Aalto University
School of Science
Master's Programme in Industrial Engineering and Management

Tea Tähtinen

How to Turn IIoT Software Solutions into Platforms: A Case Study of Three Existing Solutions

Master's Thesis

Espoo, June 10, 2018

Supervisor and advisor: Timo Seppälä, Professor of Practice

AALTO UNIVERSITY
School of Science
Master's Programme in Industrial Engineering and Management

ABSTRACT OF THE MASTER'S THESIS

Author: Tea Tähtinen

Title of the thesis: How to Turn IIoT Software Solutions into Platforms: A Case Study of Three Existing Solutions

Number of pages: 72 + 4 | Date: June 10, 2018

Major: Operations and Service Management

Supervisor and advisor: Prof. Timo Seppälä

The number of smart products connected to the Internet is constantly rising which generates a need for encompassing systems for the control of these products and the data produced by them. For this purpose, multiple companies are introducing various software solutions which are competing for the status of an industry standard. This study explores what kind for functionalities the software solutions for the Industrial Internet of Things (IIoT) currently provide and how they conform to the concepts presented in the platform literature. The study is conducted as a qualitative case study which focuses on three existing software solutions: Siemens MindSphere, IBM Watson IoT and GE Predix. The results of the study suggest that the implementation of IIoT software solutions is still in its early phases and the application domain is mostly proprietary and company specific. IIoT software users are discovered to be very protective towards their data, which seems to be the main obstacle preventing IIoT solutions to fully advantage the platform business model.

Keywords: platforms, Industrial Internet, enterprise software, data openness

Publishing language: English

AALTO YLIOPISTO Perustieteiden korkeakoulu Tuotantotalouden koulutusohjelma	DIPLOMITYÖN TIIVISTELMÄ

Tekijä: Tea Tähtinen	
Työn nimi: Miten teollisen internetin sovellukset voivat kehittyä alustoiksi: case-analyysi pohjautuen kolmeen nykyiseen ratkaisuun	
Sivumäärä: 72 + 4	Päiväys: 10.06.2018
Pääaine: Operaatioden ja palveluiden johtaminen	
Valvoja ja ohjaaja: Prof. Timo Seppälä	
Internetiin kytkettyjen älykkäiden laitteiden määrä kasvaa jatkuvasti, mikä luo tarpeen kattaville järjestelmille, jotka kykenevät sekä ohjaamaan näitä laitteita että varastoimaan ja käsittelemään niiden synnyttämää dataa. Useat yritykset ovat tuoneet markkinoille kyseiseen tarkoitukseen soveltuvia ohjelmistoratkaisuja, jotka kilpailevat määräävästä markkina-asemasta. Tämä tutkimus pohtii, minkälaisia toiminnallisuuksia nykyiset teollisen esineiden internetin hallintaan tarkoitetut ohjelmistot tarjoavat sekä miten nämä ohjelmistot mukautuvat alustakirjallisuudessa esitettyihin käsitteisiin. Tutkimus on toteutettu kvalitatiivisena case-analyysina, jonka keskiössä on kolme olemassa olevaa ohjelmistoratkaisua: Siemens MindSphere, IBM Watson IoT ja GE Predix. Tehtyjen havaintojen perusteella voidaan todeta, että teollisen esineiden internetin ohjelmistoratkaisut ovat edelleen alkutekijöissään ja olemassa olevat sovellukset on pääosin kehitetty yksittäisten yritysten tarpeisiin. Ohjelmistoratkaisujen käyttäjät suojelevat omistamaansa dataa erittäin tarkasti, mikä näyttäisi toistaiseksi estävän alustapohjaisten bisnesmallien rakentamisen kyseisten ohjelmistojen ympärille.	
Avainsanat: alusta, teollinen internet, yritysohjelmistot, avoin data	Kieli: englanti

Acknowledgements

There are a few individuals and entities who deserve special acknowledgement for their assistance in completing this thesis.

First, I want to thank my advisor and supervisor Timo Seppälä who introduced me the world of platforms and supportively guided me through the thesis process. I am grateful for the Research Institute of the Finnish Economy (ETLA) for the financing of this research project. Additional acknowledgements belong to my wonderful colleagues at ETLA who open-heartedly accepted me in their work community and shared their research expertise.

Second, I want to thank my family who has fed me when I have not had the time to cook and lifted me up when my confidence has been missing. These people have taught me that I can achieve anything if I just want it enough and I am extremely lucky to have them all in my life.

Finally, the early spring heatwave that reached Finland at the time of the finalizing of this thesis certainly made the process much more easy and enjoyable. I could not have imagined a better way to finalize my studies than in the sunshine listening the birds to sing.

Espoo, June 10, 2018
Tea Tähtinen

Table of contents

List of tables

List of figures

List of abbreviations

API	application programming interface
B2B	business-to-business
CAD	computer-aided design
ERP	enterprise resource planning
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IoT	Internet of Things
IS	information system
OS	operating system
PLM	product lifecycle management
R&D	research and development
SaaS	software as a service
SDK	software development kit

1. Introduction

The discussion around Industrial Internet was activated in 2012 by the report of General Electric (Evans and Annunziata 2012). Industrial Internet is founded on smart products that are connected to each other, and thus, form systems that can operate and optimize their operations autonomously (Juhanko et al. 2015). Smart components, such as sensors and microprocessors, amplify the capability of the mechanical and electrical parts of physical products, whereas connectivity components enable the information exchange between products and their operating environment (Porter and Heppelmann 2014). Separately, the smart, connected products are of little value, but their full potential is reached if the products are engaged in more extensive systems and the data they produce is shared (Porter and Heppelmann 2014; Shrouf et al. 2014).

The term ‘platform’ was first introduced in the product development context, referring to product families and modular product technologies (Baldwin and Woodard 2009). Since its introduction, the concept has been widely adopted by the software industry which has influenced greatly in the advancement of the term towards a point of integration between multiple parties. In modern literature, a ‘platform’ is defined as an open participative infrastructure for value-creating interactions between external producers and consumers (Van Alstyne, Choudary and Parker 2016; Rajala et al. 2018).

Platforms have been widely studied in the consumer context, frequently referring to examples such as Apple iOS, Facebook, Google’s search engine and Über (see e.g. Van Alstyne, Choudary and Parker 2016; Ghazawneh and Henfridsson 2013; Hagiu and Yoffie 2009). By the arrival of the Industrial Internet, the platform model is progressively entering the business-to-business (B2B) environment as well (see e.g. Kotiranta et al. 2017). The platform model complies well with the requirements placed for the systems operating smart, connected products, as they are open innovation structures that enable interactions between multiple parties. At present, B2B companies are more acquainted with traditional pipeline business models which are still frequently applied and highly competitive in the absence of suitable platform solutions. The traditional models are nevertheless likely to vanish as soon as an effective platform alternative enters the market (Van Alstyne, Parker and Choudary 2016).

The present research evidence from platforms in the B2B market is very limited. The aim of this thesis is to fulfill this gap by examining the existing software solutions for the management of the smart, connected products in an industrial context. Later in this thesis, these tools will be referred to as Industrial Internet of Things (IIoT) software solutions. Based on the purpose of the study, two research questions were formulated as follows:

- *Which purpose do the existing IIoT software solutions serve?*
- *What kind of actions are required to turn the existing IIoT software solutions into platforms?*

The research questions were addressed with three qualitative case studies. Relying on the diverse case selection method, the following solutions were chosen for closer inspection: Siemens MindSphere, IBM Watson IoT and GE Predix. The selected cases differ in terms of the main industry and location of the software provider and the launch year of the software. These attributes further explain the elaboration of the case solutions and their positioning in the IIoT market. The case solutions were examined by analyzing their general design as well as publicly released use cases from the manufacturing industry. Data was collected from multiple sources entailing secondary data and interviews with industry experts.

Based on the findings, the thesis concludes that the IIoT software industry is still in its early phases. Following Drath and Horch (2014), it is discovered that the existing software solutions are still lacking certain fundamental functionalities of the Industrial Internet and the platform business model. The findings suggest that the industrial users are mainly applying the prevailing IIoT solutions for their internal purposes and are not interested in profoundly collaborating with the other agents in the IIoT ecosystem. In addition, the IIoT solutions merely serve in a complementary role besides the other IT architecture of the industrial users. The applications built on top of the existing software solutions are mostly proprietary and customized, and the reluctance of the companies to share their data significantly slows down the innovation cycle.

The remaining part of the thesis is partitioned as follows: The second section summarizes the most substantial concepts and theories in the existing literature regarding platforms and Industrial Internet. The third section explains the methodological choices of the study, including case selection, data collection and analysis. Additionally, the section evaluates the validity and limitations of the study. The fourth section provides a general overview of the selected three cases. The fifth section presents the results of the study in two parts. The first part describes the general operating principles of the case solutions incorporating the secondary and interview data. The second part summarizes the findings from the cases by suggesting five fundamental challenges of the current IIoT industry and key actions required to solve these challenges. The sixth and final section concludes by evaluating the significance of this study for the platform literature and the IIoT industry.

2. Literature review

This literature review consists of four parts: The first section summarizes the core concepts in the platform literature and discusses the most important findings around these concepts. The second section compares various categorization methods proposed for platforms and IoT systems. The third section concentrates on platform openness and reflects on the different decisions platforms must make regarding their level of openness. The final section examines the IIoT solution architecture by presenting a few high-level models that shape the industry as a whole.

2.1 Core concepts

The core concepts of the platform literature are collected in Table 1. Additionally, Table 1 presents the most prominent subordinate concepts of the core ideas and some principal examples of the literature. All concepts are discussed in more detail in the following sections 2.1.1-2.1.4.

Table 1: Summary of the core concepts in platform literature.

