstrate the "audit trail.

In this dissertation triangulation from data, method and researcher perspective was used to reduce investigator bias. The details of this triangulation is mentioned in the credibility subsection. The researcher' assumptions are mentioned in chapter 1 and 2 in detail. Shortcomings of the methods are presented in chapter 3 as well as chapter 5.2.5 in detail. Given the limitation in terms of number of pages and words in every individual article, the methodological details are limited but they are sufficiently described to scrutinize the integrity of the results.

5.3.4 Transferability

Transferability deals with the aspect of applicability. Our responsibility as researchers is to provide a 'detailed description' of the participants and the research process, to enable the reader to assess whether your findings are transferable to their own setting; this is the so-called transferability judgement. This judgement is usually made by the reader because we are not usually aware of their research settings, but through different simulations we can help the reader to make this judgement. (Crozier, Denzin and Y. Lincoln 1994)

In publications 3 and 4 we have provided a detailed account of the type of companies we have interviewed; i.e. pioneering manufacturing companies that have implemented industrial internet based technologies and are using relevant platforms to manage data and information as well as leading industrial internet platforms that have a few years of experiences in helping manufacturing companies to extract value of industrial internet enabled data and information. The manufacturing companies selected are all pioneering in their industrial internet implementation and are located in Germany, Finland, Sweden and USA. Other companies in these locations and elsewhere in the world can learn from these findings because of the pioneering nature of the investigated companies. The detailed account of case selection strategy is present in the respective publications for the readers. Details of the interview process and the position of the interviewed participants allows the reader to decide if it will be applicable for their research settings. Questionnaire excerpts and categories allow the readers to adapt the questionnaire in their own research setting.

5.4 Limitations of the study and future directions

The aim of the study was to open new, interesting areas for further research by increasing the understanding of phenomena that have received scant attention in the literature and have not been considered from multiple perspectives. On the other hand, this aim limited the depth of the research because it did not focus on a single perspective or conduct an in-depth empirical inquiry in a very specific area.

This study took into account the first two parts of (Evans and Annunziata 2012) definition of industrial internet, "*intelligent machines advanced analytics*". It will be interesting to include the *"people at work"* aspect of the definition and understand the impact of machine operators and managers on value creation through industrial internet based technologies. Over the last few years it is understood that digital twins (Tao et al. 2018), i.e. a digital working instance of the physical machine, can create an huge impact on how end customers can create value from the advanced machines. This concept of digital twins enabled by industrial internet based data and information can be studied in detail from the perspective of its impact on advanced business models. Industrial internet based technologies have added various technologies to the portfolio such as edge technologies or edge analytics, artificial intelligence based technologies, machine learning and others. There is a need to explore the impact of these novel technologies on advanced business models of manufacturing companies. For example, edge technologies or edge analytics can provide faster analytics of machine processes on the machine itself, that can reduce the analytical time and effort considerably. This study focuses on the value creation through industrial internet based technologies for manufacturing companies, that manufacture the machine or equipment for the customers. Future studies should include the customer perspective as well and present possible solutions related value co-creation, value co-delivery through industrial internet based technologies. This will provide an overall multi-sided understanding of value created by industrial internet based technologies.

Systems such as ERP (Enterprise resource management), MES (manufacturing execution system), SCADA (Supervisory control and data acquisition), etc that provide data to improve the processes and eventually impact the business models were not studied in detail because the focus of this study was to understand the impact of industrial internet based technologies and related platforms on manufacturing companies' businesses. It would be interesting to take into account these systems with the novel industrial internet platforms and investigate the impacts of openness on these systems as well as on the manufacturing companies' business models.

The qualitative studies were carried out in the companies that had implemented industrial internet based technologies and had some experience in using certain platforms for managing industrial internet enabled data and information. During the period of this research there were not many companies who were pioneering in using industrial internet technologies. Today, the number has risen significantly and it would be now possible to investigate with more number of companies to extract in-depth information on the impacts of effective data and information management on advanced business models. Hence, an alternative quantitative approach using surveys can allow the researchers to understand the critical dimensions of value creation (including value co-creation and value co-delivery) through industrial internet based technologies and related data and information management.

The empirical analysis related to industrial internet platform openness in this dissertation took into account a bilateral relationship between a manufacturing company and its customer (Business to Business (B2B)). It would certainly be very useful if future studies can take into account the entire value chain, as in, B2B2B...2C and investigate the impact of openness on the business models of the entire value chain as well as the ecosystem. The qualitative studies were focused on companies from Finland, Sweden, Germany and USA. This took care of the variety in geography but access to different data sources was limited, which restricted the variety of data that could be collected for the case studies. It was not possible to interview multiple people from different units from the same company because of the access. The concept of industrial internet based advanced business models was very novel in all the companies therefore, therefore it was not possible to interview many personnel from different departments.

In this dissertation, switching cost framework is designed and presented. It would be very interesting to use this framework and analyse cases where manufacturing companies have switched from one platform to another and observe if the switch happened because of the need for openness or something else. Moreover, analysing the reasons and implications of switching costs from change management perspective will give an added benefit to the analysis.

During the finalization of this dissertation, COVID-19 [1] has impacted the manufacturing companies businesses heavily. Industrial internet based technologies and related data and information management allows the manufacturing companies to implement novel and advanced business models i.e. outcome based, use based or result based business models. These business models can lower the threshold of buying for the end-customer and increase the sales as well as guarantee constant cash flow for the manufacturing companies (Uuskoski, Kärkkäinen and Menon 2019; Uuskoski, Menon et al. 2018). This aspect can be studied in the future to help the manufacturing companies prepare themselves during such global epidemics.

[1] https://www.who.int/emergencies/diseases/novel-coronavirus-2019

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Towards a maturity modeling approach for the implementation of industrial internet

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TOWARDS A MATURITY MODELING APPROACH FOR THE IMPLEMENTATION OF INDUSTRIAL INTERNET

Research in Progress

Karan Menon, Department of Information Management & Logistics, Tampere University of Technology, Tampere, Finland, karan.menon@tut.fi

Hannu Kärkkäinen, Department of Information Management & Logistics, Tampere University of Technology, Tampere, Finland, hannu.karkkainen@tut.fi

Lester Allan Lasrado, Computational Social Science Laboratory, Department of IT Management, Copenhagen Business School, Copenhagen, Denmark, lal.itm@cbs.dk

Abstract

This Research-in-Progress paper facilitates the design and provides guidelines for the development of a maturity model to achieve a coordinated, systematic and stepwise adoption of industrial internet, thus enabling the industrial internet to be used to its full potential in manufacturing enterprises. Using analogous maturity models from the fields of supply chain management and product lifecycle maturity among others, this paper explains why a maturity model approach would facilitate the step-by-step implementation of industrial internet. The paper goes on to provide systematic design guidelines for industrial internet maturity model for mass production manufacturing industries which use heavy equipment. The detailed research design presented here uses ADR methodology to enable the construction of the ensemble artefact. The industrial internet maturity model will be tested, developed and validated using the experience-based feedback from industrial practitioners. This will enable the industry to plan a roadmap to assess the current situation and define the direction for the future development of industrial internet related activities and business models for industry.

Keywords: Industrial Internet, Maturity Model, Design Guidelines

1 Introduction

Industrial internet is a phenomenon that brings together the digital world with the physical world of machines. It combines industrial systems with the power of advanced computing, low-cost sensing, analytics and innovative connectivity using the internet (Agarwal & Brem 2015). The concept of industrial internet involves collecting large amounts of data by embedding sensors and advanced instrumentation in machines, which is analyzed to offer real-time intelligence.

General Electric (GE) coined the term "*Industrial Internet*" in 2012 (Evans & Annunziata 2012). The term points towards the meshing of the digital and machine worlds. According to (Evans & Annunziata 2012), *industrial internet* can be defined as the integration of three elements:

- ***Intelligent machines: i.e.*** connecting the worlds' machines and fleet of machines with advanced sensors, controls and software applications.
- ***Advanced analytics:*** Combination of physics-based advanced analytics, predictive algorithms, automation and domain expertise
- ***People at work:*** Connecting people at work or on the move, anytime, to support "more intelligent design, operations, maintenance and higher service quality and safety".

The implementation and gradual adoption of industrial internet and related business models can be a very complex and extensive process of change. It requires the coordinated development of a large number of versatile individual and organizational skills and competencies. Furthermore, one important challenge is that it requires the collaboration of various individuals, business functions, and even various organizations, since the business models often evolve from departmental and factory-level models to inter-organizational and even ecosystem-level business models. Due to the complexity and the extent of the concept, the implementation and adoption of industrial internet can be slow, it is often not very systematic, and decisions and investments are often made that are not optimal from the whole company's point of view.

Businesses often have to implement large and complex intra- and inter-organizational change processes such as those occasioned by Product Lifecycle Management (e.g. Vezzetti et al. 2013), Supply Chain Management (e.g. Wendler 2012) or major investments in IT or technological solutions. In such cases, the technology can drive the implementation process forward too rapidly, in that the human workforce's skills and motivation lag behind the technological/organisational progress. The industrial internet is still a new phenomenon so many companies lack a comprehensive understanding about its purpose and the solutions it can offer. Therefore, companies have to experiment to learn how to proceed. However, many of these experiments fail as they have not been designed to maximize learning and thus increase the acceptance of the new innovations by the workers. Businesses need a coordinated and systematic approach to the concept behind the industrial internet in order to increase its penetration into modern industrial production.

The maturity modelling approach (Pöppelbuß et al. 2011) is fast being recognised as a useful approach to this problem. Because of its increasing popularity and wide acceptance, we have formulated the objective of this paper, which is:

"*to help to design and provide guidelines for a maturity model to achieve a coordinated, systematic and stepwise adoption of the industrial internet and reduce the effort manufacturing enterprises need to implement it*".

The more detailed research questions are:

1. Why would a maturity approach be useful in the implementation of the industrial internet?
2. What are the most important design guidelines for constructing an industrial internet maturity model?

2 Literature Review

2.1 Industrial Internet

In some of the most advanced industrial economies, much attention is given to the latest developments in information and communications technology (ICT). Lately, its influence over industrial manufacturing, i.e. improvements to productivity and efficiency, has grown rapidly with the introduction of *industrial internet* technologies (Posada et al. 2015; Kagermann 2015; Burmeister et al. 2015). It is generally accepted that the adoption of these emerging ICT technologies will increase in coming years and will open up new business opportunities and business model innovations (Posada et al. 2015).

It is over eighty years since Schumpeter (1934) identified innovation as a critical factor for economic change. Schumpeter states that technological innovations can create temporary monopolies that can result in a surge in profits for a company. The *industrial internet* is one such technological innovation in manufacturing industries (Evans & Annunziata 2012; Kagermann et al. 2013). (Burmeister et al. 2015) argue that the *industrial internet,* is mainly about business model innovations in manufacturing industries. Business model innovations require certain skills and competences for their development (Osterwalder et al. 2005) and the early identification of such skills and competencies helps in creating a roadmap to implement increasingly sophisticated and complex business models. For example, (Lazonick & Prencipe 2005) examined complex business models like Rolls Royce Plc to demonstrate how competencies constantly need to be evaluated along with a rapidly changing financial and business environment.

Technological and business model innovations increase the complexity of products and their manufacturing processes. Increases in the functionality and efficiency of a product inevitably increase its complexity. Improvements and optimization in the agility of the production process increase the organizational and technical integration of innovations at different levels within an organisation, and through changing forms of collaboration between different companies (Kagermann 2015). One way to tackle this growing complexity is modeling. Models usually represent a snapshot of a real or hypothetical scenario with certain controlled variables. For complex innovation processes like the *industrial internet*, modeling is one approach to reducing the complexity of the change. There are planning models, explanatory models, value creation models and maturity models, all of which can be used to understand the technical and business processes affected by the *industrial internet* (Kagermann et al. 2013; Burmeister et al. 2015)

2.2 Maturity Model Literature

The concept of maturity has been widely used to describe, compare and determine a path or roadmap for improvements in industry. These improvements usually involve an entity, such as a process, a technology, people and/or organizations moving towards something which is perceived as being highly beneficial for business. The dominant idea is to describe a *path to maturation* (i.e. something better, advanced, higher performance) which is *mostly linear, forward moving* (rarely regressing), and in which the entity improves considerably in terms of the desired results, i.e. capabilities, value creation, performance, etc. Maturity models, also sometimes referred to as stage of growth (SOG) models, help to capture the interrelationships of the many multifaceted dimensions of this growth, while simultaneously providing an artificial construct to measure the concerned entity's progress.

The underlying assumption behind maturity models is, the higher the degree of maturity, the higher the positive change which will occur in multiple dimensions that directly or indirectly contribute to the maturation of the entity in the given context. To date, however, most maturity models have been conceptual (Becker et al. 2009; Wendler 2012), and the assumption of a single linear path being able to encompass several dimensions has been criticized for its lack of a theoretical and academic foundation (King & Kraemer 1984; Pöppelbuß et al. 2011). However, over their 40 year history, various types of maturity models have found wide acceptance among practitioners and researchers, because of the maturity models' facility to offer a *simplistic reductionist view of a complex problem* (Jugdev & Thomas 2002). Maturity models utilize comprehensive sets of criteria for competency, capability, sophistication etc. in a certain domain, and can thus provide practical methods to assess an organization's practices (Jugdev & Thomas 2002).