Core concept	Subordinate concepts	Examples of literature
Lifecycle	Dominant design	Anderson and Tushman 1990; West and Mace 2010; Tiwana 2013
	Phase along S-curve	Utterback and Abernathy 1975; Asthana 1995; Tiwana 2013
	Diffusion among end-users	Rogers 2010; Tiwana 2013; Pon, Seppälä and Kenney 2014
Architecture	Core	Baldwin and Woodard 2009; Pon, Seppälä and Kenney 2015

Core concept	Subordinate concepts	Examples of literature
Architecture	Complements	Teece 1986; Gawer and Cusumano 2002; Yoffie and Kwak 2006; Baldwin and Woodard 2009
	Boundary resources	Gawer 2009b; Ghazawneh and Henfriedsson 2010; Kude, Dibbern and Heinzl 2012; Ghazawneh and Henfriedsson 2013; Seppälä et al. 2015; Rajala et al. 2018
Multi-sidedness	Network effects	Rochet and Tirole 2003; Evans 2003; Cusumano 2010a; Tiwana 2013; Gawer 2014; Garcia-Swartz and Garcia-Vicente 2015; Van Alstyne, Parker and Choudary 2016
Governance	Decision rights	Tiwana, Konsynski and Bush 2010; Tiwana 2013; Hein et al. 2016; Mattila and Seppälä 2017
	Control	Tiwana, Konsynski and Bush 2010; Tiwana 2013
	Pricing	Rochet and Tirole 2003; Van Alstyne, Choudary and Parker 2016

2.1.1 Platform lifecycle

Product lifecycle explains the series of changes which follow the product from its introduction to its demise or merge with another related solution (Terzi et al. 2010). Product lifecycle has been studied widely in the product lifecycle management (PLM) literature which examines among others the appropriate strategies for the different phases of the product lifecycle, the suitable models for the management of product related information and the environmental impact of various products (see e.g. Rink and Swan 1979; Sundarsan et al. 2005; Pfister, Koehler and Hellweg 2009). The lifecycle concept is not only limited to products but can also be extended to entire business ecosystems (Rong et al. 2013). From the platform perspective, the lifecycle of the product and the ecosystem around it can be described with three dimensions: emergence of a dominant design, stage of technological evolution, and diffusion among end-users (Tiwana 2013, p. 24-31). Together, these dimensions help platforms to evaluate their current phase and choose the most appropriate strategies.

The idea of the emergence of a dominant design is grounded on the cyclical theory of technical change (Tiwana 2013, p. 24). According to this theory, the emergence of a dominant design is typically preceded by an era of technological innovation and multiple alternative solutions. The alternative solutions compete against each other until the technical or market superiority of one solution supersedes the other solutions and a dominant design emerges. The settlement of the dominant design is then followed by a period of incremental improvements. At some point, the time of incremental improvement is interrupted by the next remarkable technical breakthrough which is known as 'technical discontinuity'. (Anderson and Tushman 1990) In certain industries, the novel platform solutions have already led to significant procedural transformations which have later turned into industry standards. For instance, the introduction of Apple's iPhone completely changed the dynamics of the mobile phone business and defined the new industry standard for the upcoming years (West and Mace 2010).

The technological evolution of a platform consists of four stages: introduction, ascent, maturity and decline (Tiwana 2013, p. 27- 28). These stages can be illustrated by an S-shaped curve in which the technological progress grows slowly in the introduction phase, accelerates in the ascent phase, stabilizes in the maturity phase and starts to decrease in the decline stage. As the technology approaches the maturity stage, the marginal return on investments in research and development (R&D) begins to diminish

(Asthana 1995). Therefore, starting from the maturity phase, companies should direct R&D resources to an increasing extent to completely novel solutions instead of incrementally improving the existing ones.

Technological evolution relocates the focus of innovation from the product itself to the production and delivery processes around it (Utterback and Abernathy 1975). In the early stages of an R&D project, much of the resources are consumed by the technical development of the product. The advancement of the technology releases more resources to the development of supplementary services. One explanation for the shift is that innovation is driven by the market requirements at the beginning, but later development is defined by the competition on a market which has already met the initial price and performance requirements of the users (Adner and Levinthal 2001).

End-user diffusion can be described by dividing the potential end-users into five groups: innovators, early adopters, early majority, late majority and laggards (Rogers 2010, p. 22). New technologies spread first within the greatly cognizant and uncertainty-tolerant group of innovators, and only later reach the more risk-averse majority. The majorities constitute the largest mass of potential users which means that by the time the end-user diffusion reaches the laggards, approximately 85 percent of the potential adopters are already utilizing the technology (Tiwana 2013, p. 31). To accelerate the end-user diffusion, incipient solutions can try to benefit from the user-base of more established solutions by integrating the new services to the existing ones (Pon, Seppälä and Kenney 2014).

2.1.2 Platform architecture

The architectural models for platforms are based on the idea of modularity which refers to ‘the degree to which components of a system can be designed, operated, and changed independently of each other’ (De Weck, Roos and Magee 2011). Modular architectures enable the platforms to react quickly to changes in the operating environment but correspondingly, require more rigorous planning than monolithic systems (Tiwana 2013, p. 95-106). Modular structures allow the platforms to launch the initial functionalities faster than traditional software products, as the systems do not need to be fully complete from the beginning and additional features can be added later. Ultimately, modularity facilitates the management of complexity and fluctuation which are both evident challenges in the operating environment of many platforms (Baldwin and Clark 2000, p. 64).

The modularity of a platform architecture is typically implemented by dividing the system into core components and complements (Baldwin and Woodard 2009, p. 19; Gawer 2014). Core components constitute the foundation of the platform, whereas the complements construct the more advanced functionalities. A common example of the platform core is the Apple iOS operating system which enables the booting of the mobile device and provides the basic infrastructure for the development of supplementary applications. Third-party applications constitute the key complements of the Apple iOS platform, and the distribution of these complements is enabled and supported by the App Store service.

Core components are determined by the most significant activities, i.e., the core interactions which the platform is designed to serve (Van Alstyne, Choudary and Parker 2016, p. 38-44). These core interactions attract the participants to the platform, as they provide solutions for problems which have not been solved at all in the past or have been solved less effectively. The core components have a low degree of variety and a long lifecycle and therefore, are reusable in multiple applications (Baldwin and Woodard 2009, p. 19). The long lifecycle of the core components ensures the compatibility of the complements in the long term.

The platform core can also be understood as a ‘bottleneck’, as the core components influence the operations of all platform agents and the complements are considerably dependent on these features (Jacobides, Knudsen and Augier 2006; Pon, Seppälä and Kenney 2015). The bottleneck perspective is particularly relevant in circumstances in which the core features require significant investments in R&D, leading to high switching costs and barriers of entry (Pon, Seppälä and Kenney 2015). In these circumstances, the bottleneck is typically controlled by a limited group of agents which aim to control the mobility of other agents between similar solutions (Jacobides, Knudsen and Augier 2006). The core components and the positioning of the bottleneck may however change over time, as novel technologies and solutions change the power distribution in a certain environment (Pon, Seppälä and Kenney 2015).

Platforms are of little value as sole products and complements therefore establish an integral part of the platform business (Gawer and Cusumano 2002). The core components are designed to provide services to a wide range of customers, whereas complements finalize the offering for special market niches. The variety among complements is high, as they serve the individual needs of the platform users (Baldwin and Woodard 2009, p. 19).

Understanding the business model of the complements is essential for the owner of the platform core, as the quality of the components has a considerable effect on the success of the platform (Yoffie and Kwak 2006). Bad quality of complements will not satisfy customer needs and may entirely drive them away from the platform. On the other hand, from the complementor perspective, the reputation of the platform as well as its ability to provide integrated systems constitute the most important motives for complementors to partner with a certain platform (Kude, Dibbern and Heinzl 2012).

The owner of the platform core must consciously decide what kind of relationships it forms with the external complementors and how collaborative or competitive it wants to be with them (Cusumano and Gawer 2002). The owner can for example participate in the complement market by creating its own complements or alternatively leave the development of complements completely for third parties. By investing in its own complements, the owner of the platform can develop examples of possible solutions and inspire external creators. The creation of complements can also build protective barriers which prevent external companies from achieving a dominant position on the key application areas (Pisano and Teece 2007). On some occasions, the platform owners might even be forced to invest in their own complements if the complements can relatively effortlessly imitate their innovations and would therefore have the opportunity to collect the largest profits (Teece 1986).

The core and the complements are connected to each other via interfaces (Baldwin and Woodard 2009, p. 19; Tiwana 2013, p. 98) which specify how these two interact and exchange information (Tiwana, Konsynski and Bush 2010). The interfaces act as a bridge between the two main elements, and similarly as lanes define the direction of the traffic on a highway, the interfaces determine the rules of interaction between the main components. Interfaces also help to hide the complexity of the system by abstracting some of its functionalities (Baldwin and Clark 2000, p. 64) which facilitates the independent work of the different parties.

In some parts of the literature, interfaces are known as 'boundary resources' (see e.g. Ghazawneh and Henfriedsson 2013, Seppälä et al. 2015) which consist of social and technical aspects. The social boundary resources contain for example the formal agreements between the owner of the platform core and the complementors, whereas technical boundary resources incorporate the software development kits (SDKs) and application programming interfaces (APIs) (Ghazawneh and Henfridsson 2010). APIs are tools which enable software developers to use the features of the platform without profoundly familiarizing themselves with the operating logic of the system (Tiwana 2013, p. 112). These tools shortly describe how the API functions, i.e., what kind of values are needed as an input and what kind of values can be expected as an output. SDKs extend the functionalities of APIs, providing an extended set of function libraries, documentation and sample codes.

2.1.3 Multi-sidedness and network effects

Platform ecosystems primarily consist of four groups: platform owners, platform providers, complementors and users (Van Alstyne, Parker and Choudary 2016). Platform owners control the intellectual property of the platform and dictate who is allowed to enter the platform. Platform providers, on the other hand, deliver the embodiments of the platform. For example, Google is the owner of the Android platform, but the platform providers include multiple suppliers which produce Android based mobile devices, such as Samsung and Sony. Complementors, as the name suggests, produce the complements on the platform and complete the platform offering. Ultimately, users consume the value created on the platform and define the original needs for the services. The key players of the platform ecosystem and their relationships are collected in Figure 1.

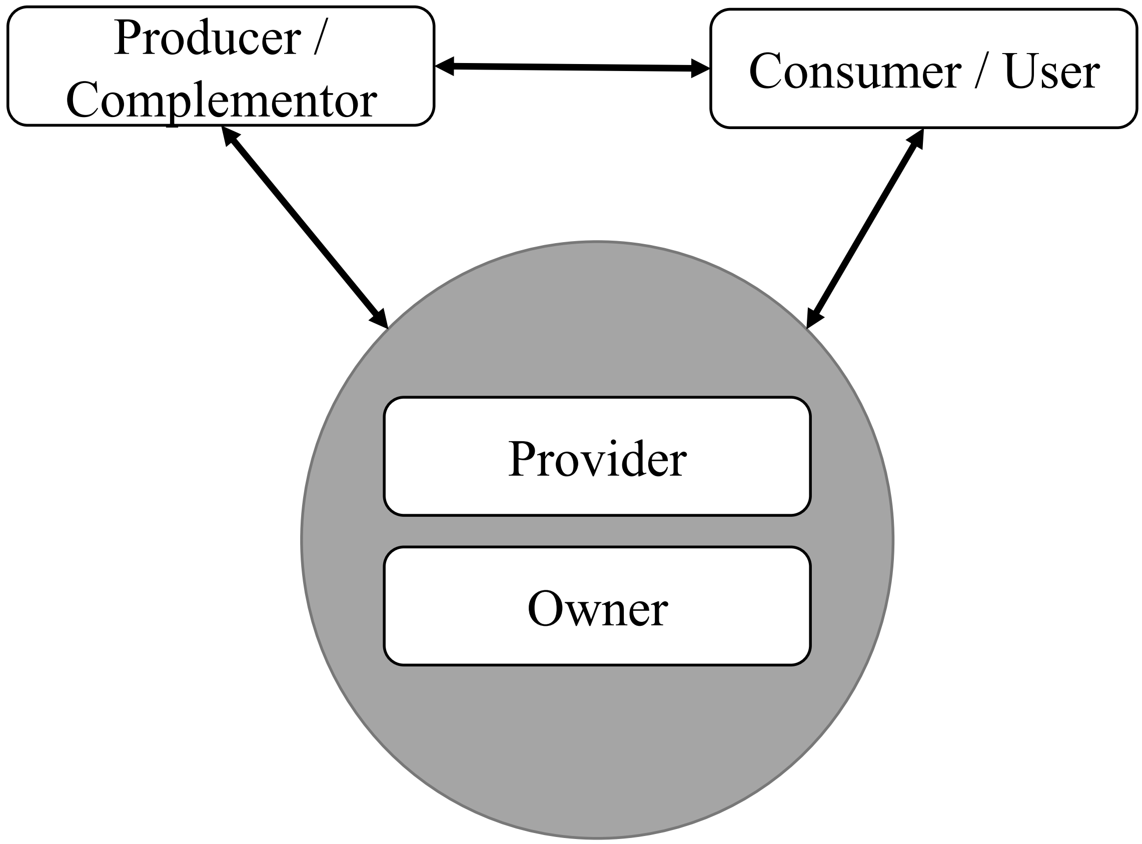

Figure 1: Platform ecosystem players (adopted from Van Alstyne, Parker and Choudary 2016).

Platform ecosystems form multi-sided markets which differ considerably from traditional buyer-supplier relationships (Hagiu and Wright 2015; Hagiu 2014). In traditional business models, the roles of the supplier and the customer are apparent and discrete. On platforms, the roles of the platform agents may alternate in different situations (Van Alstyne, Parker and Choudary 2016). For example, the subscribers of YouTube can act both as content providers (complementors) and consumers of the content (users). Similarly, the owner or provider of the platform may act as the producer of some complements. The owner and provider roles can also be combined, which is the case in Apple's iPhone and the iOS operating system.

The impact that an increasing number of complementors and users have on the value of the platform is described with the terms ‘network effects’ and ‘network externalities’ (Rochet and Tirole, 2003; Cusumano 2010a; Tiwana 2013, p. 33-36; Gawer 2014; Van Alstyne, Choudary and Parker 2016, p. 16-34). These network effects can be either direct or indirect (Gawer 2014; Van Alstyne, Choudary and Parker 2016, p. 21). In direct network effects, the increase of the participants in one group accelerate the adoption of others in that same group. For instance, in social networks, the probability of an individual to join a new service increases as the number of his or her friends enrolled to the platform grows. Indirect network effects, on the other hand, arise when the increase of the participants in one group intensifies the adoption rate of the other groups. The increasing number of applications built on a certain operating system for example increases the number of users which in turn attracts more application developers to the system (see e.g. Garcia-Swartz and Garcia-Vicente 2015).

Furthermore, network effects can be divided into positive and negative network effects (Van Alstyne, Choudary and Parker 2016, p. 17) and the direction of impact depends on the situation. Positive network effects accelerate the adoption rate as the number of participants increases. Positive network effects were present in the both examples introduced in the previous chapter. Negative network effects, on the other hand, slow down the growth of the platform. Negative network effects might emerge for example if a platform owner runs out of resources to provide sufficient support for the growing number of complementors.

Indirect network effects are commonly a substantial driver of the growth of a platform. User adoption frequently requires a large base of existing complements, thus arising a ‘chicken-and-egg’ problem. The complementors are not willing to engage to the platform before it has reached a certain number of users, and in the absence of adequate complements, users are not willing to experiment with the platform (Caillaud and Jullien 2003). Getting both sides on board has been found as one of the main problems in multi-sided markets, in addition to balancing the interests of different ecosystem players (Evans 2003).

A platform must achieve a ‘critical mass’ of users and complementors to obtain traction (Ruutu, Casey and Kotovirta 2017). Critical mass is the turning point which activates the network effects when an adequate number of users or complementors have joined the platform. To reach the critical mass, platforms must first align their strategy and metrics to maximize participant adoption and consider financial targets only as a secondary challenge. The most substantial metrics for emerging platforms may include participant engagement and match quality besides the more apparent objectives of maximizing the number of users and interactions on the platform (Van Alstyne and Parker 2017).

Users and complementors can operate on multiple similar platforms if a single platform cannot fulfill all their needs. This kind of arrangement is known in the literature as ‘multihoming’ (Tiwana 2013, p. 36; Evans 2003; Rochet and Tirole 2003). Mobile application developers, for example, often build their solution on top of both Apple’s iOS and Google’s Android at the moment. Multihoming enables the users and the complementors to benefit from the best features of each solution. Simultaneously, multihoming consumes additional resources as switching between platforms is rarely completely effortless and sometimes even multiplies the amount of work required.

Positive network effects enforce a winner-takes-all type of competition. The platform market is dominated by the player who most proficiently manages to exploit the enforcing cycles of the positive network effects. As the market matures, competitive platforms die out one at a time and the barriers for new entrants increase constantly. Scholars have however identified that the winner-takes-all scenario can be avoided if the user needs are highly differentiated or if it is relatively easy for users to switch to another platform (Gawer and Cusumano 2008).

2.1.4 Platform governance

Multiple definitions for the term ‘governance’ emerge in the existing platform literature. On one hand, governance is characterized as a mechanism to manage conflict and reach consensus between different agents on the platform (Brousseau and Pénard 2007). On the other hand, governance is defined as the structure of ‘who makes what decisions about a platform' (Tiwana, Konsynski and Bush 2010). Based on these definitions, governance can be interpreted as an instrument to align the various objectives of platform agents and steer the development of the platform. In a broader context, Prakash and Hart (2003, p.2) define governance simply as the organization of collective action.

Platform governance shapes the legitimacy of the platform owner as well as the identity of the other platform agents (Gawer 2014). Governance policies determine the rules of collaboration and competition on the platform as well as the incentives that control the actions of different agents. Governance regulates both access to the platform and interactions that are completed on the platform (Hagiu 2014). Governance policies can be described by using three dimensions which consist of decision rights, platform control and pricing structure (Tiwana 2013, p. 118-131).

Decision rights are set to designate who makes the fundamental decisions about the development of the platform. These decisions include what kind of functions are built on top of the platform and how these functions are built (Tiwana, Konsynski and Bush 2010). Tiwana (2013, p. 122) labels the decisions answering the 'what' question as strategic decisions and the decisions answering the 'how' question as implementation decisions. In addition to the 'what' and 'how' questions, decision rights delineate who is responsible for each function.

Decision rights are divided among the platform agents and can be highly centralized or alternatively give more freedom to different agents. In a decentralized platform, the amount of administrative work is minimized, but the possibility of the platform owner to affect the development of the platform is weakened (Hein et al. 2016). As an extreme example of a decentralized platform, blockchain architectures follow no formal decision-making protocols, resulting in informal negotiation processes (Mattila and Seppälä 2017). The blockchain models distribute not only the governance structure but also the provision of the entire platform.

Platform control ensures the compatibility of different solutions on the platform. The control structures include output control, input control, process control and relational control (Tiwana 2013, p. 122-126; Tiwana, Konsynski and Bush 2010). Output control considers the performance of the platform agents against specified performance targets, whereas input control enforces the objectives of the platform by granting entry only for agents that fulfil certain criteria. Process control rewards or penalizes the platform agents based on their compliance on pre-described methods and procedures. Relational control, which is also referred to as 'clan control' (Tiwana, Konsynski and Bush 2010), guides the actions of the platform agents by shared norms and values.