The literature on maturity models is predominantly focused on developing new models, e.g. business process management (De Bruin et al. 2005), web/social media (Back & Haager 2011; O'Reilly et al. 2012), Analytics (Davenport & Harris 2007) among others. Despite the variety of applications for maturity models, many researchers, (Mettler et al. 2010; Becker et al. 2009; Maximilian Röglinger et al. 2012; Solli-Sæther & Gottschalk 2010) have put a lot of effort into standardizing maturity model development and research by prescribing guidelines, vocabulary and procedures. Maturity model design has been described as an *evolution where new challenges emerge as soon as previous challenges have been solved* (Solli-Sæther & Gottschalk 2010). Steenbergen et al. (2010) follows this paradigm in the science of design, and De Bruin (2005) has proposed a six-phase model for development which utilises the concept of maturity model layers and a schema for defining the general characteristics of the model, such as focus, stakeholders, audience, method of application, respondents, etc.). Based on the design science guidelines proposed by Hevner et al. (2004), Becker et al. (2009) have proposed a detailed 8-step procedure for developing a maturity model as an IT artifact. Furthermore, (Solli-Sæther & Gottschalk 2010) have proposed the stage-modelling process, which defines the core topics in the different stages of growth and defines their dimensions, paths of evolution and major problems on a theoretical level.

2.3 The Industrial Internet and a maturity model approach

Since as long ago as 1993, maturity models have commonly been associated with Capability Maturity Models (CMM). This has resulted in the development of Capability Maturity Model Integration (CMMI) as espoused by Wendler (2012). CMMI is a CMM-rooted framework that includes, for instance, the best practices for developing products and services. However, unlike with CMM models, more recent research into maturity models has shown that they need not be restricted merely to software-related domains (Wendler 2012) or to the evolvement of the maturity of individual company processes. Furthermore, maturity models have found acceptance in a wide variety of application areas and now encompass the maturing of knowledge and data quality, amongst other things. Over the course of three studies, Wendler (2012) shows a total of 20 application domains and 18 application areas in a variety of industries such as IT, manufacturing and services. Even in the adoption and implementation of hugely complex, inter-organizational, multi-process applications, such as those incurred in, for example, Product Lifecycle Management (PLM) (Vezzetti et al. 2013), Supply Chain Management (SCM) (Netland et al. 2007), Social Media (Geyer & Krumay 2015) and Product-Service Systems (Neff et al. 2014). Table 1, below, describes recognized and analyzed Maturity Models (MMs) used for relatively similar but highly complex inter-organizational implementation processes (mainly in the context of manufacturing industries). The table highlights the major similarities and analogies in the analyzed MMs for Industrial Internet implementations, including features such as the objectives of the adoption, the extent of the adoption, and the sources of complexity that this necessarily entails. However, relatively few papers on maturity models, particularly those related to very complex adoption or implementation processes, have reported on the benefits that empirical validation of the models can bring. The advantages of maturity models in the adoption of particularly complex systems include:

- Serving as a basis for building a longer-term roadmap for investment decisions or the development of required novel competencies
- Providing a structured checklist for the implementation, and the management of competencies in the implementation process

- Making the complex adoption process faster and more efficient
- Helping to assess the current as-is situation of an implementation in terms of various critical management areas.
- Determining the desired future outcome in an optimal way (Neff et al. 2014; Batenburg et al. 2006; Sharma 2005; Savino et al. 2012; Kärkkäinen et al. 2014; Jussila et al. 2011; Wendler 2012). Time and again, the adoption of complex systems has been significantly slower and less efficient than was expected due to inadequate coordination (Batenburg et al. 2006; Wognum & Kerssens-Van Drongelen 2005) which results in unplanned and unexpected bottle-necks in certain management areas.

Table 1. Maturity Models of complex phenomena analogous to Industrial Internet

Analyzed Maturity Models (MMs) for comparable complex inter-organizational implementation processes (mainly in manufacturing industries)	**Similarities and analogies of analyzed MMs in Industrial Internet implementations (e.g. extent of adoption, sources of complexity in adoption, objectives of adoption)**	**Academic references used in this table**
Product Lifecycle Management (PLM) MMs	• MMs emphasize inter-organizational collaboration especially at higher levels of PLM maturity e.g. (Batenburg et al. 2006) • Adoption involves a multitude of interacting business processes and actors (individuals, functions, organizations) (Batenburg et al. 2006; Sharma 2005) • As in II, PLM adoption is essentially about efficient management and sharing of data, information and knowledge (Kärkkäinen et al. 2012)	(Batenburg et al. 2006; Sharma 2005; Savino et al. 2012); see also lit. reviews of (Vezzetti et al. 2013; Stentzel et al. 2014)
Supply Chain Management (SCM) MMs	• SCM is focused on inter-organizational collaboration along supply chains • Adoption involves a multitude of actors, while focusing on fewer processes related to supply processes • Supply chains may, in many cases, be networks or even ecosystems as in Industrial Internet	(Netland et al. 2007; Archie Lockamy III & Kevin McCormack 2004)
Product-Service Systems (in manufacturing companies) MMs	• Service systems and related MMs need to facilitate inter-organizational collaboration at least in higher levels of maturity • Adoption involves a multitude of actors and processes (both product and service-related) • Service and product data gathering, exploitation and integration is essential in both types of MMs • Product-service systems and related MMs deal closely with development of both services and new business models, analogously to Industrial Internet	(Neff et al. 2014; Rapaccini et al. 2013)
Social Media MMs	• MMs emphasize inter-organizational collaboration and value co-creation especially at higher levels of PLM maturity • Adoption involves a multitude of actors and processes (depending on the topics for which social media is used) • As with Industrial Internet, adoption is essentially about efficient management and sharing of data, information and knowledge e.g. (Kärkkäinen et al. 2012)	(Lehmkuhl et al. 2013; Jussila et al. 2011; Geyer & Krumay 2015)

Thus, it seems reasonable that similar benefits would also be gained in the context of potential maturity models designed for the adoption and implementation of the processes involved with Industrial Internet applications. It is an extremely complex process because of the related development of completely new types of business ecosystems (Kagermann et al. 2013; Posada et al. 2015; Evans & Annunziata 2012), very novel types of business models and value creation models (Posada et al. 2015; Bruner 2013). The industrial internet maturity model also takes into account the transformation of businesses from product-centered to service-centered organizations (Neff et al. 2014), as well as the large number of actors and organizational processes potentially involved in the adoption process (Kagermann 2015; Evans & Annunziata 2012) especially in the later phases of industrial internet adoption.

2.4 Design Guidelines for Industrial Internet Maturity Model

Based on the maturity model design framework (Mettler 2009) for decision-making parameters during the development of a maturity model, development, Table 2 defines the scope and presents the design guidelines for maturity models in an industrial internet context.

Table 2. Maturity Models of complex phenomena analogous to Industrial Internet

Phase	Decision Parameters	Characteristics	Examples	Design Guidelines /Recommendation
Define Scope	Focus/Breadth	Generic Model	Industrial Internet as a phenomenon can be the scope	Industrial Internet as a phenomenon can result in a broad maturity model for a company to use.
		Specific Model	Industry Specific, i.e. manufacturing industry (heavy equipment manufacturing industry), IT industry (data analytics, data visualization) Manufacturing-techniques specific i.e. mass manufacturing, engineering to other kinds of manufacturing	A heavy equipment manufacturing company, for example, needs a design based on processes, people and object-related outputs. The maturity model can be based on mass manufacturing, project-oriented manufacturing or engineering for designer manufacturing.
	Audience	Both, Management - oriented and technology oriented audience	Industrial internet is a phenomenon, which involves intelligent machines, advanced analytics and people working together. Hence, it is important to have both technological as well as management oriented needs.	To find out the needs and roles of management and technology personnel in the area of industrial internet in order to keep the context directed at the target audience.
Design Model	Maturity Definition	Combination of Process, people and object-focussed parameters/dimensions	Industrial internet maturity can be defined keeping intelligent machines' maturity, advanced analytics' maturity and people's skills and competences in mind.	Optimization of system of systems involving people and people's capabilities and a multitude of business processes & technologies, including IT and sensors
	Goal Function	Multi-Dimensional	Connectivity (sensor related) and the spread of connectivity over different business units can be examples of two dimensions	Complex processes like the industrial internet require more than one dimension to understand the benefits of their adoption.
	Design Process	Literature and Practitioner Based	PLM, Supply Chain Management, Service System related maturity models	Take analogous models from literature (Table 1) and discuss the pros and cons with industry practitioners.
	Application Method	Self-Assessment or Third Party certified professional	Self assessment if industry professional is designing the model for the same industry evaluation	Depending on the audience and respondents the model should be applied either by the industry or by third party professionals
	Respondents	Combination of internal (staff and administration) and external (Business partners)		If model is applied internally, Management & Staff are respondents and if it is applied externally to an industrial ecosystem, then the business partners are the respondents

Mettler (2009) emphasizes that it is important to define the focus of the phenomenon to be studied using an appropriate maturity model. Any Industrial Internet implementation demands a specific technological and strategic implementation in a company's business process. In order to fully understand the effects of the implementation of industrial internet, a more specific (industry specific, domain specific, production method specific) maturity model is required to define the breadth of the model. The Industrial Internet is of particular significance to manufacturing industries and Information Technology

(IT). This allows us to tailor the maturity model for the implementation of industrial internet towards the manufacturing industries, especially heavy equipment manufacturing. Global companies like GE, Siemens and Kone cranes, which are active in the heavy equipment manufacturing sector, and IT and IT-service companies like Intel, Cisco and AT&T would all benefit from a maturity model fashioned according to industrial internet design guidelines (Agarwal & Brem 2015; Neff et al. 2014; Bruner 2013). The goods and equipment that are produced by the heavy equipment manufacturing industry are characterized as long-lasting and highly productive. Hence, processes such as maintenance, repair and change operations are very important capabilities for these industries to have in order to achieve and maintain high profit margins (Neff et al. 2014).

The scope and the focus of an industrial internet maturity model for heavy equipment manufacturing can be further refined based on the production techniques, i.e. mass production or bespoke engineering techniques. PLM maturity models are a good case for portraying models based on production techniques, i.e. mass production, project-specific production or engineered-to-order production techniques (Table 1).

Given that the implementation of industrial internet is both a business and technological innovation affecting an organization's business strategy (Kagermann et al. 2013; Evans & Annunziata 2012; Agarwal & Brem 2015), the audience (Mettler 2009) for the industrial internet maturity model in the heavy equipment manufacturing industry will encompass both technology-oriented and management-oriented personnel (Mettler 2009). This is similar to what happens with the social media maturity models in B2C and B2B (Lehmkuhl et al. 2013; Jussila et al. 2011) where it is important to assess the maturity of an organization from both the management technological perspectives.

The Industrial Internet is well defined as being at the convergence of three essential elements: intelligent machines, advanced analytics and people at work (Evans & Annunziata 2012), and as such it involves the optimization of a large system of systems (Evans & Annunziata 2012; Bruner 2013; Agarwal & Brem 2015; Kagermann et al. 2013). The Industrial Internet incorporates all three elements of any manufacturing business' system, i.e. processes, people and objects (Mettler 2009; Neff et al. 2014; De Bruin et al. 2005). Hence, maturity for industrial internet can be defined as the optimization of the system of systems involving people and their capabilities, a multitude of business processes, and different technologies including sensors and IT.

The complexity of industrial internet means that its maturity will influence process functions (e.g. efficiency, optimization), technologies and IT-related functions, and people's capabilities and skills. Hence, any study of the effects of the adoption of industrial internet, demands a multi-dimensional approach which will provide a wide range of relevant information. The same applies to other complex process like PLM maturity design (Kärkkäinen et al. 2014), in which the design process of the model has to be based on a combination of literature and the practical, experience-based knowledge held by industry-based professionals. Table 1 shows comparable models to the industrial internet which can be used as benchmarks in designing the model for industrial internet. The method of application for any such model has to be planned and designed for systems built by external professionals based on academic research or by industry insiders using their own practical experience. If the maturity management model is used for internal evaluation, then the respondents will be internal managers and technical experts. If the model is used to analyse an industrial ecosystem, then the model will be aimed at the external business partners.

3 Research Design

3.1 Overview

(Mettler 2009) has defined and categorised the design parameters to be used when developing a maturity model. In this paper we present the design guidelines for developing a maturity model for industrial internet using the design guidelines from the developer's perspective (Mettler 2009), complemented with the design principles for maturity models recommended by Pöppelbus (2011). An Action Design Research (ADR) (Sein et al. 2011) methodology will be used to create and validate the model, which is appropriate for the nature of the problem and the ensemble artefact. While developing a maturity model as an ensemble artefact in industrial internet, it is important to design, shape and reshape the ensemble artefact (maturity model in this case) as well as to have interventions in the organizational work practices while the evaluation of the ensemble artefact is ongoing. This approach is the key reason to use ADR as a methodology (Sein et al. 2011). We use the design guidelines presented in this paper to create a conceptual maturity model of industrial internet, making use of the analogous models referred to above in this paper (both structure and content), as well as the literature on industrial internet implementations and its success factors. The dimensions and the levels of this conceptual model will be presented to senior managers and technical experts from 15 global pioneers in industrial internet solutions, manufacturing and IT companies. They will be interviewed about the dimensions and the levels of maturity of the conceptual model, and their responses will be utilised in designing, shaping and reshaping the ensemble artefact (the maturity model, in this case). Once this has been done, the finished maturity model will be presented to the same set of managers and technical experts, who will implement it in a workshop environment in their own company or industry in order to assess its effectiveness. The desired outcome of this workshop will be the validation of the maturity model for industrial internet.

The research will follow the steps outlined below:

1. *Theoretically present the design guidelines to develop a maturity model for an industrial internet:* In the first phase, we define the need for a maturity model approach in industrial internet implementation using comparable theoretical maturity models applied to the industrial internet. This will result in basic design guidelines for developing a maturity model in industrial internet.
2. *Interviews with Industry experts:* Our industrial internet maturity model design guidelines and the conceptual model will be shared with the 15 senior managers and technical experts from globally pioneering companies in industrial internet solutions, manufacturing and IT. These experts will subsequently be interviewed again about the conceptual model and the design guidelines used to design it. The feedback about the constructs of the model from these experts will be collected and analysed to improve the maturity model.
3. *Refine the conceptual maturity model in industrial internet:* Based on the interviews and the inputs from the experts, we will refine the conceptual maturity model and finalize its dimensions and the stages covered by the maturity model.
4. *Workshop with experts to validate the maturity model:* The same group of experts will be invited to attend a workshop in which they will validate the model based on their experience as representatives of leading companies in the implementation of industrial internets (manufacturing and IT companies).
5. *Final refinement based on the validation workshop:* Based on the data analysis from the workshop, we will finalize the maturity model. This will mean that we will juxtapose the theoretical principles of maturity model (Mettler 2009; De Bruin et al. 2005) with the data from the workshop and create the final form of the artefact.
6. *Present the maturity model in industrial internet to the community:* In the final step, we will elicit feedback about the final maturity model through its dissemination to the IS research community in academic publications.

3.2 Data Collection and Analysis

In the interviews with the industry experts we will look for experience-based advice about the design guidelines and the conceptual model proposed in this paper. The experience-based advice will be regarded s as existing theories-in-use about the industrial internet and associated maturity models. The interviews will proceed with the following structure:

1. The interviewees will *identify and define the concepts* presented in the conceptual maturity model and the design guidelines used to create the conceptual maturity model.
2. The interviewees will *evaluate and rank* the preferences they have propose in the previous step.
3. We will *record the findings* during the interviews, to refine the conceptual maturity model and the design guidelines that led to the creation of the model.

Based on the recorded findings of the interviews, the existing literature on the industrial internet and research on maturity models and design frameworks (Mettler 2009), we will revise the construct and finalize the construction of the maturity model.

In the final workshop with the same set of industry experts, we will present the final maturity model construct. Our experts will super-impose this model on their respective company's business practices in the area of industrial internet, and provide feedback and validation. Finally, we will triangulate the data from the workshop, the industrial internet literature and the literature on maturity models to present the final construct of the maturity model to the IS community.

4 Expected Contributions

The research design outlined so far describes a comprehensive research process to develop a novel maturity model framework in the context of the industrial internet. This will be based on literature and our experts' own, practical experience with the implementation of industrial internet in heavy equipment manufacturing industries operating in the mass production of industrial goods (e.g. in the metals and electronics industries). The research design will clearly contribute towards the very scarce literature on the industrial internet and the related development of a specific maturity model. From a managerial perspective, the resulting industrial internet maturity framework will enable the company to assess the as-is situation of their industrial internet adoption. It will also aid the company in determining future targets and provide a roadmap for future investment and endeavours in facilitating their own industrial internet activities and business models. A maturity model framework in industrial internet will allow industry to have a common language of communication while discussing the current situation and planning the future development of industrial internet amongst interested professionals from various backgrounds (for example, amongst mechanical engineers, software engineers and managers in the same company).

5 Conclusion

In this research in progress paper we have argued why a maturity model approach might not only be possible, but also useful in very complex inter-organizational implementation processes such as those demanded by the industrial internet. We also categorically state the benefits of having a maturity approach to implementing industrial internet. Finally, we have provided guidelines for developing an industrial internet maturity model framework. This will be built using (Mettler 2009) the Mettler framework (2009), and will demonstrate which decisions should be made in the early phases of the model design, and some major options for these decisions. We will make use of ADR as a methodology to develop the model, and validate it using interviews and workshop methods. This will provide maturity model designers with clear guidelines on how to build an industrial internet maturity model.

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Industrial internet platforms: A conceptual evaluation from a product lifecycle management perspective

Karan Menon[1], Hannu Kärkkäinen[1], Thorsten Wuest[2] and Jayesh Prakash Gupta[1]

Abstract

Industrial Internet platforms have the ability to access, manage and control product-related data, information and knowledge across all the lifecycle phases (beginning of life, middle of life and end of life). Traditional product lifecycle management/product data management software have many limitations when it comes to solving product lifecycle management challenges, like interoperability for instance. Industrial Internet platforms can provide real-time management of data and information along all the phases of a product's lifecycle. Platform openness in combination with the above-mentioned industrial internet platform characteristics helps solve the product lifecycle management challenges. This article describes the product lifecycle management challenges in detail from the existing literature and presents solutions using industrial internet platform openness and related dimensions as well as sub-dimensions. A wide pool of platforms is narrowed down to specific platforms that can solve the documented product lifecycle management challenges and allow the manufacturing companies to collaborate as well as enhance their business. We also present in detail managerial implications toward long-term and sustainable selection of industrial internet platform.

Keywords

Industrial Internet, Industry 4.0, platforms, product lifecycle management, openness, interoperability, product lifecycle management challenges, industrial internet platforms

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Introduction

Product lifecycle management (PLM) can be defined as a systematic and controlled concept for managing product-related information and products throughout the whole product lifecycle.[1–3] Fundamentally, PLM is focused on data, information and knowledge (D-I-K) and how to use those to properly serve a company's business and product development,[4–6] as well as to create value for the customer.[4] For industrial manufacturing companies, the content of D-I-K is focused on the machines. Machines generate the data related to processes and operations. These data are translated into useful information using analytical frameworks. Operators and other personnel translate this information into actionable knowledge which can be used to improve the processes or operations or functioning of the machines based on their experience and expertise. However, there are various challenges related to accessing and managing all relevant D-I-K related to products' lifecycles, which is often due to the fact that such relevant information may be dispersed among a number of various actors who also have their personal conception of the product and its performance.[7] Relatively recently, it has been understood that various technologies and approaches related to Internet of Things (IoT) and Industrial Internet, such as sensors, machine-to-machine communication and various types of platforms, can offer important and novel solutions to the management of product lifecycle information, such as providing access and real-time insights into the data of many PLM-related actors. For instance, the flow of

[1]Laboratory of Industrial and Information Management, Tampere University of Technology, Tampere, Finland
[2]Industrial and Management Systems Engineering, West Virginia University, Morgantown, WV, USA

Corresponding author:
Karan Menon, Laboratory of Industrial and Information Management, Tampere University of Technology, Korkeakoulunkatu 8, PL 541, Tampere 33101, Finland.
Email: karan.menon@tut.fi

real-time data from the various sensors across the value chain will enable for the first time the chance to observe the entire value chain instantly. This allows the optimization of the entire value chain rather than just selected parts of it.[8] Hence, the Industrial Internet will go way beyond the traditional factory automation and will reduce the transaction costs for every transaction in the value chain. Yet, partly due to the recent maturation of many industrial internet–related technologies and concepts, there is relatively little research that studies the possibilities offered by the industrial internet to the PLM field. One of such topics is the role of various types of industrial internet–related platforms to enhancing the management of relevant D-I-K related to products' lifecycles and the various lifecycle phases.[9–11] The significance of platforms is continuously growing at a fast pace.[12] In addition, it has been understood that platforms and platform-like digital services can provide new ways to access and accelerate the capturing of data and converting it into insightful information and knowledge. The role of various platforms and related platform openness, industrial internet–related platforms in particular, in the context of PLM and in facilitating the management of product lifecycle information has not been studied previously, according to our survey of current PLM and industrial internet literature.[4,8,13,14] Thus, the following fundamental research questions have been derived to better understand the current status. The questions will be thoroughly addressed in this article:

RQ1. What kind of PLM-related D-I-K management challenges are addressed by novel platforms in industrial internet?
RQ2. How do the industrial internet platforms address the information and knowledge management challenges in PLM?
RQ3. What is the role of industrial internet platform openness in D-I-K management in PLM, and how can the different dimensions of openness be structured in the context of industrial internet platforms?

To address the above research questions, this study will analyze novel types of industrial internet–related platforms from the literature as well as other relevant sources. Different types of platforms are selected for analyses and evaluated based on their capabilities to address the various challenges related to the management of D-I-K in a PLM context. This study will provide detailed criteria for selection of appropriate industrial internet platforms based on the PLM challenges and industrial internet and related platform capabilities. One of the major PLM-related functionalities which is a challenge for most PLM/PDM software is openness related to D-I-K and is studied in detail to develop criteria for industrial internet platform selection from the perspective of effective facilitation of D-I-K within and between PLM lifecycle phases.[15–19] The remainder of this article is organized in a manner that we discuss the PLM challenges, industrial internet platforms and related selection criteria. Then we analyze the selected platforms based on industrial internet functionalities. We provide a detailed analysis of the selected platforms based on industrial internet–related platform capabilities and PLM challenges. The final analysis provides the selection criteria purely based on platform openness. Finally, we discuss the findings and provide managerial implications, conclusions and future directions for the research.

PLM challenges

PLM can be defined as a systematic and controlled concept for managing product-related information and products throughout the whole product lifecycle.[20] However, the focus of our study lies essentially in the management of D-I-K related to products and product lifecycle, not, for example, product management as such. PLM aims to provide a shared platform for effectively capturing, representing, organizing, retrieving and reusing product-related lifecycle information across companies and to support the integration of existing software systems. PLM is often understood as mainly PLM software (in the form of either a single PLM solution or a large group of different types of solutions, such as product data management (PDM), customer relationship management (CRM), enterprise resource planning (ERP), excel sheets and various collaboration tools). However, PLM is also understood as more of a holistic concept which involves, for example, people, processes and technological solutions.[4,21] In our study, we focus on the latter, more extensive concept of PLM.

There are a number of different types of challenges related to the management of product lifecycle information. We will review some of the major challenges here and analyze how such challenges can be dealt with through the novel possibilities of industrial internet and specifically the identified various industrial internet platforms in the later sections. Here, we focus on the important overall challenges of PLM that can most probably be addressed by means of industrial internet and industrial internet platforms, not, for example, topics related to standards.

There are various PLM-related literature reviews, outlook or survey-type articles[1,7,13,22–24] and other relevant generic articles on the broad topic of D-I-K management in a PLM context. The many challenges in the management of D-I-K in a PLM context are rooted in the long lifecycles of products:[25] the transfer of information between product lifecycle phases (beginning, middle and end of life) and the so-called "closed-loop" PLM;[1] problems related to the extended enterprise and the collaboration and communication of companies, customers and other relevant actors with relevant expertise and knowledge during the lifecycle;[26] the real-time accessing, transfer, management, aggregation and analysis of all different types of D-I-K required in

PLM, including structured, non-structured and even tacit knowledge of employees[26] as well as making sense of the data and connecting them to the decision making of various PLM-related processes. The goals and challenges of PLM might be very different in different types of companies, for example, project-based or one-of-the-kind organizations versus mass-customized or many-of-the-kind organizations.[6,7] The interoperability of information systems throughout the product's lifecycle is primordial for a successful PLM approach. The ability of two (or more) systems to communicate, cooperate and exchange services, data and so on, despite differences in languages, implementations, executive environments and abstraction models.[22] Interoperability of information systems in the context of PLM is studied extensively in the literature.[22,27] Interoperability is a subset of openness in the case of platforms.[28] The various PLM studies of interoperability do not address openness in terms of various dimensions and sub-dimensions as well as connection of various lifecycle phases to openness.[7]

Industrial Internet platforms

Types of platforms

Platforms on a very broad level can be divided into "internal" or firm-level platforms and "external" or ecosystem-level (industry-wide) platforms. This broad classification allows us to place external or industry platforms as key enablers for enhancement in the management of D-I-K during the lifecycle of a product.

We take the definition of Industry Platform by Gawer and Cusumano.[12] According to them, "industry platforms are defined as products, services or technologies developed by one or more firms, and which serve as foundations upon which a larger number of firms can build further complementary innovations and potentially generate network effects." External or industry platforms are probably the most relevant forms of platforms in the context of PLM, because they can enhance the management of D-I-K not only internally, but also among the various organizational actors (stakeholders) throughout the lifecycle phases (beginning of life (BOL), middle of life (MOL) and end of life (EOL)).

In the case of industry or external platforms, there are differences in the degree of platforms' openness meaning how "open" the platform is in order to let third-party developers and companies to develop applications for the platform using the data and information from the platform.[12,29] In an external platform, the degree of openness may vary based on a number of factors or dimensions:[12] the access to information in the platform to build applications can vary, the rules that allow the usage of platform can differ and even the fee to get the access (license fee) can vary significantly. The more open the platform is in these three dimensions, the more easily it is for the different parties to access and share the relevant data through the platform.

Industrial Internet platform functionalities

Industrial Internet, Industry 4.0 and cyber-physical system (CPS) can be collectively defined as industrial systems that integrate computational and physical capabilities of machines in order to provide advanced analytics and interactions with humans.[14,30–34] In this study, we define industrial internet platforms as platforms which adhere to the general definition of industry platform (as in section "Types of platforms") and the industrial internet definition mentioned above.

In the context of PLM, there has been a marked shift in its vision, which would ideally mean the ability to access, manage and control product-related information across various phases of the lifecycle.[7] In the case of PLM, industrial internet platforms can provide the real-time management of data and information flows as well as help in the data–information–knowledge (D-I-K) transformations along all the phases of product lifecycle.