Moreover, platform control can be considered more as the orchestration of available resources than as a sole attempt to dictate the direction of the platform (Van Alstyne, Parker and Choudary 2016). The reduced control stimulates innovation by increasing the independence and motivation of third-party complementors. In any case, control structures should be kept as simple, transparent and fair as possible to avoid excessive bureaucracy (Tiwana 2013, p. 139-141). Control structures cause additional costs which correlate with the extensiveness of the agreements governing the interaction (Anderson and Dekker 2003).

The final dimension of platform governance is the pricing structure which is closely linked to the profitability of the platform's business model. The pricing structure determines which agents are charged and for how much. The platform owner may decide to charge all platform agents equally, or alternatively subsidize some groups of agents (Van Alstyne, Choudary and Parker 2016, p. 122-125). The platform can for example provide its services free of charge for the users and collect its revenues from the advertisers which is the case in Facebook's social media platform. One alternative solution is to sell the products or services at deficit for the platform users and balance the deficits by collecting more money from the complementors. The latter tactic has been exploited for instance in the video gaming industry in which the gaming consoles are sold at a price below the production costs and the profits are made from the sales of the video games (see e.g. Rochet and Tirole 2003).

The pricing instruments may vary from charging a transaction fee to charging for the access to the platform or charging for enhanced curation of the content on the platform

(Van Alstyne, Choudary and Parker 2016, p. 115-122). Airbnb, for example, reserves a transaction fee from every booking that is made via the platform. On the other hand, many streaming services, such as Netflix and Spotify, charge a monthly fee for the access to the platform. Enhanced curation is possibly so far the least applied pricing structure, but it enables the enforcement of positive network effects by enhancing the suggestions and service the user receives.

Governance principles are realized in written agreements and laws in addition to the application of these principles in the technical and social architecture of the platforms and their pricing policies. Laws define the operating environment of the platform and may either limit or enforce the activities of the platform. In some cases, the development of new platform business models may even change the interpretation of laws or the laws themselves (see e.g. Chander 2013). Agreements on the other hand formalize the governance principles and ultimately enable the resolution of disagreements in court.

The development of governance principles starts from the analysis of the market structure, from which the governance configuration and control mechanisms can then be derived (Manner et al. 2012). The maturation of the platform modifies the most suitable governance mechanisms which forces the platform owners to review their policies from time to time. Research suggests that power-based governance is most effective in the early stages of the platform development, whereas trust-based governance takes over in the commercialization phase and contract-based governance in the roll-out phase (De Reuver and Bouwman 2012).

2.2 Platform typologies

Literature identifies two predominant types of platforms: internal or company specific platforms, and external or industry-wide platforms (Gawer and Cusumano 2014, Gawer 2009a, Ailisto et al. 2015). Internal platforms facilitate single companies to develop a stream of derivative products, whereas industry-wide platforms provide a foundation on top of which external companies can develop their own complements (Gawer and Cusumano 2014). Gawer (2009a) has created a more detailed typology of platforms dividing external platforms into three categories: supply-chain platforms, industry platforms and multi-sided markets or platforms.

In a similar manner to the platform categorization, Porter and Heppelmann (2014) have constructed their own typology for the systems operating in the world of the Internet of Things (IoT). This model has been further elaborated by Ailisto et al. (2015) to entail even larger networks of systems. A comparison of the models by Gawer (2009a), Ailisto et al. (2015) and Porter and Heppelmann (2014) is presented in Table 2.

Table 2: Comparison of platform and IoT system typologies.

Source	**Typology**
Gawer 2009a	Internal platform → Supply-chain platform → Industry platform → Multi-sided markets or platforms
Ailisto et al. 2015	Intranet: Component → Smart component → System; Extended Intranet: System of systems; Internet: Network of systems
Porter and Heppelmann 2014	Product → Smart product → Smart, connected product → Product system → System of systems

In the typology of platforms by Gawer (2009a), supply-chain platforms are still limited to a certain, pre-defined group of entities, but in comparison to internal platforms, they introduce multiple companies within the same system. Industry platforms and multi-sided markets adhere better to the most recent interpretation of platforms as the mediator between multiple agents. Industry platforms and multi-sided markets share many characteristics, including the existence of indirect network effects. However, these two categories differ by the pursuit for innovation incorporated in the platform design. In multi-sided markets, the only objective is to facilitate the exchange of value between different agents and act as a mere market place. Industry platforms, on the other hand, enable third-parties to develop their own complements to the platform by utilizing the boundary resources. (Gawer 2009a)

The model by Porter and Heppelmann (2014) divides the development of the IoT industry into five phases. First, there are physical products which are next advanced with smart components and then upgraded with connectivity components. The smart, connected products are then joined to form product systems which are further connected to a system of systems. The system of systems is commonly a cross-industry initiative which re-defines traditional industry boundaries. (Porter and Heppelmann 2014)

The model by Ailisto et al. (2015) is initiated with similar elements as Porter and Heppelmann (2014). First, there are basic components which are then upgraded with smart modules. These smart products form systems which further jointly create a system of systems and a network of systems. The first three stages take place within one firm, so they can be collectively called as the 'Intranet'. The system of systems requires collaboration between multiple companies, so it is described as 'Extended Intranet'. Finally, the network of systems is a universal platform wo which all systems are connected, thus extending our current conception of the 'Internet' with the peculiar features of IoT. (Ailisto et al. 2015)

The further platforms proceed from internal solutions to industry-wide products, the more collaboration and openness is required from the various participants of the system. An adequate level of openness enables the efficient operation of the platform and spares the platform participants from reinventing the wheel within their closed circle. Platform openness will be discussed more in detail in the following section.

In addition to the categorizations presented earlier, Jansen and Cusumano (2013) propose a classification of platforms based on their base technology (software platform, software service platform or a software standard) and the coordination structure (privately owned entity or community). This categorization provides interesting insight to the platform discussion for two reasons. First, standards are rarely considered as platforms even though they possess multiple features frequently used to define platforms. These features include positive network effects and the opportunity of third-parties to build solutions relying on the standard. Second, community-driven coordination structures represent a minority in the recent study objects of platform literature. Although successful platforms have been built for instance by the Linux community, community-based alternatives are still outnumbered by the privately-owned solutions.

2.3 Platform openness

De Reuver, Sørensen and Basole (2016) define platform openness as 'the extent to which platform boundary resources support complements'. Platforms can be open to complements in terms of two dimensions: first by not placing restrictions on who can participate in the development, commercialization and use of the platform; and second by applying consistent and reasonable rules to all platform agents (Eisenman, Parker and Van Alstyne 2009, p. 131). The second principle may concern for example the pricing policy and technical requirements of the complements.

Besides complements, platform openness involves the possibility of platform providers and users to participate in the platform and its development (Van Alstyne, Choudary and Parker 2016, p. 134-156). Platforms can control their openness with multiple strategies which can be divided into horizontal and vertical strategies (Eisenmann, Parker and Van Alstyne 2009, p. 137-150). In the horizontal strategies, platforms consider rivals that provide similar solutions. Horizontal strategies restrain the interoperability of diverse platform solutions and the possibility of cross-platform transactions (Eisenmann, Parker and Van Alstyne 2009, p. 137-143). The platform owner may for example allow its users to interact directly with the users of the competing platform or restrict the transferring of data to alternative solutions. Interoperability has been found to be one of the most significant challenges in industry software (Menon, Kärkkäinen and Gupta 2016).

Vertical openness strategies determine which functionalities the platform owner produces in-house and which functionalities it assigns for third-parties (Eisenmann, Parker and Van Alstyne 2009, p. 143-150). These vertical strategy decisions are similar to the traditional ‘make-or-buy’ choices. Before making vertical decisions, the platform must prudently consider which functionalities belong to its own core competences and which functionalities can be supplied more efficiently by third-parties. With vertical strategies, the platform owner may for instance aim to restrain some functionality under its own discretion.

Platform openness is not a black-and-white decision, but instead a continuum between openness and closeness (Van Alstyne, Choudary and Parker 2016, p. 131). The platform owner must find an adequate balance between the two extremes which best supports the development of the platform. Maximizing the openness does not automatically lead to the best outcome, as it limits the control power of the platform owner (Parker and Van Alstyne 2017). The adequate balance between openness and closeness must be obtained in terms of all platform ecosystem players, ranging from platform users and complements to competing platforms.

Increasing the level of openness has been discovered to have several positive impacts on the development of a platform. First, the increasing openness positively affects the speed of innovation on the platform (Boudreau 2008). Open interfaces facilitate platform adoption among complements which leads to positive indirect network effects (Ruutu, Casey and Kotovirta 2017). Finally, platform openness reduces the users’ concerns regarding platform lock-in and stimulate the production of differentiated services which better meet the user needs (Eisenmann, Parker and Van Alstyne 2009).

The increasing level of openness also generates certain disadvantages. Openness may increase the perceived risks among platform participants and lead to a less secure platform (Hein et al. 2016). As the number of participants increases on the platform, it becomes more difficult for the participants to build trust to other agents, thus increasing the perceived risk. Additionally, platform growth complicates the quality control of complements which may compromise the security of the platform in the long run. Even though openness enhances the transparency of the platform, it simultaneously reduces the power and control of the platform owner (Hein et al. 2016).

Cloud computing and software as a service (SaaS) are gaining momentum in enterprise computing, but these solutions can grow into industry-wide platforms only if companies open their technologies to other players (Cusumano 2010b). When evaluating the degree of openness of a platform solution, open access to data and information is one of the key variables (Menon, Kärkkäinen and Gupta 2016). The openness of data has an immensely important role in the novel IIoT systems, as the amount of data produced by the smart, connected products is completely unprecedented. In this new era of mass data, companies must reconsider how they manage data rights, access and security (Porter and Heppelmann 2015).

2.4 IIoT industry structure

Industry architecture determines the positioning of the companies within that industry and how these companies operate with each other. The architecture of an industry is often determined by the architecture of the products and services the industry is producing (Baldwin and Clark 2000, p. 1). For example, the computer industry has been historically organized in a 'vertical' architecture, in which each company produces all elements of the computer from physical components to operating systems and applications (Baldwin and Clark 200, p. 6-10). The emergence of personal computers has however shifted the industry architecture to a more 'horizontal' model, in which the companies specialize in only one or a few layers of the computer architecture (Pisano and Teece, 2007).

To describe and analyse the IoT industry, Porter and Heppelmann (2014) suggest a technology stack which is presented in Figure 2. The core elements of the IoT industry stack are the smart products and product cloud as well as connectivity components which combine the first two. The core elements are further linked to identity and security services, external information resources and other business systems. To function effectively, IoT systems require the interplay of multiple agents. These agents include physical product manufacturers, connectivity providers, suppliers of data storage, application developers and the suppliers of other business systems, such as enterprise resource planning (ERP) system providers. The competitive positioning of each company in the industry is determined by the choice of layers in which they are operating in the stack.

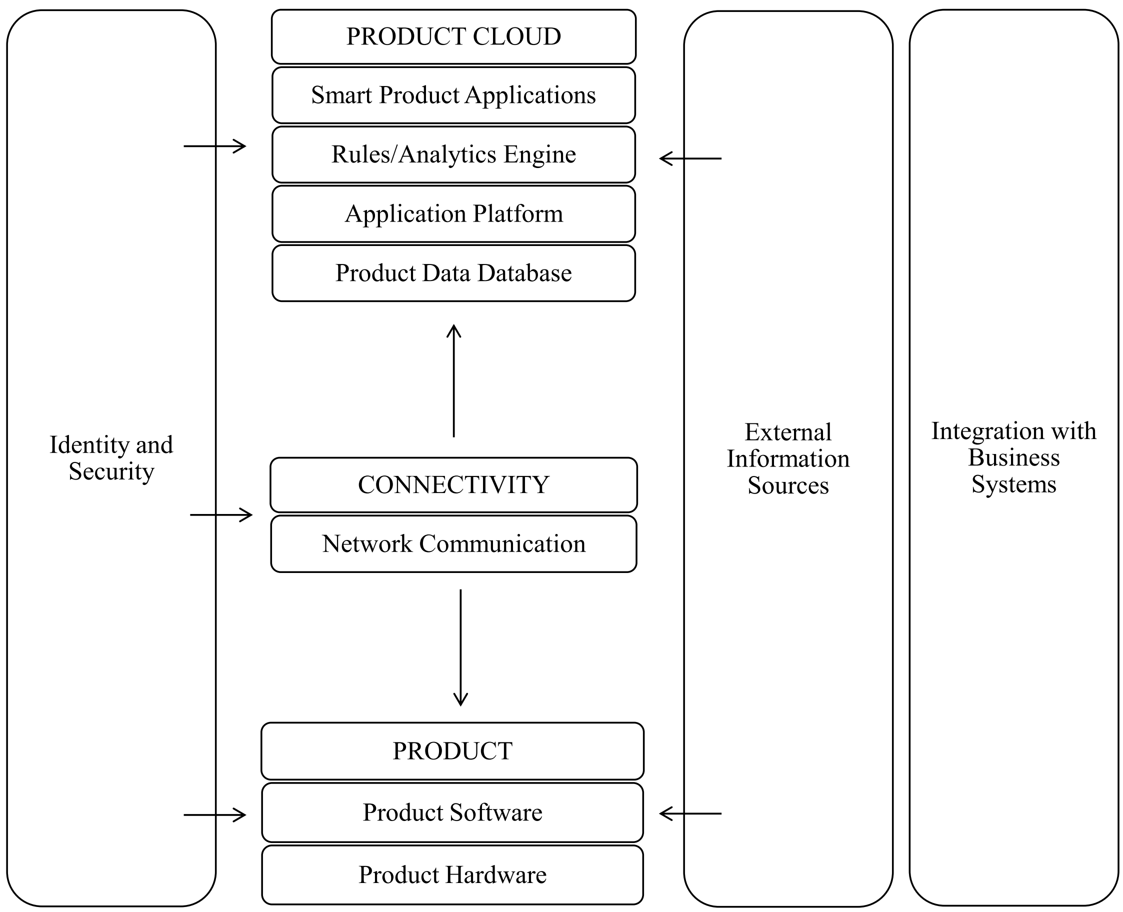

Figure 2: IoT industry stack (adopted from Porter and Heppelmann 2014).

The IoT industry stack is complemented by the more detailed reference architectures. Industrial IoT systems are a subsection of the IoT industry as a whole, and the peculiarities of the IIoT systems are considered in the reference architectures developed specifically for this subsection. Industrial Internet Consortium (IIC) maintains a version of the IIoT industry architecture which is often referred to in industry publications. The IIC reference architecture consist of four viewpoints, each of which emphasizes the needs of different stakeholders. In addition, the architecture identifies a three-tiered structure of an IIoT system, comprising of the edge, the platform and the enterprise tiers (Industrial Internet Consortium 2017). Compared to the model by Porter and Heppelmann (2014), the IIC reference architecture separates the enterprise tier into its own entity, whereas the IoT industry stack spreads it within several layers.

Kenney and Pon (2011) suggest a more simplified version of an industry structure for the smartphone industry. The model is portrayed in Figure 3, and it is based on the distinct technological layers of a smartphone. The smartphone industry stack consists of the physical components (handset), the mobile operating system (OS), the native apps which run on the mobile device, the storefront for third-party applications, and the other online services (Kenney and Pon 2011). A similar, more simplified model could also be adapted to the IIoT industry.

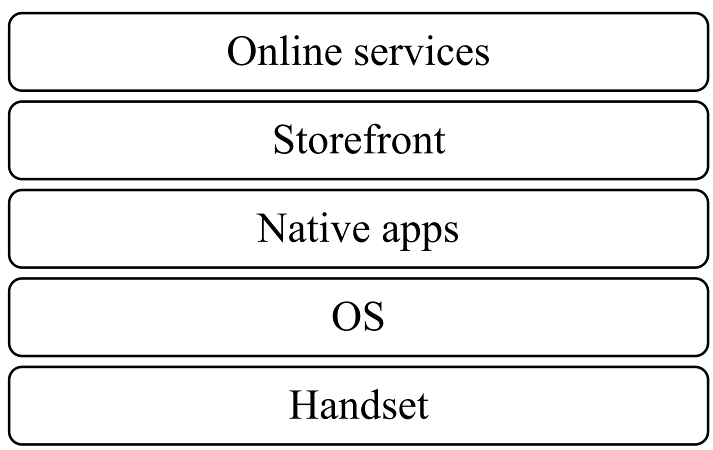

Figure 3: Smartphone industry structure (adopted from Kenney and Pon 2011).

Industry architectures and high-level models can be utilized to determine where different platform agents capture value and lock in customers (Kenney and Pon 2011). Customer lock-in refers to the arrangements which encourage platform agents to stay on the platform in question and not to switch to alternative solutions. Customer lock-in may be either coercive or value-driven (Tiwana 2013, p. 37). Coercive lock-in is grounded on the technical barriers which complicate the platform switch and increase the switching costs. On the contrary, value-driven lock-in is based on the unique capability of a certain solution to satisfy customer needs.

3. Methods

This study was conducted as a qualitative case study. The case study method is particularly suitable for novel topics where the lack of existing literature necessitates an innovative and fresh approach (Eisenhardt 1989). The objective of this study was to review the current state of the IIoT solutions from the platform perspective. Although the existing literature on platforms is extensive, the IIoT solutions have entered the field fairly recently. Therefore, the application of the case study approach is well justified.

Case studies have been found to be suitable in the information systems (IS) field for several reasons. First, they enable the observation of the topic in a natural setting which leads to theories that are drawn from practice. Second, case studies help to understand the true nature and complexity of the research object by answering 'how' and 'why questions. Third, the rapid pace of change in the IS field is constantly producing numerous new research topics, which necessitates a method suitable for unexplored areas. (Benbasat, Goldstein and Mead 1987) IIoT systems are a subcategory of the IS field which further supports the selection of the case study methodology.

Qualitative research is based on four philosophical assumptions concerning ontology, epistemology, axiology, and methodology. The ontological assumption suggests that every viewer has a subjective perception of the nature of reality which the researcher then attempts to report for instance by using the actual words of the research participants. The epistemological assumption encourages researchers to minimize the distance between themselves and the participants so that they can become as close to an 'insider' as possible. The axiological assumption acknowledges that qualitative research is susceptible for the bias of the researcher and recommends researchers to openly consider their values and assumptions. Finally, the methodology in qualitative research is very much grounded on inductive reasoning in which the theories are developed bottom up from data instead of relying on preliminary hypotheses. (Creswell 2018, p. 19-21)

Qualitative case studies are frequently perceived as a less scientific method than quantitative research. The opponents of the case study methodology claim that case studies are merely verifying the researcher's preconceived impressions instead of objectively building theories from the emerging data. Even though the researcher bias is a valid concern, it can be remediated with appropriate methods. (Flyvbjerg 2006) The following sections explain in more detail the case selection, data collection and analysis methods applied in this study. In addition, section 3 is concluded by considering the methodological limitations of the study.

3.1 Case selection

The number of companies providing IoT software solutions has been constantly rising in recent years. From 2015 to 2017, the number of IoT solution providers has been reported to grow from 260 to 450 (Williams 2017). Even though only a small subset of IoT solutions are utilized in the industrial context, the trend seems to be the same for the industrial solutions as well.

Table 3 presents the most remarkable IIoT solutions and their providers. The solutions have been selected to Table 3 based on their acknowledgement in the recent IIoT industry reports (Crook and MacGillivray 2017; Pelino and Hewitt 2016). In addition to the companies recognized in these reports, two recent entrants have been added; Google and Siemens to be exact. As it can be seen from Table 3, most of the IIoT software solutions have been launched after the publication of the Industrial Internet report by General Electric in 2012. The pace at which new solutions have been introduced has further accelerated over the past few years.