The industrial internet platforms can access data from different sensors, actuators, enterprise systems, social media and other novel data sources.[35,36] The industrial internet platform is able to aggregate data into a single database which can be stored, either in dedicated in-house servers or with other third-party cloud storage providers.[31,33] These organized data can be used, for example, by technicians to remotely monitor the condition of machines without physically being present,[37] and the data can also be run through machine learning algorithms to predict the health condition of a machine and notify the concerned technician to make an informed decision about the need for machine maintenance.[38] The data, via the platform, can provide different analytics results and visualizations, for example, descriptive, predictive and prescriptive, to create proper infographics which facilitate experienced knowledge workers.[39] Consider the example of a new industrial internet platform-based risk assessment solution in the oil and gas sector, which allows real-time visual representation of risks to oil pipeline, based on internal and external environmental factors. These infographics provide the experienced pipeline operators a new way to check pipeline integrity.[40] In many cases, the industrial internet platforms enable the development of applications ("apps") on top of the platform. These applications help in sharing the relevant information between the different actors and also in sensemaking.[41] The ability to develop individual apps extends the realm of potential users significantly and virtually allows theoretically "limitless" functionality.

Industrial Internet platform openness and PLM

Industrial companies need to select the platforms based on optimal levels of openness because of their requirement to use the platforms with various different actors (e.g. suppliers, customers, designers). Furthermore, in a PLM context industrial internet platform openness can

Table 1. Dimensions and sub-dimensions of platform openness.

Dimensions of openness	Detailed sub-dimensions of openness	Definitions
Demand-side user (end user)	Access to information	Level of access to information on interfaces to link to the platform or utilize its capabilities[12]
	Cost of access	Cost of access as in patent or licensing fees[12]
	Control in terms of rules to use the platform	Types of rules governing the use of the platform[12]
Supply-side user (application developer)	Core developers	They are developers employed by the platform management company itself. They develop tools and applications which allow the users to use the platform effectively[28]
	Extension developers	They are outside parties or third-party developers who add features (applications) and value to the platform to enhance the functionality of the platform[28]
	Data aggregators	Data aggregators collect different interaction-based data and resell them to the companies (as per the platform laws), who then can target advertisements to the users[28]
Platform-provider- and sponsor-related openness	Proprietary model	A single firm plays both provider and sponsor roles[42]
	Licensing model	A single firm sponsors the platform and then licenses to multiple providers[42]
	Joint venture model	Multiple sponsors jointly sponsor the platform but a single firm serves as its sole provider[42]
	Shared model	Multiple sponsors collaborate to develop the platform's technology and then compete with each other to provide differentiated but compatible versions to the users[42]

provide different benefits, possibilities and restrictions considering the management of D-I-K both within and between lifecycle phases. As defined by Eisenmann et al.,[42] *A platform is "open," as long as, (1) no restrictions are placed on participation in its development, commercialization or use; or (2) any restrictions-for example, requirements to conform with technical standards or pay licensing fees-are reasonable and non-discriminatory, that is, they are applied to all the potential platform participants*. This definition is applicable to a variety of actors that participate in the creation, usage and propagation of the platform. These actors are distributed in three categories: (1) demand-side user (end users of the platform), (2) supply-side users (application (app) developers on the platform) and (3) platform providers and sponsors (platform companies). Industry platforms generally have platform providers and sponsors as the same entity (e.g. GE Predix, Microsoft Azure). In some cases, they could be different entities, for example, with PTC ThingWorx, in Finland, PTC is the sponsor and Elisa is the provider. In this study, we have developed an analytical framework that presents the dimensions of platform openness and their detailed sub-dimensions by combining the theoretical frames presented by Gawer and Cusumano,[12] Parker et al.,[28] Eisenmann et al.[42] and Benlian et al.[43] The conceptual analytical framework can be found in Table 1. Table 1 explains the dimensions and the sub-dimensions in detail in the context of industrial internet platform for PLM. For demand-side user (end user)-related openness, the sub-dimensions focused on (1) access to information—this deals with the level of access to information on interfaces to link to the platform or use its capabilities, (2) cost of access—this deals with the cost of access pertaining to licensing or patenting fees, and (3) control in terms of rules to use the platform—this deals with the types of rules governing the use of platform. In the case of supply-side user (application (app) developers on the platform), the sub-dimensions focus on openness related to (1) core developers—application developers working in the platform companies to develop the applications, (2) extension developers—third-party developers to develop applications on the platform, and (3) data aggregators—collect different interaction-based data and resell to the platforms, who can target advertisements to the end users (industrial companies). Finally, platform-provider- and sponsor-related openness adopts four models as sub-dimensions that can define the openness in different ways: (1) proprietary model—one company plays both provider and sponsor roles, hence controlling the openness, (2) licensing model—one single company sponsors (provides the funds or investment) the platform and then licenses to multiple providers (distributors or resellers), (3) joint venture model—multiple sponsors together sponsor the same platform and only one provider resells or distributes the platform, and (4) shared model—considered to be the most open model in a way that multiple sponsors as well as providers collaborate to develop the platform's technology and then compete with each other to provide differentiated but compatible versions to the end users.

Openness within the lifecycle phases

In this section, the value and characteristics of openness within the different lifecycle phases (BOL, MOL and

EOL) are discussed. The general structure is based on the three main "openness criteria" identified previously (see Table 1).

The openness from demand side (end user) can generally be understood to be essential during the BOL and EOL phases and in most cases also during the MOL phase. During BOL and MOL, the end users are relatively clearly defined and their openness requirements are also well understood. Access to the platform information is essential for many operations happening during BOL and EOL, and as such the openness requirement during these two phases is high. During the MOL it depends what stake-holders are understood as end users, which explains the possible limitation. In some cases, the end users will not have access to information, but other stakeholders, for example, the manufacturer who is collecting data on the usage, require openness to access the information. The cost of access and control over the rules of the platform are also important aspects that differ between BOL/EOL and MOL with a similar result as the access to information. While stakeholders with a business interest during the BOL/EOL can calculate how much the openness is "worth" to them, this might be different for private end users and thus lead to less demanding requirements toward demand-side openness during the MOL phase.

When investigating the openness requirement from the supplier side (application developer), the different phases are more homogeneous than the previously discussed demand side. As application developers during all the phases, BOL, MOL and EOL, have similar requirements toward the openness of the platform i.e. to being able to create their core applications, extensions or data aggregating services. While, during the BOL, the focus of these tasks is on, for example, design or manufacturing support, during the MOL the applications might provide services directly to the users themselves or other (professional) stakeholders, for example, in terms of product service system type of arrangements (e.g. uber) or predictive maintenance.

In terms of the openness criteria of the platform provider and platform sponsor, the implications on the different lifecycle phases are mostly related to interoperability issues. For the platform provider criteria, especially regarding coupling of OS and hardware, a licensing model is preferable in most cases, especially during BOL and EOL, so the existing infrastructure can be used to a large extent that is already available in most professional environments. With regard to platform sponsorship, this becomes relevant when thinking of the privacy (and/or competitive) issues (e.g. governmental access/backdoors; unclear rules of data usage, etc.). For example, with GE's Predix, it is highly unlikely that (1) a direct competitor like, for example, Siemens or a subsidiary will use it during any lifecycle phase without access to the source code and (2) GE is highly unlikely to provide access to the source code to a direct competitor. This extreme example highlights that there are certain requirements toward openness at the platform sponsor level, but these will most likely be relatively rare cases.

Openness between the lifecycle phases

The following structure presents a simplified view on the interfaces of the three main lifecycle phases. There might be more complex constellations that require taking all phases in a more networked structure into account to replicate interdependencies between all phases. However, this needs to be studied in detail and is not in the focus of this study. More information regarding the information flows between different phases themselves can be found in Wellsandt et al.[24,44] The demand-side (end user) openness requirements at the interface between BOL and MOL are expected to be high. Information access over lifecycle phase borders is essential for many applications. A rather common application of such cross-border information exchange that demands openness is design based on usage data.[45] The same high requirements toward openness stand true for the BOL–MOL and MOL–EOL interfaces. Many EOL applications require detailed information of the materials used, manufacturing/assembly processes (BOL–EOL) and also information about the usage of the product to determine if the materials might be contaminated (e.g. biohazard due to use in operating theater) or if remanufacturing is possible/reasonable (MOL–EOL).

From the supplier-side (application developer) openness criteria, the interfaces are rather important as well. Designing an application to collect usage data for use during the beginning of life requires a high degree of openness regarding the interface between BOL and MOL for example. And this certainly stands true for other cross-platform applications. As these services are in most cases very case specific, openness toward third-party developers for core application, extension and/or data aggregation is a necessity for most applications. Behind the applications, extensions and data aggregation services is a lot of expertise and dedicated knowledge that is unlikely to be shared by third-party developers with the platform operators in the case of a low level of openness. The reasons are that (1) this knowledge and expertise is a core competency of the developers and (2) the platform operator will most likely not be able to develop the solution in the required quality as it is outside of their expertise. Therefore, the supplier-side openness criteria are understood to be significant when it comes to the interfaces between the different phases.

With regard to the openness criteria of the platform provider and platform sponsor, the same arguments can be used for the interfaces between phases as for the phases themselves. In this case, it also strongly depends on the individual constellation or case to being able to judge the required or desired level of openness of a platform.

Table 2. Large pool of industry platforms by their domain.

Division by domain	Platform examples
Industrial Internet/Industry 4.0 /cyber-physical system (CPS) platforms	General Electric's Predix, Microsoft Azure, CyberLighting's CyberVille, Schneider Electric's Wonderware, SAP Hana Cloud Platform (Connected Manufacturing & Predictive Maintenance and services), Bosch Production & Logistics, LifeCycle Care (Your KoneCranes + TrueConnect), John Deere, Forest Insight, Kaa IoT Development Platform
Internet of Things platforms	PTC ThingWorx, IBM BlueMix, Exosite, Google, Brillo, Sap IoT Platform, Intel IoT, Salesforce IoT Cloud, IBM Watson
Social media, platforms in manufacturing and industrial companies	Yammer, LinkedIn, Twitter
Crowdsourcing and collaboration platforms	IndustryHack, GrabCad, InnoCentive

Industrial Internet platform selection criteria

Today, there is a plethora of platforms available. We selected a subset of platforms that enable efficient and real-time management of D-I-K over various lifecycle phases. These platforms were identified mainly from academic articles[30,46–49] and other relevant sources which reviewed the characteristics, functionalities and data and information management perspective of platforms. Some platforms, such as Exosite and IndustryHack, were added into this pool because they were discovered to be interesting (e.g. unique or novel) in some of their characteristics. From this subset, a large pool was selected based on the following inclusion criteria:

1. Platforms that are relevant to industrial internet and cater to manufacturing and industrial companies;
2. Platforms that are international. This allows various actors involved in the lifecycle of the product to use them from different geographical locations.

Platforms that satisfy the definition of external/ industry platforms[12] allow the inter-organizational collaboration to manage D-I-K. Table 2 shows the examples of various platforms in the domain of industrial Internet/Industry4.0/CPS,[14,30] IoT,[46] social media platforms in manufacturing industrial companies[50] and crowdsourcing and collaboration platforms.[51] These examples are not an exclusive list of platforms but they are representatives of the domains.

Research methodology

The aim of this article is to identify PLM-related D-I-K challenges as well as the role of industrial internet platform openness to address these challenges. In order to do this, first we identify the key PLM challenges related to D-I-K from the literature. Primary data from the literature and secondary data from credible and reliable sources related to industrial internet platforms were collected and a theoretical understanding was established to see how these platforms can address the above-mentioned PLM challenges, within as well as between the lifecycle phases. We understood from theory that platform openness can address PLM challenges in an effective manner. In order to investigate the above, we devised a conceptual framework (Table 1), where different dimensions and sub-dimensions are described. The selected industrial internet platforms (selection criteria are presented in the next section) were analyzed using the secondary data with respect to the openness dimensions and sub-dimensions.

Analyses of industrial internet platforms from PLM perspective

In order to perform an in-depth analysis of industrial Internet platforms from the perspective of PLM, we further selected 10 platforms (see Table 3) that represent different platform domains and have unique features as platforms, considering especially their capabilities to address various challenges (drawn from section "PLM challenges" and represented as the major evaluation criteria in Table 3). We further selected five platforms (see Table 4) that provide analysis to highlight the effects on management of D-I-K across various PLM phases using industrial internet as a technology enabler. In Table 3, IndustryHack is a unique actor as it uses the concept of hackathon[52] in an industrial setting to bring together outside experts who can help in rapid prototyping[53] and present a proof of concept for the given industrial problem. In terms of data access, Predix, MyJohnDeere and Bosch IoT Suite have the unique advantage of providing their own sensors which can work in different environments.[14,36,41] These platforms have the capability to directly access a new source of data which is not possible for platforms which do not provide their own hardware (e.g. sensors, actuators). On the other hand, IndustryHack collects data in terms of a pool of experts which can collaborate with industries in the hackathons. Hana, Azure, Predix and ThingWorx also allow the real-time data integration with data from novel data sources like social media.[46–48] This kind of combination of data can lead to the creation of new

Table 3. Platform analysis based on industrial internet based on data, information and knowledge.

Industrial Internet–based information and knowledge functionalities	GE Predix	MyJohn Deere	Bosch IoT Suite	Kaa IoT Platform	Microsoft Azure	PTC Thing Worx	CyberLighting-CyberVille	Industry Hack	Yammer
Data access and collection	+ +	+ +	+ +	+	+	–	–	+ +	–
Data aggregation and sharing	+ +	+	+	+ +	+ +	+ +	+	–	–
Data storing	+	+	+	+	+	–	–	–	–
Analytics and visualizations	+	+	+	+	+	+ +	+ +	+	–
Information sharing	+	+	+	+	+	+	+	+	+
Sensemaking	–	+	–	–	–	–	–	+ +	+ +

information. Platforms like CyberVille provide features like multilayered three-dimensional (3D) view of a complex network in real time. ThingWorx lowers technological complexities for users through codeless mashup capabilities. This enables easy creation of a variety of visual infographics.[47,49] In business context, sensemaking needs experts who can help in making quality decisions after an informed sensemaking process.[41] While sensemaking is enabled by most of the platforms in the above list. Platforms like Yammer (microblog) and IndustryHack directly support sensemaking by bringing together relevant experts to make sense of provided information. Table 4 provides a detailed analysis of five platforms that address the challenges of PLM in the context of D-I-K management. Platforms have different degrees of openness:[12] access to data and information, rules governing the platform and cost of access to data and information. CyberVille is open from the viewpoint of D-I-K in a way that it follows the open source standards of the Internet technology. Access to D-I-K across the lifecycle phases and within the different phases (in the case of closed-loop PLM) is the key to the value creation from product-related lifecycle D-I-K.[13] MyJohnDeere is a kind of platform that enables the product manufacturer to tap into all the data and information throughout the lifecycle phases and also access within different lifecycle phases. Interoperability[22] which is one of the key issues in all industrial software solutions (e.g. PLM, PDM, CRM, ERP) is addressed by industrial internet platforms through the use of plugins. In order to create value of data and information, it is important to get this data and information in real time and provide analytics based on these data in real time as well. The GE Predix and Microsoft Azure which are examples of industrial internet platforms have incorporated Big Data technologies in the platform architecture to enable real-time monitoring as well as advanced analytics.[14,40,46] One of the key differentiators between traditional industry software solutions and platforms like PTC ThingWorx, CyberVille and GE Predix is the availability of on-demand tailored solutions[47,49] or "apps" which ultimately result in a marketplace offering a wide variation of dedicated solutions. These "apps" or applications create value of D-I-K for the platform users. The popularity and acceptance of this marketplace generates network effects for the platform.[12]

Analyses of industrial internet platforms and openness

Table 4 analyzes the platform openness in a unidimensional manner (only demand-side user-related openness) when it comes to openness because the purpose of the analysis was to understand its role in the management of D-I-K in a PLM context. Table 5 shows the details of the dimensions that provide the view on the degree of openness. The same six platforms that are analyzed in Table 4 are analyzed in Table 5. The dimensions and sub-dimensions are explained in Table 1.

In the case of demand-side user openness dimension, Kaa IoT platform has a complete access to information (uses all open standards) for the end user, whereas GE Predix allows access to user data only, not to the source code of the platform instance implemented by the end user. In the case of the cost of access to information, Kaa IoT platform is completely free because a lot of development of Kaa IoT platform happens by the open source community, so Kaa IoT platform is like Linux. But platforms like Microsoft Azure, PTC ThingWorx and CyberVille have a fee for the end user which allows them the access to information. GE Predix even with a fee allows limited end user access to information. Governance or control in terms of rules to use the platform differentiates the very open (Kaa IoT platform) from the very closed (PTC ThingWorx, Microsoft Azure, CyberVille and GE Predix). For a platform user, at a higher level, all the platforms mentioned in Table 5 enable D-I-K management but when the sub-dimensions are considered, the openness to manage D-I-K varies for different platforms.

The supply-side user dimension which is further divided into core developers, extension developers (3rd party) and data aggregators is analyzed for all the five platforms. PTC ThingWorx and Microsoft Azure do not have core developers because their core business is driven by extension or third-party developers. Core developers for Kaa IoT platform and CyberVille mainly develop the core functionalities of the platform and do not have an end-to-end access to customer data and information. For GE predix, core developers are

Table 4. Detailed analysis of industrial internet platforms in the context of PLM.

Criteria for analysis	Detailed criteria for analysis	Platforms to be analyzed					
		GE Predix	Microsoft Azure	PTC ThingWorx	IBM Watson	CyberVille-CyberLighting	Kaa IoT platform
Openness of the platform Level of openness—low, medium and high	Access to information	High	High	High	High	Medium	High
	Cost of access	High	High	Medium	Medium	Low	Free
	Control in terms of rules to use the platform	High	Low (users can decide about data access)	Low (users can decide data access)	Low (users can decide about data access)	Low	Low
Used in product lifecycle phases	BOL	Across and within all phases	Across and within all phases	No	Across and within all phases	No	Across and within all phases
	MOL			Across and within BOL-MOL		Extensively in MOL	
	EOL					Less in EOL	
Interoperability between different information systems	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes
Real-time monitoring/analytics	Basic Advanced	Advanced	Advanced	Advanced	Advanced	Basic	Advanced
On-demand tailored solutions	Demand-side user (end user)	Yes	Yes	Yes	Yes	Yes	Yes
	Supply-side (application developer)	No	Yes	Yes	Yes	Yes	Yes

BOL: beginning of life; MOL: middle of life; EOL: end of life.

Table 5. Detailed analysis of industrial internet platforms based on dimensions and sub-dimensions of platform openness.

Dimensions of openness	Detailed sub-dimensions of openness	Kaa IoT platform	PTC ThingWorx	Microsoft Azure	CyberVille-CyberLighting	GE Predix
Demand-side user openness (platform user)	Access to information	Open (all standards)	Open (not all standards)	Open (not all standards)	Open (restricted)	Open (restricted)
	Cost of access	Open (free)	Open (with a fee)	Open (with a fee)	Open (with a fee)	Open (restricted with a fee)
	Control in terms of rules to use the platform	Open	Closed	Closed	Closed	Closed
Supply-side user openness (application developer)	Core developers	Open	No core developers	No core developers	Open	Open (all data and information)
	Extension developers (3rd party)	Open	Open	Open	Open (restricted)	Open (restricted)
	Data aggregators	Open	Open	Open	Closed	Closed
Platform-provider- and sponsor-related openness	Proprietary model				✓	✓
	Licensing model		✓	✓		
	Joint venture model	✓				
	Shared model	–	–	–	–	–

the main developers, and hence they have a lot of access to customer data and information, in order to provide tailor-made solutions. Data aggregators are relatively new in the manufacturing or industrial business. Not all platforms allow the data aggregators an access to data to merge similar kind of data from various industries and create meaningful insights. CyberVille and GE Predix, among the five platforms studied, do not allow data aggregators to access the data and information. Different platforms have different protocols for management of D-I-K, which leads the differences in access to core and extension developers as well as data aggregators.

In the case of the platform provider and sponsor dimension, platforms follow different models (models are represented as sub-dimensions). CyberVille and GE Predix follow the proprietary model, PTC ThingWorx and Microsoft Azure follow the licensing model and Kaa IoT platform follows the joint venture model. Partnership between different platforms affects the model they follow. The model that they follow also defines the D-I-K management policies. In the next section, we will discuss the findings and present the implications in detail.

Discussion and conclusion

Our purpose was to analyze and understand the potential role of industrial internet platforms in the management of product lifecycle–related D-I-K as well as understand the various dimensions and sub-dimensions of platform openness that influence the selection of these platforms.

Answering the research question 1 (RQ1), from PLM-related literature, we identified major D-I-K management–related challenges both within and between product lifecycle phases. In this article, we identified different types of novel platforms that handle D-I-K in a different manner in the context of industrial Internet. Some of the platforms are more focussed on addressing machine-related D-I-K, whereas others are more focussed on internal and external collaboration, and sensemaking of data and information. Such platforms are shown in Table 2.

Answering the research question 2 (RQ2), demonstrated in Tables 3 and 4, we found that industrial Internet–related technologies and platforms can address all of the identified major classes of challenges of D-I-K during and within the different PLM phases. We found that the platforms address PLM challenges in a different manner and showed more specifically in Tables 3 and 4 how different industrial internet platforms address different PLM challenges. For example, CyberVille is about innovative 3D visualization of industrial internet–related data and information, and addresses the PLM challenges using 3D visualizations. PTC ThingWorx-like platforms provide mobile applications that, for instance, enable companies to tap into real-time industrial internet–related novel data and information, use these data to collaborate with colleagues and make insights of it, and feed in information to the systems that can be used easily by people who are not experts in complex PLM/PDM systems. Most of the platforms listed in Table 4 can address PLM challenges (e.g. Table 4 shows most of the platforms that can be used to facilitate bringing information across and within the product lifecycle phases) which are normally not handled well by traditional PLM/PDM software.[7,54]

Answering the research question 3 (RQ3), we found that there are industrial internet platforms that had very different types of strategies and profiles related to openness. Industrial Internet platform openness, more specifically, was found to have a clear impact on many of such challenges and can be used to address various challenges in a structured manner. All the three identified major dimensions of openness as well as the resulting degree of openness were found to matter significantly to the management of D-I-K for both within and between product lifecycle phases. It was found from Table 5 that there are clear differences in the profiles related to openness and these differences matter in the management of D-I-K within and between product lifecycle phases. It can be found from Table 5 that sub-dimensions like access to information, cost of access and openness toward extension developers (3rd Party) matter to management of D-I-K within and between product lifecycle phases, and different platforms have different profiles when it comes to such sub-dimensions.

Limitations

A possible limitation of this study is that it focuses on creating a conceptual model to analyze industrial Internet platforms as well as dimensions of platform openness. Empirical validation which is not in the scope of this study will be carried out as a part of future studies where platform companies in Tables 4 and 5 as well as their customers will be interviewed about criteria of analysis and openness dimensions.

Managerial implications

Here, we consider mainly the managerial implications toward platform users, not for instance platform owners and developers. First, since this study demonstrates that many industrial internet platforms are designed to support interoperability and connections to external software and hardware, and can thus facilitate exchange of information between partners and customers relatively easy, as well as facilitate and speed up the implementation of industrial internet; these possibilities and capabilities should be carefully considered. Second, since there are clear differences and different emphases in industrial internet platforms' capabilities to handle data and information, for instance related to their degree of openness, they should assess the overall benefits and risks (both short-term and long-term ones) from that perspective, making use of related frameworks and analyses provided by this study. Third, especially if the companies find the product lifecycle perspective important for their business, due to either long lifecycles of their products or the significance of the extended enterprise and related information management, they should consider the capabilities of various platforms to manage data in a longer term (e.g. legacy and interoperability issues) and to address other PLM challenges (e.g. the ability to connect different lifecycle phases such as MOL and EOL to BOL, which industrial internet technologies and platforms can address on the basis of this study). Fourth, not only the generic concept of platform openness, but, in more detail, also the overall impact of openness, as well as the different dimensions of openness in the considered industrial internet platforms, should be considered in the platform-related decision making. While selecting platforms, companies should consider at least these dimensions: access to information, cost of access and openness toward extension developers (3rd party), because they impact in various ways most of the challenges related to D-I-K. Fifth, when companies invest into platforms that enable and facilitate the extraction, storing, analysis and sharing of various data and information, allowing the tapping into vast amounts of data, they should also consider investing into platforms that enable them to better make sense of the data and make use of the data in managerial decision making, such as social media and crowdsourcing platforms discussed also in this article.

Sixth, while openness can offer significant benefits, but at the same time we clearly also notice that openness does not come for free. While a large established company might prefer a more mature and developed platform like Predix or ThingWorx, a small or medium-sized company might want to prefer a platform based on relatively open source standards and open interfaces, such as CyberVille-CyberLighting. However, small and medium-sized enterprises (SMEs) should also consider the platform selection from their limited resource perspective—they should not only consider the benefit perspective, but also take into consideration whether they can deal with the potential openness-related risks and problems (e.g. quality control, platform administration or potential information security problems). The costs of platforms and their various approaches to openness, especially in the long term, are often much more difficult to estimate than the short-term benefits provided by them.

Finally, companies should also consider carefully not only the extent of openness in their decisions as such, but also ponder in a more in-depth manner what is the suitable type of openness for them. For instance, in high-security organizations, such as the military, airplane industry or the energy sector, managers should not prefer the platform that is open in all aspects, but consider the significance of the implications of openness to information security or the quality control of applications for their business.

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ORCID iDs

Karan Menon https://orcid.org/0000-0001-9948-9659
Thorsten Wuest https://orcid.org/0000-0001-7457-7927

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PUBLICATION

III

Industrial internet platform provider and end-user perceptions of platform openness impacts

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IV

Is Openness Really Free? A Critical Analysis of Switching Costs for Industrial Internet Platforms

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Is Openness really free? A critical analysis of switching costs for Industrial Internet Platforms

Karan Menon[1], Hannu Kärkkäinen[1], Thorsten Wuest[2] and Timo Seppälä[3]

[1] Tampere University of Technology, Finland,
karan.menon@tut.fi, hannu.karkkainen@tut.fi
[2] West Virginia University, USA,
thwuest@mail.wvu.edu
[3] ETLA, The Research Institute of the Finnish Economy, Finland,
timo.seppala@etla.fi

Abstract. The core idea of Industrial Internet, Industry 4.0, Smart Manufacturing and Cyber Physical Systems (CPS) is to utilize Internet of Things (IoT) based technologies and applications for the purpose of enhanced operations productivity. These IoT technologies and applications help companies to integrate their business as well as their engineering, manufacturing and service processes making their operations more robust, efficient and sustainable (green) with supreme quality. Switching cost and openness of the industrial internet (II) platform has many short and long-term impacts on the end-users' business. Hence the openness is often considered to be free or synonymous to open source. The purpose of this paper is to understand and analyze the impact of II-platform's increased openness and its dimensions on switching costs framework. For empirics and to test the developed framework we conducted a training and a workshop, where 11 manufacturing and service industry representatives describe the main types of switching costs that would be impacted because of increased openness of II-platforms. As a managerial implication this new switching cost framework seem to provide a tool to evaluate the specific preferences and potential positive and negative impacts of II openness on their respective businesses.