Table 3: IIoT industry overview

Company	Location	Industry	Software solution	Software launch
Amazon	U.S.	E-commerce	AWS (Amazon Web Services) IoT	2015
Ayla Networks	U.S., Silicon Valley	IoT Software	Ayla IoT Platform	2013
Bosch	Germany	Conglomerate	Bosch IoT Suite	2016
Cisco	U.S., Silicon Valley	Communications infrastructure	Cisco Jasper Control Center	2004, acquired by Cisco in 2016
Exosite	U.S.	IoT Software	Murano	2016
Fujitsu	Japan	IT Infrastructure	Fujitsu Cloud IoT Platform / Enterprise Cloud Service K5 Ecosystem	2015
General Electric (GE)	U.S.	Conglomerate	Predix	2013, opened for public use in 2015
Google	U.S., Silicon Valley	Internet search	Google Cloud IoT	2017 (beta, no general release)
Hewlett Packard Enterprise	U.S., Silicon Valley	IT Infrastructure, Enterprise software	HPE Universal IoT Platform	2016
IBM	U.S.	IT Infrastructure, Enterprise software	Watson IoT	2015, predecessor IBM Internet of Things Foundation launched in 2014
KaaIoT Technologies	U.S.	IoT Software	Kaa IoT	2014 (beta, no general release)

Company	Location	Industry	Software solution	Software launch
LogMeIn	U.S.	Enterprise software (remote services)	Xively	2013
Microsoft	U.S.	Software (OS and office tools)	Azure IoT Suite	2015
Oracle	U.S., Silicon Valley	Enterprise software (databases)	Oracle IoT	2016
PTC	U.S.	Enterprise software (CAD/PLM)	ThingWorx	2011
SAP	Germany	Enterprise software (ERP)	SAP HANA Cloud Platform for the IoT	2015
Siemens	Germany	Conglomerate	MindSphere	2016 (beta, no general release)
Zebra Technologies	U.S.	IT Infrastructure, Enterprise software (barcode & RTLS)	Zatar	2013

Each company operating in the IIoT field has its unique approach to the IIoT business which is linked to the main industry in which the company primarily operates. The companies exhibited in Table 3 can be divided roughly into four categories based on their primary industry. These categories are conglomerates, enterprise software companies, IT infrastructure companies and others. Conglomerates derive their main advantage in the IIoT software market from their prolonged experience in manufacturing. On the contrary, enterprise software and IT infrastructure companies are more familiar with the provisioning of software products. Enterprise software companies form the largest category in Table 3, but their core competences vary substantially, ranging from ERP systems to computer-aided design (CAD). The IT infrastructure providers are specialized in computing and connectivity devices which are often combined with reasonable software capabilities. The ‘others’ category consists of a miscellaneous selection of companies ranging from start-ups solely focusing on IIoT software to large corporations concentrating on e-commerce or Internet search.

The location attribute suggests that the development of IIoT solutions is exceedingly centralized in two countries, the U.S. and Germany. The ecosystem around mobile Internet is particularly strong in Silicon Valley in the U.S which appears to carry this area and the country as a whole to the era of smart, connected products as well. Germany, on the other hand, has actively pushed its profile as one of the leading countries in the IIoT industry with the Industrie 4.0 initiative. The initiative is supported by the German government and the objective is to promote the deployment of decentralized, autonomous production in various types of manufacturing companies (Germany trade and invest 2017).

Besides the multitude of solutions listed in Table 3, a number of IIoT solutions have been built to serve exclusively a particular company or a restricted industry. For example, Tesla has developed an internal end-to-end system for the servicing and updating of their products (Lambert 2016). Although these internal systems are developed for the management of smart, connected products, they are not within the scope of this study, as they are not aiming to become universal solutions.

From the list presented in Table 3, three cases were selected for closer inspection for the purpose of this thesis: Siemens MindSphere, IBM Watson IoT and GE Predix. The cases were chosen by using the diverse case selection methodology which aims to maximize the variability among relevant attributes and is thus suitable for exploratory research (Seawright and Gerring 2008; Flyvbjerg 2006). The relevant attributes considered in this study were the main industry and the location of the IIoT software provider as well as the launch year of the software. These attributes explain the historical trajectory of the IIoT software solutions which consecutively impacts the current state of these solutions. The relevant attributes of the selected three cases are compiled in Table 4.

Table 4: Key attributes of the selected cases

IIoT Software Solution	Main industry	Location	Software launch
Siemens MindSphere	Conglomerate	Germany	2016
IBM Watson IoT	IT Infrastructure	U.S.	2015
GE Predix	Conglomerate	U.S.	2013

The variability of the selected cases is difficult to determine quantitatively, as the 'main industry' and 'location' attributes are categorical and the final 'software launch year' attribute is quantitative but discrete. However, the variability between cases can be evaluated qualitatively by comparing the combinations of relevant attributes. As Table 4 demonstrates, the full combination of the three relevant attributes differs in all three selected cases. Additionally, the combinations vary across all instances if the relevant attributes are compared in pairs. The variability of one attribute could still be increased for example by including cases from the other main industry groups, but this would most likely decrease the variability of the sample across all three attributes.

3.2 Data collection and analysis

The data for this thesis was collected from multiple data sources to ensure the comprehensiveness of the data. Multiple data collection methods are common in case studies, as they enable triangulation between different sources (Eisenhardt 1989; Benbasat, Goldstein and Mead 1987). The credibility of the constructed theory increases, as the results are supported by multiple data sources. In addition, a larger volume of data is generally reached by multiple data sources compared to a single source.

The data sources of this study consisted of publicly available secondary data and interviews with IIoT industry experts. Even though secondary data is rarely used in the case study setting in the IS field, it enables access to a large volume of data which is seldom available via other qualitative methods (Ghazawneh and Henfridsson 2013;

Romano et al. 2003). The secondary data was gathered from six primary resources: press releases and news posts of the case companies considering their IIoT software solution; service descriptions and terms of use of the software solutions; annual reports of the case companies; posts in IIoT developer forums; keynotes and speeches from the case company officials; as well as interviews and online articles regarding the case solutions.

The interviews with IIoT industry experts included interviews with case company representatives and a few complementary interviews with other relevant players of the IIoT industry. The interviews were conducted in the period from June to August 2017, and the duration of each interview was approximately an hour. The full list of interviewees is presented in Appendix A, and the interview questionnaire template is introduced in Appendix B.

Data analysis was highly integrated into the data collection which is common practice in case studies (Eisenhardt 1989). The data was processed immediately after it was received, which further directed the subsequent data collection to fulfil the remaining gaps. The data processing resulted in extensive notes including the most important findings from both secondary sources and the interviews. The data collection phase was finished when the new data started to overlap with the formerly obtained information. After the data collection phase, the final results of the study were composed by comparing the material across the various cases. These results were then compared with the principles of the platform literature summarized in section 2 which were further derived into fundamental challenges of the IIoT industry presented in section 5.2.

3.3 Limitations of the study

The applied methodology and the limited resources of the study incur a few limitations to this research. First, the number of cases selected is rather small which makes it more difficult to obtain a representative sample. Second, the chosen case selection methodology considers only three relevant attributes which might not fully represent the variability between cases. Unsuccessful selection of cases might distort the results and lead to false conclusions. Third, the large volumes of data may result in overly complex theories, or alternatively, the bottom up approach typical for case studies may produce overly simplistic theories (Eisenhardt 1989).

To overcome the first two limitations, more extensive research is required to confirm the results of this study. The exploratory methods applied in this study must be replaced with more suitable methods for the confirmation of hypotheses (Seawright and Gerring 2008). The first part of the third limitation is guiding the theory building process, aiming to produce as simple theory as possible without limiting the representativeness of the theory. The second part is mitigated by associating the results of this study with the general theories about platforms and enterprise software. The objective of this study is not to produce a completely novel theory, but to support the existing one by providing an IIoT perspective.

4. Case overviews

The following three sections present a general overview of each selected IIoT software case and the companies providing these solutions. At present, the IIoT solutions seem to have an integral role in the overall business of the solution providers across all cases. In the future, the IIoT software solutions are predicted to bring an even more significant proportion of the companies' revenues which can be noted for instance from the frequent references to these solutions in the annual reports of the companies. Figure 4 summarizes the number of entries of each case software in the annual reports of the particular company. From Figure 4, it can be noted that the hype around the IIoT solutions seems to have steadied for the more experienced players (IBM and GE), whereas Siemens is still building traction as the most recent entrant.

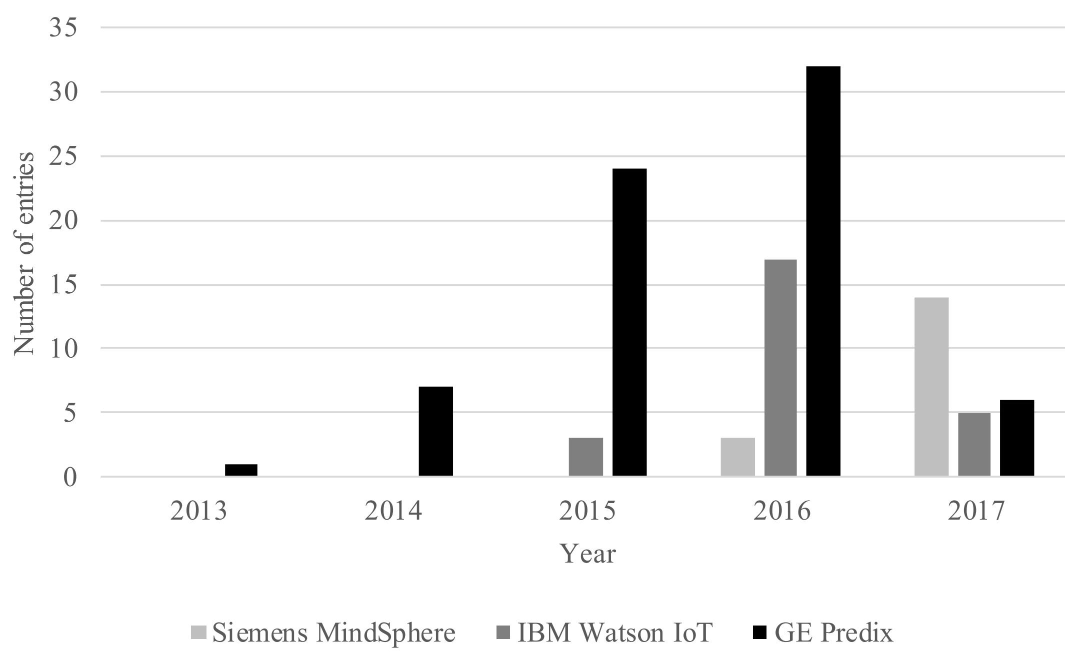

Figure 4: Number of entries in annual reports

4.1 Siemens MindSphere

Siemens is a German conglomerate operating in almost all countries of the world. The company was established in 1847 to serve the telegraph industry, and the current main industries consist of energy, building technology, mobility, production technology and healthcare. In September 2017, the company employed approximately 372 000 people, generating slightly under 85.7 billion euros of revenue and 6.2 billion of net income in the fiscal year 2017 (Siemens 2017a).