Keywords: Industry 4.0, Industrial Internet, Smart Manufacturing, Platforms, Openness, Switching Costs, Lock-in, IIoT, IoT

1 Introduction

Industrial Internet or Industry 4.0 utilizes internet of things (IoT) based technologies to combine business and engineering processes improving the production efficiency, robustness as well as producing high quality products at lower costs.[1, 2] Various Industrial internet or industry 4.0 platforms allow the manufacturing companies to manage data and information efficiently in order to implement IoT related technologies to enhance their business and create value for the customers. [3–5]

Platforms and platform economy has been of increasing academic and industrial interest, both in general as well as in the specific context of industrial internet. Some common topics in platform research include, platform business models [6, 7], platform related network effects[6, 8], platform openness [9, 10], interoperability, lock-in [11], to name few. In the manufacturing companies' context, platform related openness is considered very important for technology implementation and creating business value.[12–14, 4] This requirement from the industrial end-users also enforces platform providers to make critical decisions on platform openness. [15, 12, 5]

Industrial internet platform openness has many benefits for manufacturing companies such as, enhanced interoperability with different machines because of open standards, diverse and high end applications made by core as well as third party developers. Literature primarily discusses about the downsides or risks of platform openness from the platform supplier or provider perspective and not from the platform end-user perspective.[12, 16] In our previous work we have discussed the downsides of industrial internet platform openness for platform end-users.[4] Lock-in, which is understood to be one of the long-term downside of openness, can be a result of multiple factors including increased switching costs. However relatively little is known about the impact of switching costs in a B2B context. Furthermore the impact of increased openness on switching costs is also not studied well. Hence, in this paper we apply a multi-dimensional switching cost concept together with the multi-dimensional openness concept to evaluate the impact of increased openness for manufacturing companies that use industrial internet platforms.

We have derived the following research questions to address the identified research gap related to platform openness and related switching costs especially in the context of industrial internet platforms' end-users:

RQ1 *What types of switching costs would be perceived impacted by increased openness of industrial internet platforms?*

RQ2 *How would increased openness of industrial internet platforms impact the identified perceived switching costs?*

The remainder of the paper is divided into theoretical background, research methodology and design, results and findings, discussion and conclusions.

2 Theoretical Background

2.1 Industrial Internet Platforms and related trends

Today, innovation and value creation is happening more and more digitally and online. This stands true across all industries, from marketing to manufacturing. The increasing pace of this development can be credited to some extent to the available infrastructure, on which digital offerings and applications are built upon. This development is commonly referred to as platform economy.[17] In this paper we follow the platform definition by [18], that defined industry platforms as "products, services, or technologies developed by one or more firms, that serve as foundations upon which a larger number of firms can build further complementary innovations and potentially generate network effects." In essence, platforms provide a structure to utilize connectivity (through the internet), analytics (computational resources) and data.

Platforms can be designed narrowly for a specific purpose or industry. However, in this paper, we focus on platforms that can be utilized on an eco-system level across different industries and/or purposes. These platforms have in common that they allow a variating degree of customization and openness towards, e.g., third party developers. Platforms in an industrial setting are often used in unison with paradigms like Industrial Internet, Industry 4.0, Internet of Things (IoT), Cyber-Physical Systems (CPS) and Smart Manufacturing. [19] argue that Industrial Internet Platforms are one of the key enabling technologies for Smart Manufacturing Systems. Industrial Internet Platforms can be used to access, store, aggregate and analyze data from a variety of sources in a manufacturing environment (e.g., machine tools, sensors, ERP or MES systems) as well as provide access to data to dedicated applications and services throughout the smart factory and beyond. One major aspect of high relevance to industrial end-users is the openness of a platform (see following chapter) and the impact on the (direct and indirect) switching costs associated with it.

2.2 Industrial Internet Platform Openness

From the literature, we can see that platforms are not just open or closed, they belong on a continuum between open and close.[20, 14, 21, 22, 4] Manufacturing companies need to select the right industrial internet platform in order to attain optimal openness between their customers, suppliers, sub-contractors and partners. Eisenmann et al. 2009 [23] defined that a platform is "open", as long as, 1) no restrictions are placed on participation in its development, commercialization or use; or 2) any restrictions, for example, requirements to conform with technical standards or pay licensing fees, are reasonable and non-discriminatory, that is, they are applied to all the potential platform participants. [23] This is applicable to all the actors participating in the use and propagation of the platform. These platform actors are divided into three categories; 1) Demand-side user (end-users of the platform) 2) Supply-side users (application developers in the platform) 3) Platform providers and sponsors (platform companies).[15, 18, 13, 4]

Platform openness is divided into three broader dimensions keeping the above mentioned platform actors in mind and then further divided into sub-dimensions, which results into a multi-dimensional framework for platform openness. [22, 4] The impact of industrial internet platform openness on platform providers' strategy and platform end-users' strategy has been discussed in our previous work using the same openness framework mentioned above. [22, 4]

2.3 Platform openness and switching costs

Some of the major effects of platform openness decisions are related to the interoperability (of platform users), network effects, as well as transaction costs and switching costs.[18, 15, 24, 22] Choosing an optimal level of platform openness is crucial for companies that design and maintain the platforms (e.g. [12, 23, 25]), as well as companies that use those platforms [13]. In determining the level and type of openness, switching costs are one approach that can be utilized to understand especially the longer-term impacts of openness [13, 11].

Blut et al. [26] define switching costs as "the customer's perception of the magnitude of additional costs required to conclude the current relationship, and secure an alternative supplier." However, they state that relatively little is known about the relevance of switching costs, yet, particularly in industrial and B2B markets. Furthermore, switching costs should be seen in B2B-context as a multifaceted construct.[26] Thus, part of the novelty of this study is derived from the use of multi-dimensional switching cost concept, and reflecting the importance of platform openness from the perspective of individual switching cost components in the relatively little studied industrial B2B context, as well as the little studied perspective of industrial internet platform use, and the platform user perceptions on the impact of openness to switching costs. We present the multi-dimensional openness (see [4] for details) versus the multi-dimensional switching costs (see [26] for details) evaluation framework in Table 1.

Table 1. Platform openness [4] and switching cost framework [26]

			Switching Costs							
			Procedural				Financial		Relational	
			Uncertainty costs	Search costs	Training costs	Setup costs	Sunk costs	Lost performance costs	Brand relationship and psychological costs	Personal relationship and psychological costs
Openness Dimensions	End-user related openness	Access to information								
		Cost of access								
		Control in terms of rules to use the platform								
	Application developer related openness	Core developers								
		Extension or 3rd party developers								
		Data aggregators								
	Provider or sponsor related openness	Proprietary model								
		Licensing model								
		Joint venture model								
		Shared model								

On the supplier side, significant part of management practices and tactics are often aimed at increasing switching costs, for instance through introducing loyalty schemes or offering unique customer solutions. It is rather commonly experienced that increased openness is generally something positive when viewed from the perspective of platform users: from the perspective of platform users and related switching costs, platform openness can e.g. allow the end users to reduce the switching cost to an alternative platform, thus allowing the end users to avoid a lock-in to the used platform ([27]).

One challenge with the proper understanding of the role of switching costs, as well as the impact of openness to switching costs is related to the nature of switching costs developing and often increasing in the course of time (see e.g. [26]). It has also been demonstrated that users have a tendency to fail to anticipate the impact of future switching costs, while having a preference of minimizing immediate costs, and thus, this leading to lock-in. Furthermore, due to common difficulty of anticipating future switching costs, as well as the many-dimensionality of both openness and switching cost concepts, it may be difficult for a platform user to identify the multitude and the importance of different impacts of openness to switching costs, especially in the long run.

3 Research Methodology and Design

The empirical material for this paper stems from a qualitative questionnaire, training and workshop of eleven manufacturing and service companies. The material and data were collected in February, 2018. The logic of the data collection resembles that of a multiple case study.[28] Table 2 describes the industry focus and the role of the respondent in the company.

Table 2. Information on companies

Company	Industry	Role of the respondent
Company A	Manufacturing	Production Director
Company B	Manufacturing	Production Manager
Company C	Manufacturing	Production Manager
Company D	Manufacturing	Vice President Sourcing
Company E	Manufacturing	Production Manager
Company F	Manufacturing	Supply Chain Project Manager
Company G	Manufacturing	Supervisor
Company H	Manufacturing	Program Manager
Company I	Industrial Service	Business Operations Senior Manager
Company J	Media Company	-

We collected data following methods; 1) a qualitative questionnaire was sent to the eleven participants three working days before the training and workshop. This is because we wanted to understand: a) the level of general knowledge of the participants about the platform economy and its characteristics and b) what are the platforms of industrial internet the participating companies are applying for their operations and services, and 2) an in-depth qualitative training and workshop was executed of the platform economy. All participants who participated the questionnaire, training and workshop work as senior operations manager positions of participating companies. Furthermore, separate discussions about the platform economy and its characteristics were conducted with the participants during the training and the workshop. In this paper we will present results only from the workshop, i.e. point 2), which focuses on the switching cost framework.

The qualitative training and workshop were conducted in a structured way: first, the participants received a three-hour introduction to the topic of platform economy and its characteristics; second, the participants received and 30min introduction to the switching cost analysis model and to its characteristics; third, the participants executed the switching cost analysis from the openness perspective as an individual task. The analysis took 60min and iterative discussions were allowed to take place during the analysis between the two instructors and the participants. The data collected in training and workshops were supplemented and elaborated through the feedback collected after the training and workshop by the organizers.

During the workshop, the participants were introduced to the switching cost and openness framework, presented in Table 1. They were asked to evaluate the switching costs that would be impacted if individual sub-dimensions of openness were significantly more opened up either by their own platform or a new platform. Once they finished pointing out the switching costs, they were asked to give a +H to the switching costs that would have a maximum impact on their business and give a reason next to every +H that they mark.

4 Results and Findings

In this section, we report the results of our initial workshop focusing on switching costs in conjuncture with our Industrial Internet Platform Openness Framework. The results are based on the data provided by ten participants with variating backgrounds regarding their companies and II platforms used. In this section, the results are strictly reported and not interpreted. An interpretation of the results and a detailed discussion with regard to the initial research question, including possible limitations of the study, is presented in the following section.

We merged the answers that the individual participants provided within the framework table depicted in Table 1 in a combined table (Table 3). This allowed us to see general patterns that emerged across the different participants feedback.

However, before describing emerging patterns, we will present ***general results***. It is noticeable that each participant, all of them working with different platforms in their daily life, have identified multiple areas where openness relates to switching cost.

The two individual cross sections with the overall highest response count are at the intersection of the openness sub-dimension ‘Access to information’ and procedural switching costs category ‘Setup Costs’ with 10 total responses as well as ‘Access to information’ and ‘Training Costs’ with 9 total responses.

The same ranking occurs when only counting individual ‘high impact’ responses, with a score of 5 for ‘Access to information’/ ‘Setup Costs’ and 4 for ‘Access to information’/‘Training Costs’.

After merging the individual answers of the participants in one template, several ***patterns within the answers emerged***. One very prominent pattern is that the *openness dimension* ‘End-User related openness’ received the most attention with a combined total of 80 selected boxes across the participants. The second openness dimension ‘Application Developer related openness’ is a close second in total number of 68 selected boxes. The third and final openness dimension, ‘Provider or Sponsor related openness’ lags behind with only 32 reported correlations. In this sense, it is also noteworthy that while all 10 participants have a minimum of 6 (dimension 1) and 3 (dimension 2) ticked boxes while a total of four participants reported no impact for dimension 3.

Table 3. Results from the workshop

Openness Dimensions		Switching Costs								
		Procedural				Financial		Relational		Total
		Uncertainty costs	Search costs	Training costs	Setup costs	Sunk costs	Lost performance costs	Brand relationship and psychological costs	Personal relationship and psychological costs	
End-user related openness	Access to information	4	5	9 (four +H)	10 (five +H)	3	6	3	2	42
	Cost of access	1 (one +H)	5	3	4 (one +H)	2	1			16
	Control in terms of rules to use the platform	2	2	8 (two +H)	2	2	1 (one +H)	3 (one +H)	2	22
Application developer related openness	Core developers		4 (one +H)	5 (one +H)	5 (one +H)	4	2 (one +H)	4	2	26
	Extension or 3rd party developers	3	2 (one +H)	5	5 (one +H)		4	5	3	27
	Data aggregators	2	4 (one +H)	2 (one +H)	2 (one +H)			2	3	15
Provider or sponsor related openness	Proprietary model	1	1	1	2	1	1	1		8
	Licensing model	1	3	1	1 (one +H)	2	1	4 (one +H)	1	14
	Joint venture model		1	2		1		1	1	6
	Shared model		1	1		1			1 (one +H)	4

Ranked 1 in High Impact on business responses
Ranked 2 in High Impact on business responses
Ranked 1 in responses to openness dimensions
Ranked 2 in responses to openness dimensions
Ranked 3 in responses to openness dimensions
No responses

Looking closer at the *openness sub-dimension level*, there is a clear preference visible with the first openness sub-dimension ‘Access to information’ receiving a total of 42 responses with openness sub-dimensions five - ‘Extension or 3rd party developers, and four - ‘Core developers’ accumulate 27 and 26 responses respectively. The highest score of any individual sub-dimension within openness dimension 3 is achieved by ‘Licensing Model’ with 14 responses, making up almost half of the total responses for this dimension.

It has to be noted that there are *two intersections of between openness* dimension and switching costs category standing out. Openness dimension one ‘End-User related openness’ and ‘Procedural Switching Costs’ have the most ‘high impact’ +H responses with a count of 13. Followed by the intersection of openness dimension two ‘Application Developer related openness’ with the same switching cost category scoring a total of 8 ‘high impact’ responses.

Another interesting pattern that emerging from the accumulated data is that the openness sub-dimension ‘Cost of access’ has no reported correlation with ‘Relational Switching Cost’. Similarly, the participants reported no correlation of the openness sub-dimension ‘Data aggregators’ with ‘Financial Switching Costs’.

The participants were asked to provide ***reasoning for their top-three ‘high impact’ cross-sections*** of openness related switching cost. We clustered and condensed the individual reasons to provide an overview of the reported impacts. Switching the platform to more open would mostly affect the set-up cost as well as training costs of the company. Typically, these terms set-up cost and training cost denote money and time used as an investment to benefit the company (for more information about the training costs see [29]). In our study the respondents considered that set-up cost and training cost would be quite high or high for their companies. They also considered that companies sometimes have difficulties in obtaining financial resources for such cost, especially training. Additionally, the openness of the platform would lead to even higher set-up cost and training cost.

Hence, the respondents considered that set-up cost and training cost also add value for the company (it is not always a bad thing one of the respondents said) and will lead to higher licensing revenues from the platform. They also identified new opportunities for larger indirect network effects by implementing shared revenue business models. Adding developers to the platform would lead to even larger indirect network effects (more developers make the platform better another respondent said). Furthermore, a more open platform, from the end user perspective, allow companies to get much more innovations out of it such as new data, new knowledge and new patents. However, sometimes openness might lead to higher search cost, lost performance, lost competence and for more varied systems architecture.

5 Discussion and Conclusions

It can be seen from Table 3 that the overall procedural costs get impacted by increased openness of end-user related openness and application developer related openness dimensions. Procedural costs are associated with the costs that involve time and effort in searching, adopting and using a new platform as well as the uncertainty associated with the new platform. On increasing openness for end-user related dimension certain procedural costs (for example setup and training costs) increase to an extent that they have a significant impact on the platform end-user's business. This happens because the end-user manufacturing company incurs costs with respect to setting up either new servers, databases or systems related to the new platform. There is also an additional training cost associated with the features of the new platform. Similarly, increased openness for application developer related dimension also has a substantial impact on procedural costs. New applications can mean concentrated effort and investment on infrastructure as well as training the personnel on how to efficiently use these applications. Hence, it is important to understand that increased access to data, better control over the use of the platform and increase in the number of applications can increase the switching costs significantly in long term.

One of the various findings of this study was that increased openness for access to information was commonly perceived to increase the switching costs related to training and setup costs. This means access to more data and information, which can result into investments in infrastructure as well as training the personnel. None of the respondents consider increased openness towards cost of access, i.e. cost of the platform usage reduces, will impact the relational switching costs. This means that for industrial manufacturing companies it is the access to data and information that is more vital when compared to the cost of access to the platform. Another interesting finding of the study was that if the openness towards 3rd party developers would increase then some of the perceived procedural costs will have a significant impact. The is because it is the 3rd party developers or application developers, in general, that create business opportunities for the platform end-users by developing novel applications. Hence, if the openness increases for 3rd party developers then more applications will be developed on the platform motivating the end-user to stay on the platform for a long time and therefore, increasing the switching costs.

There are several limitations that need to be mentioned regarding the nature of this study and the conclusions drawn. One limitation is the size and setup of the group surveyed. While all participants have some form of experience with industrial internet platforms, they are all from different companies and serve in different roles. This might result in a bias in the answers provided. Another limitations might be inherited in the framework itself. Given the time limit of 60min for the whole exercise, the participants might spend more time on the top part of the matrix and rush through the later parts. This might have an effect on the number of responses for the different parts (higher for earlier parts, lower for later parts). The complexity of the framework itself and the explanation given to the participants can also be perceived as a possible limitation that should be taken into consideration when interpreting the results.

It is imperative that the managers while making an industrial internet platform selection take into consideration, not only, the benefits of openness but also the long term risks or downsides. Openness versus the switching costs framework gives an indication towards long term lock-in. It was observed in our workshop that the managers were interested to learn new kinds of costs related to switching that their company would incur if the selection is made purely based on the positives of increased openness. It is important that the managers in collaboration with different users of the platform in the company make the decision related to the impacts of openness on their business.

As part of the future studies, it would be interesting to interview multiple people from the same company, involved in platform strategy as well as platform usage related senior roles. After understanding the role of switching costs towards lock-in, it would be beneficial to understand the role of different factors, such as, network effects, transaction costs, interoperability and others.

Overall, openness in industrial internet platform brings many benefits in short and long term but understanding the long term risks such as lock-in related switching costs gives us an understanding that openness is not always "free" as it is perceived occasionally.

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V

Impact of IIoT Based Technologies on Characteristic Features and Related Options of Nonownership Business Models

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Impact of IIoT based technologies on characteristic features and related options of nonownership business models

Karan Menon[1], Hannu Kärkkäinen[1], Sameer Mittal[2] & Thorsten Wuest[2]

1 Tampere University, Finland,
karan.menon@tuni.fi, hannu.karkkainen@tuni.fi
[2] West Virginia University, USA,
samittal@mix.wvu.edu, thwuest@mail.wvu.edu

Abstract. Industrial internet of things (IIoT) can positively impact business from the process and the technical perspective. There is a limited understanding of the impact of IIoT on business models in general especially the novel nonownership business models (NOBMs). In this paper we analyze the literature, especially case study literature, to understand the impact of IIoT based technologies and related features on the NOBMs using a morphological box (developed by Lay et al. 2009) as a framework. We understood that IIoT- enabled technologies enables the implementation of a larger variety of NOBMs, such as, the pay-per-use, pay-per-output and pay-per-outcome business models, as well as a variety of options related to them. We also realized that there is a need to develop a morphological box for capital intensive manufacturing companies by developing new characteristic features and related options that can take IIoT enabled technologies.

Keywords: Industrial internet of things, Industry 4.0, Business Models, Nonownership Business Model, IIoT, IoT

1 Introduction

The academia and managers are currently having high expectations on the potential of the IIoT[1]. However, these benefits are not very apparent and easy to realize. While recognizing the uncertainties related to the realization of business benefits from IIoT, the novel types of Nonownership Business Models (NOBMs) enable collaborating companies to share both opportunities and downsides of IIoT for mutual benefit, thus creating novel networked value creation opportunities. Regarding such benefits, in general, IIoT has been demonstrated e.g. to enable decreases in transaction costs between companies in various manners [1], while increasing transparency in collaboration through increases in the quantity and quality of data and information (e.g. [2]).

Currently, there is a limited understanding in academic literature about the value and benefits of IIoT to business and novel business models (see e.g. [3]). Therefore, the central novelty of this study is to understand the role of IIoT technologies in NOBMs (especially pay-per-use, pay-per-output and pay-per outcome) in the domain of industrial (business-to-business) capital-intensive manufacturing goods. The novelty is derived, in more detail, partly also from the use of a business model structuring framework [4], previously not made use of, to understand the role of IIoT technologies in the NOBMs. We will review the perspective of earlier studies have addressed this topic in the next section.

We focus on companies that not only produce products for other companies, but more specifically, on companies the products (machines or machine components) of which are used as part of the other companies' manufacturing processes, and mostly, are capital-intensive in nature, i.e. B2B companies. Thus, for instance, the risk aspect, associated to all NOBMs which transfer product ownership from customers to suppliers, is emphasized, while e.g. failures in products or product components can cause even significant interruptions in the whole production process, and thus, the supplier has significantly higher responsibility of such risks.

To address the above research gaps, our aim is to answer the following main research question: "*How do IIoT- based technologies impact the characteristic features and related business model enabled options of the nonownership types of advanced business models of business-to-business manufacturing companies*?"

The structure of this study is as follows: we first introduce the major concepts, primarily IIoT and NOBM business models, and related frameworks for this study. Second, we review existing research and the research gap in more detail. Third, we introduce the methodology of this paper. Fourth, we present the results, and discuss them, leading finally into the conclusions and managerial implications.

2 Theoretical Background

2.1 Industrial internet of things-based technologies

Smart Manufacturing (SM) improves the efficiency and responsiveness of a production system by integrating data with information technology and manufacturing. IoT employs sensors to communicate between the physical world and computers and was first used in 1999 [5]. IoT can record and measure parameters like temperature, pressure, and light with the help of affordable electronic sensors and wireless processors over the internet and considered as a technology that can revolutionize the future [6]. IIoT connects the factory machines with IoT [5]. IIoT consists of devices and sensors, communication technologies, gateways and switches, analytical and optimization programs, interconnected apps, and people (that use it) [5, 7]. Based on the literature, [1]four technologies are important for IIoT, i) *Internet and communication protocols and middleware*, ii) *Sensors*, iii) *Actuators*, and iv) *IT-driven services like AI and big data analytics*.

Evolution of digital technologies has transformed B2B companies [8]. Similarly, the information interoperability possible because of IIoT has wholly changed the relationships between the customers, manufacturers and the suppliers, and thus modifying the business models of the manufacturing companies [5, 6]. For example, now the electrical engineering and information and communication technology companies seek for novel key partner networks and automotive suppliers use IIoT to increase their cost efficiency [3]. A systematic review study [9] has also shown that the scientific works have not looked at all the aspects of the business models, and these studies mainly focus on the key resources and activities of the companies, and utterly ignored the effect of IIoT adoption from the customer perspective. Therefore, although, literature refers to the right business models as the force behind profitable use of IIoT, however, it lacks a comprehensive business model that caters towards the aspect of IIoT [5].

2.2 Nonownership Business Models

Nonownership model can be defined as *"service in which customers acquire some property rights to an asset and are offered a certain degree of freedom in using this asset for a specified period of time while the burdens of ownership remain with the owner"* [10].

The above definition describes the concept of nonownership in a clear manner from the customers point of view as it talks about how a customer can use the asset but not own it, by keeping the ownership with the manufacturer. To take the manufacturer's point of view into consideration, the earning logic of nonownership business models must be described. This can be done by dividing the nonownership model into pay-per-use, pay-per-output and pay-per-outcome models. Pay-per-use type nonownership model implies that the customer pays for the use of the machine and every other aspect related to the machine, i.e. ownership, installation, maintenance, upgradation, recycling is taken care of by the manufacturer. Pay-per-output type nonownership model focuses on the result of the machine use, which is usually quantified in monetary terms. Pay-per-outcome type nonownership model focuses on the value derived by the customer after using the machine provided by the manufacturer.

Literature has covered the nonownership models from various different sectors; such as, software industry [11], B2C product manufacturers such as washing machine manufacturers [12], manufactured products such as the copier and printer [2]. The above-mentioned product ranges are easy to scale because the economies of scale work very well for software products, B2C products and use intensive copiers and printers. B2B manufacturers that make equipment or machines that are critical in customers process, such as the air-compressors or jet engines (critical components for an airplane manufacturer) have a very different risk profile when it comes to these nonownership models when compared to the above-mentioned products. There are some authors that discuss the risk profile for these kind of manufacturing companies [13]. Some of the authors [2, 13, 14], discuss the impact of IIoT on the business models of the manufacturing companies using the business model framework. They do not discuss the impact of IIoT on specific nonownership business models, such as the pay-per-use, pay-per-output and the pay-per-outcome models in a manner that the companies can define the value proposition for every individual model. Hence, we take the morphological box designed by [4] and understand the impact of IIoT on each and every characteristic feature as well as related options of the morphological box for manufacturing companies.

2.3 Morphological Box - framework for nonownership business models

Advanced business models that enable manufacturing companies to transition from sales-based revenue to a more continuous, service-based revenue generation are very appealing for a myriad of reasons, including closer customer relations, lock-in, more control of complex assets, and access to the system's operational data for the manufacturer. There are several tools and frameworks available that aim at supporting manufacturing companies during the early phases of this complicated transition. In this paper, we specifically focus on the strategic perspective of the business model development. One established framework is Lay et al.'s [4] morphological box that allows to describe service/based business models in a structured way. Table 1 illustrates the basic structure of Lay et al.'s morphological box. This framework is intended to allow manufacturing companies with limited experience in nonownership business models to envision their own, unique set-up.

Table 1. Morphological box framework for nonownership business concepts [4]

<table>
<tr><th colspan="2">Characteristic Features</th><th colspan="4">Options</th></tr>
<tr><td rowspan="2">Ownership</td><td>During the phase of use</td><td>Equipment producer</td><td>Leasing bank</td><td>Operating joint venture</td><td>Customer</td></tr>
<tr><td>After the phase of use</td><td>Equipment producer</td><td>Leasing bank</td><td>Operating joint venture</td><td>Customer</td></tr>
<tr><td rowspan="2">Personnel</td><td>Manufacturing</td><td>Equipment producer</td><td colspan="2">Operating joint venture</td><td>Customer</td></tr>
<tr><td>Maintenance</td><td>Equipment producer</td><td colspan="2">Operating joint venture</td><td>Customer</td></tr>
<tr><td colspan="2">Location of operation</td><td>Equipment producer's establishment</td><td colspan="2">Establishment "fence to fence" to the customer</td><td>Customer's establishment</td></tr>
<tr><td colspan="2">Single/multiple customer operation</td><td colspan="2">In parallel operation for multiple customers</td><td colspan="2">Operation for a single customer</td></tr>
<tr><td colspan="2">Payment model</td><td>Pay per unit</td><td>Pay for availability</td><td>Fixed rate</td><td>Pay for equipment</td></tr>
</table>

Lay et al.'s morphological box depicts five different characteristic features, ownership, personnel, location of operation, single/multiple customer operation, and payment model. By "characteristic features", we mean the central features of novel manufacturing business-to-business product- related business models, which are typical, as well as centrally differentiate the different types of novel business models from each other, and thus can be used for identifying the variety of options in the case of novel business models.