The MindSphere offering was launched by Siemens in 2016 as a closed beta for a limited selection of industry partners. The beta phase was terminated at the end of summer 2017 when the access to the software was opened for the general public. The MindSphere solution consists of three layers: MindSphere, MindApps and MindConnect. MindSphere is the operating system which provides the various tools and interfaces for the distinct applications. MindApps, on the other hand, are the applications designed by Siemens and its nearest partners which enable the transformation of data collected from smart products into knowledge and business insight. The MindConnect layer facilitates the secure data communication between MindSphere and the smart products.

4.2 IBM Watson IoT

IBM, an abbreviation from International Business Machines Corporation, was founded in the U.S. in 1911. In the past, the company has produced various products from hardware to software for the computer industry, but during the last couple of years, it has fixed its principal focus on cloud computing and cognitive solutions (IBM 2018). IBM is well-known for its R&D capabilities which have led the company to earn the most patents in the U.S. for the past 25 consecutive years. In terms of size, IBM is relatively similar to Siemens. In fiscal year 2017, the company employed approximately 367 000 employees, turning over 79.1 billion dollars in revenue and nearly 5.8 billion dollars in net income (IBM 2018).

IBM Watson was originated from a project which aimed to develop a software that could beat the human champions in the Jeopardy! quiz show. The development of the software was initiated around 2007, and the original goal was reached in 2011. After its victorious introduction in the quiz show, IBM realized that the cognitive capabilities of the Watson solution could have various applications in other fields as well. The current application areas range from healthcare and research to finance and retail. An example of such an application is Watson Oncology which was developed in collaboration with the Memorial Sloan Kettering Cancer Center. Watson Oncology helps doctors to find the best cancer treatment options and personalize the treatment for each patient with the help of Watson's cognitive solutions.

In 2014, IBM launched a new unit called IBM Watson group to coordinate the development and commercialization of cloud-based cognitive solutions within the company. At the same time the company decided to invest over one billion dollars to the new unit. A tenth of the investment is directly targeted to the establishment of an entrepreneur and partner ecosystem around Watson. At present, the cognitive capabilities of Watson consist of vision, speech and natural language recognition.

IoT solutions were officially integrated to Watson in 2015 as IBM introduced the Watson IoT unit to 'bring the power of cognitive to the challenge of extracting and analysing data embedded in intelligent devices for real time' (IBM 2016). The Watson IoT unit was a successor of the IBM Internet of Things foundation which had started the development of IoT solutions at IBM. At present, the Watson IoT business is centred in Munich which belongs to the most notable hub cities within the IoT field.

4.3 GE Predix

GE was established in 1892 in the U.S. to provide diverse products to the electricity and lightning industry. At present, the company has grown into a massive global conglomerate, the main industries of which include aviation, transportation, healthcare, energy, current and lighting, as well as financial services. In 2017, the company generated approximately 122.1 billion dollars in revenues, but ended up reporting a total loss of 5.8 billion dollars (GE 2018). The GE businesses are operated internationally by over 313 000 employees.

GE Predix was originally launched in 2013 as an internal solution to collect and analyse the data produced by GE products. In the first years, the company announced to invest

300-400 million yearly to the development of the environment, and within the first year alone, the company managed to create over 120 new applications to the Predix environment (GE 2015). In 2015, GE decided to release the software for general use and for products from any manufacturer.

GE has announced that it intends to belong to the top 10 software companies in the world by 2020 (Winig 2016). In order to achieve this goal, the company established the GE Digital Unit in 2017 and is vigorously hiring new software talents. Predix and the other digital solutions are expected to open doors to completely new businesses for GE (Hardy 2014).

5. Results

This section consists of two parts, each of which are designed to address one of the research questions presented in the introduction of the thesis. The first section, section 5.1, examines the purpose of the existing IIoT software solutions by presenting their general operating principles. The second section, section 5.2, studies the actions required to turn the existing IIoT solutions into platforms by reviewing the most notable conflicts between the case solutions and the platform literature. From these conflicts, a number of challenges are identified, and concrete actions are suggested to overcome these challenges.

5.1 General operating principles of IIoT solutions

The next six subsections focus on the findings of the study considering the general operating principles of the case solutions. These subsections are composed as follows: The first section describes the basic features provided by the IIoT solutions, and the second section defines the most common use cases of these solutions. The final four sections focus on applications, software governance, interoperability, and data management.

5.1.1 IIoT solution architecture

As discussed in the literature review section, the IIoT industry architecture consists of multiple layers. In the modern business environment, practically no company can effectively operate in all layers of the industry architecture, as the complexity of the environment is constantly increasing. Therefore, most companies are primarily specializing in a certain, well-defined set of activities which are often referred to as 'core competences' (see e.g. Hitt, Keats and DeMarie 1998). The providers of the case IIoT solutions have also chosen only certain layers of the IIoT stack they are concentrating on.

Based on the data collected, the case solutions are currently mainly focusing on four layers within the IoT industry stack presented by Porter and Heppelmann (2014). These layers include the network communication, application platform, rules/analytics engine, as well as identity and security management layers. In addition to these core layers, IIoT solutions are occasionally offering services to other layers of the stack as well. These services are however not provided as systematically as the other core functionalities. The positioning of the case solutions within the IIoT industry is presented in Figure 5 applying the IoT industry model by Porter and Heppelmann (2014). In Figure 5, the core layers provided by all case solutions are indicated with dark grey, whereas the more occasionally provided layers are portrayed with light grey.

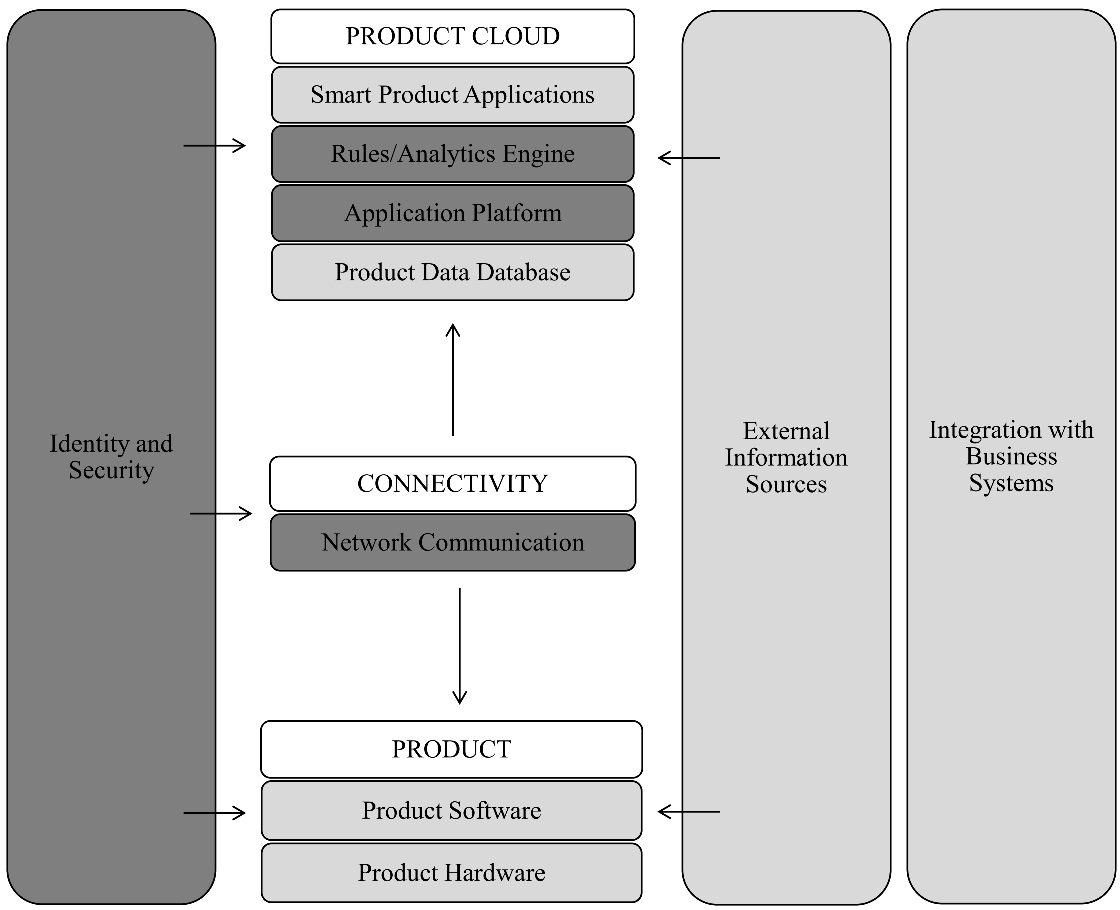

Figure 5: Implementation of the IoT stack in the IIoT industry (adopted from Porter and Heppelmann 2014).