The first two, ownership and personnel are split in two sub-sets of characteristic features, during*/after the phase of use*, and *manufacturing/maintenance* respectively. For each of the characteristic features, different options are provided, reflecting the different possible set-ups for nonownership business models in manufacturing companies.

2.4 Impact of IIoT enabled technologies on NOBMs

While there is still a relatively small amount of academic studies discussing IIoT technologies' various roles in novel business models, and furthermore, especially aiming to understand these roles from the perspective of investment- and capital intensive business-to-business products, some studies [1, 2, 14–16] have addressed the topic. This literature that focuses on software products cannot be directly applied for understanding NOBMs in manufacturing capital intensive products. This is since software products can be scaled up as well as delivered and installed to customers' machines and manufacturing lines in a very different manner than large and expensive manufactured products. Second, due to such scalability and delivery challenges, risks related to suppliers' earnings being significantly linked to manufacturing customer e.g. not using the equipment in their production, bring significant risks to NOBM use in manufacturing context, limiting the adoption of experiences received from earlier literature derived from software NOBMs or consumer product NOBMs (see e.g. [15]).

We have studied literature reviews on IoT impacts to business models, literature reviews on NOBMs (e.g.[15]), and their references through forward and backward references of these reviews. No studies were found directly addressing our research question from the selected perspectives of capital-intensive manufacturing companies and from the perspective of NOBMs and the related changes in ownership of machines. We review the literature which is most closely associated with our research aim, context and research question.

Recently, [1, 2, 14, 16] have studied the role of IoT technologies in NOBMs. However, their studies do not address the topic from the perspective of capital-intensive manufacturing products. Metallo et al. [16] studied IoT technologies in three cases (Intel, Apio and Solair), making use of BM framework of [17], the so-called business model canvas, related to BM building blocks, but of which none are about capital intensive manufacturing products. Bock & Weiner [14] aim to study IIoT technologies' roles in NOBM's, their case study is focusing on capital-intensive manufacturing products, and they make use of [18] well-known BM framework. However, their perspective is focused on how these technologies can help to manage the uncertainties and risks (upsides and downsides of IIoT technologies) associated with NOBMs. Ehret & Wirth [1]focused on the role of IIoT technologies on NOBMs' BM components (Osterwalder's (see e.g. [17] well known BM framework), making use of economic theories (transaction cost theory and entrepreneurship theory) to understand the roles in more detail. However, their study is conceptual, and not concentrating on manufacturing capital-intensive products. They do neither, however, address directly the topics and issues of changing ownership in machines, related to NOBMs.

There are also some relatively recent systematic literature reviews on links of IoT and BMs [3, 15]. However, [15] discussed IoT's impact to software business models, which, for the above reasons, cannot be applied reasonably into manufacturing companies' product-oriented business models in the case of NOBMs. Arnold et al. [3] focus on generic business model impacts of IIoT into individual business model components of Osterwalder's business model canvas framework. They do not, however, discuss directly the implications to changes in ownership of investment products or NOBMs as such, but overall benefits to BM components, , or on the changes in customer relationships.

3 Research methodology

In this research we take a literature-based approach to investigate the impact of IIoT on the morphological box for NOBMs [4]. Lay et al.'s [4] framework was published in 2002, and since then, the digital transformation within the Industry 4.0 paradigm has had a significant impact on the feasibility and design of advanced, NOBMs.

After identifying the relevant papers in a literature review, in a next step we map the reported case studies to the morphological box. More specifically, we analyze first, whether a certain characteristic feature is addressed in the case studies and second, if and how IIoT had an impact on said characteristic feature. Similarly, we proceed about the different options presented in the morphological box and apply the same methodology. After identifying the impact of IIoT on the individual characteristics features and associated options, we discuss the overall impact and the validity of the morphological box given the changes in the technological landscape. Furthermore, we analyze whether there are additional aspects that are reported as relevant in the recent case studies that are not represented in the morphological box at present. These missing aspects are discussed and put into context to build the foundation for future work aiming at creating an updated framework, taking advanced digital technologies and their requirements and opportunities into consideration.

4 Results and findings

In this section we present the findings related to the impact of IIoT based technologies on the morphological box (shown in Table 1) in two parts. Table 2 shows the impact of IIoT based technologies on the characteristic features, whereas, Table 3, shows the impact of IIoT based technologies on the options related to the characteristic features (shown in Table 2).

IIoT technologies influence the tracking of the ownership using the sensors and the actuators as well as impact the prediction of the wear and tear to estimate the recycle time of the machine after the phase of use [1]. Lay et al. [4] did not separately considered the ownership of data component (under ownership) in the morphological box. After embedding IIoT based technologies with the machines and the equipment, it is possible to collect data of processes and the condition of the machine. This collected data on further analysis can enable process optimization, wear and tear prediction and new product design with better optimization for the manufacturer. Hence, it becomes imperative to consider the ownership of data associated with the process of manufacturing and condition of the machine [2, 14]. As per Lay et al. [4], operating "personnel" characteristic feature describes the allocation of the workforce in a business concept. IIoT based technologies have a big impact on the way personnel carry out the work in a manufacturing process. IIoT technologies create a connected environment for the machines via cloud, which enables the machine operator to remotely control the machine from another location. Thus, the customer worries only about the output of the machine. For example, Kaeser Compressors while adopting the IIoT enabled nonownership model, agreed with the customer that Kaeser will be the owner of the equipment and will also manage the operation of the compressors on customers' behalf [19–21].

Kaeser made use IIoT based technologies to enable operational efficiencies resulting from big data analytics and predictive maintenance. Real-time or near real-time condition monitoring of the machine's operation makes the "location of operation" decision making simpler for the manufacturer to remotely control the process and maintenance of the machine. adaptive control allows the manufacturer to let the customer make the decision on the location of the machine [2, 22, 23]. The characteristic feature that deals with the exclusivity of use of the machinery (Lay et al. 2009) focuses on "single/multiple customer operation" aspect. IIoT technologies enable real time or near real time monitoring of the machine use. This allows the manufacturer to create a system where multiple customers in the same location can use the machine as per a dedicated timeslot.

Table 2. Impact of IIoT based technologies on characteristic features of advanced business models

Characteristic Features			Impact of IIoT based technologies	References
A	Owner-ship	During the phase of use	Ownership of Data associated with the process of manufacturing and condition of the machine	[2, 14, 19, 20, 22]
		After the phase of use		
B	Person-nel	Manufactur-ing	Adaptive control using predictive analytics of the machine impacts the Personnel activities. Predictive maintenance impacts overall maintenance activities.	[1, 19, 21, 24, 25]
		Maintenance		
C	Location of operation		Condition monitoring gives more freedom when it comes to selecting the location of operation	[2, 23, 24, 26]
D	Single/multiple customer operation		Real-time or near-real time monitoring allows multiple customer operations with ease.	[14, 19]
E	Payment model		IIoT based technologies enable flexible and smart contracts	[27]

For example, if Kaeser has five customers in the same industrial area then it can set up a compressor system in a manner that all the five customers can use the same compressor system without purchasing any compressor [14, 19]. Kaeser can monitor the usage and the wear and tear of the compressor system and control the operation using IIoT based technologies.

Table 3. – Impact of IIoT based technologies on the options related to characteristic features of advanced business models

C.F.*	Options	Impact of IIoT based technologies

A	Equipment producer	Leasing bank	Operating joint venture	Customer	Condition Monitoring and Predictive Maintenance enables the equipment producer to take more risk in ownership
	Equipment producer	Leasing bank	Operating joint venture	Customer	
B	Equipment producer	Operating joint venture	Customer		Adaptive control allows the equipment producer to take control of the manufacturing process and maintenance
	Equipment producer	Operating joint venture	Customer		
C	Equipment producer's establishment	Establishment "fence to fence" to the customer	Customer's establishment		Optimization, prediction and geo-localization allows the equipment producer to operate the machine at any location
D	In parallel operation for multiple customers	Operation for a single customer			Usage monitoring, intensity assessment and condition monitoring allows the equipment producer to serve multiple customers with the same machine.
E	Pay per unit	Pay for availability	Fixed rate	Pay for equipment	Smart contracts based on all the IIoT based capabilities allows flexibility in payment contracts.
* C.F. – Characteristic Features as in Table 2					

Finally, IIoT based technologies in combination with Blockchain technology can lean-up the payment model for the manufacturer. Manufacturers can use smart contracts [27] to create more dynamic contracts with the customers. They can customize the smart contracts in a manner that it can cater to the pay-per-use model in the beginning but as the usage intensifies the contract automatically advances to pay-per-output and then to pay-per-outcome, giving maximum benefits to the customer and increasing the profit margin for the manufacturer. Blockchain in combination with the machine's real time operational data and related analytics enables the manufacturer and customer to agree on the dynamic nature of the contract [27].

Table 3 assesses the impact of IIOT based technologies and the enabled improved process capabilities (such as condition monitoring, predictive maintenance, etc.) on the options under the characteristic features (A to E from Table 2). Table 3 enables decision making, especially for the manufacturer. IIoT based technologies allow the manufacturer to select options which give them more control over the machine's operation and usage by minimizing the risks. For instance, in case of the "ownership" characteristic feature (A), the manufacturer or equipment producer can take control of the ownership related to the equipment as well as maintenance by using condition monitoring and predictive maintenance [2, 19, 20].

Similarly, adaptive control allows the manufacturer's personnel to control the operation and maintenance remotely or limiting the visits to the customers facility [2, 19]. Hence, the manufacturer can have their own "personnel" for both manufacturing and maintenance. When it comes to the "location of operation", the manufacturer can provide any of the option, equipment producer's establishment, establishment "fence to fence" to the customer, customer's establishment, because manufacturer can control the operation using optimization, prediction and geo-localization. IIoT enabled technologies allow usage monitoring, intensity assessment and condition monitoring letting the manufacturer to serve multiple customers using the same equipment system [14, 19]. Finally, when it comes to the options for payment model, smart contracts [27], give dynamic capability and freedom to the manufacturer to offer any nonownership contract, pay-per-use, pay-per-output or pay-per-outcome.

5 Discussion and conclusions

In our paper, the objective of the morphological box (originally by [4]) was to demonstrate the larger variety of possible different types of NOBMs, making use of the characteristic features and related options (as shown in Table 1). According to the results demonstrated above, IIoT- enabled technologies and facilitated process capabilities impact the above-mentioned characteristic features and related options in a way that this enables the implementation of a larger variety of NOBMs, such as, the pay-per-use, pay-per-output and pay-per-outcome business models, as well as a variety of options related to them.

The characteristic features and related options described by [4] in Table 1 were found relevant to the NOBMs. We found it possible to implement any type of NOBM using the characteristic features and the related options in different combination as demonstrated by [4]. IIoT based technologies on the other hand, were found to impact the characteristic features and related options in a manner that manufacturers can implement the variety of NOBMs. As shown in Table 2, "ownership" changes the way NOBMs are implemented because of IIoT enabled technologies. At the business model level, IIoT based technologies were found to impact the "ownership" characteristic feature in a manner that manufacturers interested in NOBMs can take better control of the ownership. This, in turn, may impact the "personnel" provided by the manufacturer to operate and maintain the machine, impacting the "location of operation" to be at the customer's site and finally impacting the way "payment model" is designed. Bock et al. [19] discuss how Kaeser changed the way they did business by employing the NOBM (pay-per-output model). With the IIOT based technologies, Kaeser took over the "ownership" of the compressor system and provided compressed air to the customer at customer's location using Kaeser's personnel to operate the compressor system and maintain them. In return, Kaeser was able to deploy the pay-per-output model for their customers to make payments for the compressed air they received [19].

NOBMs can be implemented without IIOT technologies as well. But, IIOT technologies were found to allow the manufacturing companies to implement a large variety of NOBMs. This variety can be seen using a morphological box, which constitutes of various characteristic features and options [4]. It is the options in the morphological box, that enable the variety in the NOBMs. IIoT based technologies enable the tapping into every detailed data point in a machine, providing big data and good quality data in real time or near real time. This access to data makes all the options (as in Table 3) that can contribute the variety of NOBMs i.e. pay-per-use, pay-per-output and pay-per-outcome feasible. Manufacturer can take control of the ownership, personnel that can operate the machine and do the maintenance, location of the machine as well as whether the machine system can be used by one or multiple customers. Finally, it is using the morphological box manufacturers can recognize and design novel business model -related experiments with their customers, and thus understand better the potential of various types of NOBMs and their feasibility.

After the analyses of results making use of the morphological box by [4] , originally designed for various types of novel manufacturing business models, and the related IIOT enabled technological impacts analyzed from the literature making use of the morphological box, we realize that there is a need to create a facilitated new morphological box for manufacturing companies to take better into consideration these specific types of novel business models, NOBMs (such as pay-per-use, pay-per-output and pay-per-outcome). For instance, there is a need to design new characteristic features that, for example, can take the overall changes in asset ownership into account. This means, in addition to the machine ownership, that for instance data ownership, software ownership etc. are considered in the model. These changes and additions will allow the manufacturing companies to better design the advanced NOBMs such as the pay-per-use, pay-per-output and pay-per-outcome business models.

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