In the connectivity layer, IIoT software solutions provide simple tools for the connection of smart products to the overall system. These connections are handled either directly or via gateways, but the connection services are mainly limited to various software tools. For example, Predix provides a connection tool that can be installed on gateways, industrial controllers and sensors. MindSphere, in contrast, makes an exception within the case solutions by providing also physical MindConnect products for the data transfer and linkage of smart products.

All case platforms have implemented the application platform layer by offering SDKs for third-party developers. These packages include tools that assist developers to build, test and run IIoT applications[1]. The technical resources are further supported by documentation and developer forums in which developers can assist each other and receive advice from the IIoT solution provider[2]. In addition to the technical resources, two case platforms support the marketing of third-party solutions by providing an open marketplace. Similarly to Apple's App Store, MindSphere and Predix offer a marketplace from which the software users can download complementary applications. Watson IoT, on the other hand, does not include a marketplace for third-party solutions. Some software extensions developed by IBM partners are added directly to the software development environment, but other than that, IBM Watson IoT does not have a direct channel for marketing complementary products.

The analytic capabilities provided by all three case solutions include basic data visualization, monitoring and analysis services. The data visualization tools enable the real time display of the data produced, whereas the monitoring services include rule functions generating exceptions and alerts when certain conditions are met. The data analysis capabilities of the case solutions are limited to only a few basic algorithms, while more advanced algorithms are typically implemented as separate applications. The applications will be examined in more detail in section 5.1.3.

---

[1] See e.g. IBM Cloud Docs https://console.bluemix.net/docs/services/IoT/index.html (retrieved May 27, 2018); MindSphere Developer Documentation https://developer.mindsphere.io/ (retrieved May 27, 2018); Predix Developer Network Documentation https://docs.predix.io/en-US/platform (retrieved May 27, 2018)

[2] See e.g. MindSphere Community General Forum https://community.plm.automation.siemens.com/t5/General-Forum/bd-p/MindSphere-forum (retrieved May 27, 2018)

The identity and security management services belong to the core features of all three case implementations. The identity management services consist of user authentication and authorization tools which control who can access certain data or software environment. Additionally, the case solutions provide instruments for data encryption and information leakage prevention. Watson IoT, for instance, provides two separate security levels from which the users can select the most appropriate for their business.

Outside of the core functionalities discussed earlier, the case solutions have chosen diverse approaches to the other layers in the stack. Starting from the data management layer, Watson IoT primarily utilizes its own IBM Cloud service, whereas MindSphere is operating on various third-party cloud infrastructures. Despite exploiting the external services for data storage, MindSphere handles the pre-processing of data independently in its own solution. The approaches of Watson IoT and MindSphere are combined in Predix which allows the users to choose either its own Predix cloud infrastructure or some other underlying public cloud service, such as Amazon Web Services.

The product layer is substantial especially for Siemens and GE, as these companies are supplying a wide variety of physical industrial products in addition to the IIoT software solutions. Siemens is piloting the MindSphere software in its mobility division by integrating its rail data tracking system to MindSphere. In the rail tracking system, an integral proportion of the data is produced by trains and railway electrification systems originally supplied by Siemens. In a similar manner, GE has developed software solutions for its mobility and energy segments that are running on top of Predix. Watson IoT, on the other hand, is more product agnostic, as the company is not providing any industrial assets directly.

Finally, the case solutions provide miscellaneous integrations to external data sources and other business systems. IBM, for example, has extended its IIoT offering with weather data by acquiring the Weather Company in 2015 (IBM 2016, p. 23). Additionally, the case solutions have built integrations to other business software, but these integrations are predominantly user specific and not commonly available. The integration and interoperability of IIoT systems with other business systems is discussed in more detail in section 5.1.5.

5.1.2 Use cases

Despite the considerable amount of IIoT software solutions on the market, the number of public reference cases of these solutions is still very limited. At the time of the interviews and data collection, all case solutions had only a few publicly released references and in many of these references, the implementation phase was still in progress. Due to the incompleteness of the implementations, most of the reference company representatives were not yet willing to give detailed interviews about how they are planning to utilize the IIoT solutions and what kind of benefits they are expecting.

Only one use case, the elevator company Kone agreed to explain their IIoT approach in more detail in an interview. Kone is currently utilizing the Watson IoT solution to collect elevator data and improve their service business. The first phase of the implementation concentrates on predictive maintenance and improving the safety and reliability of the elevators, whereas the second phase is planned to involve the cognitive capabilities of Watson IoT to optimize the flow of people in buildings (Kone n.d.).

Based on the publicly available information, the remaining use cases are also mainly focused on the collection of data at present, whereas data processing and analytical solutions are still mostly under development. In many cases, it is not financially feasible to immediately build a dedicated software solution for the analytical purposes, as the first analytical experiments can be done with simpler and already existing software tools. These simpler solutions can then be later replaced with more advanced tools if the functionalities are found valuable:

'In many cases, it depends on the readiness of the customer whether even the customer knows exactly what to do with the data and what kind of application they need. It is easier to start collecting the data, then make conclusions for example with some other tools, and finally create the application.' (Current Siemens employee)

As the previous quotation also affirms, the reluctance of industrial companies to experiment with the IIoT seems to be linked with their uncertainty of the purpose and benefits of IIoT solutions. Industrial companies may have only recently started to collect data from their products and assets and may additionally lack the capabilities to discover valuable insights from the data. The uncertainty of the purpose of IIoT solutions seems to increase towards the heavier industries, which was reported in one of the interviews as follows:

'In some industry sectors, there might be thinking that they have so far managed to get along perfectly well with the existing [systems]. If they are supplying a large industrial bearing or a valve, they do not necessarily see that selling bulk products could somehow be associated with the Industrial Internet.' (Former IIoT startup employee)

The lack of references and evidence about the benefits of IIoT makes it more difficult to convince top management to invest in new, large IIoT projects. Consequently, many companies are testing the IIoT solutions first with small experiments before engaging in considerable investments. The experiments allow companies to test the potential benefits of IIoT for that particular business in a risk-free environment:

'Proof of concept type of approach is fairly common. We make a small pilot project, demonstrate that it works, and start proceeding from there.' (Current Siemens employee)

In many cases, industrial companies end up experimenting the IIoT solutions with partners they are already familiar with and which supply some other products or services to the company. Starting with a well-known partner is convenient and less risky, as the user does not have to implement a time- and resource-consuming selection process:

'In experiments, it is easy to rely on a familiar operator. For example, if someone uses the cloud services of Microsoft, the first IoT solutions often are obtained from them as well.' (Current IBM employee)

5.1.3 Applications

In addition to internal application development, all case solutions have opened the application development for third-parties with SDKs and APIs. The total number of applications in all case solutions is still relatively small, as they provide at maximum a few hundred applications of which the majority is created by the platform owner. The most common features implemented in the applications are machine and configuration tools as well as data processing and analytics tools[3]. As discussed in section 5.1.1, a portion of the existing third-party solutions categorized as applications are merely algorithms which can perform a very limited set of tasks.

Based on the interviews, the generalizability of the IIoT applications seems to be reasonably low across different industries in all cases. At the industry level, the interviews however provide slightly contradictory statements about generalizability. From IBM's perspective, the customer needs appear to be reasonably similar within one industry which has encouraged the company to develop industry specific solutions on top of Watson IoT. These solutions are standardized products which can be adapted to the needs of a certain company with minimal changes:

'We will deliver an 80% [ready] solution. – In a certain industry, we can see that the use cases are more or less analog, no matter what is actually produced. [With these solutions,] we can diminish the amount of customization.' (Current IBM employee)

Siemens, on the other hand, has the completely opposite perspective on the industry-wide requirements. According to the interviewees, the user needs might vary considerably even between very similar companies. The company has thus chosen to principally handle the user needs as separate projects and to develop the IIoT applications according to the needs of specific users:

'If we develop an application, it is mainly customized. – Machine manufacturers have usually very different types of machines and there is something specific which the

[3] See e.g. Predix Catalog https://www.predix.io/catalog (retrieved May 27, 2018)

company wants to analyze and visualize. This requires customization at least to some extent.' (Current Siemens employee)

In some cases, the industrial users of the IIoT solutions are willing to build their IIoT applications internally, and only benefit the high-level infrastructure provided by the case systems. By participating in the development, the users can enhance their internal knowledge base and capabilities regarding the IIoT solutions and reduce their dependency on other companies:

'Very likely some customers want to develop [the IIoT applications] themselves, so that they can keep the knowledge, and the versioning and control of the software in their own hands. A very large proportion will also purchase the applications. – One must consider whether it makes sense to do them yourself or purchase them from some reliable supplier.' (Current Siemens employee)

By developing the applications by themselves, the users have more control over their quality. Quality concerns are much more significant in the industrial environment than in consumer solutions, as B2B companies are more concerned about the limitation of liabilities. The industrial companies must for example know who is liable for which damages if they allow third-party software to control the operations of their machines. Based on the data collected, the current IIoT solutions provide very limited tools for standardized limitation of liabilities, especially when third-party developers are involved in addition to the principal IIoT solution provider. Contractual terms will be discussed more thoroughly in the following section 5.1.4.

In addition to the open ecosystem of third-party developers, IIoT software solutions are forming more formal partnerships with certain companies. These partnerships are essential to supplement the shortages in internal capabilities of the case companies. Some partners are selected upfront, but some are contacted based on a certain customer need:

'In Finland, we are currently selecting the first partners. Many [partners] have joined us with customer cases. There has been a certain customer need, and then we have

considered what kind of partners could be suitable to develop the application or generate the analytics.' (Current Siemens employee)

Partners support the IIoT solutions not only by developing complements but also by collaborating to outline the elaboration of the industry as a whole. Predix, for instance, is working with Intel to optimize the co-operation of the software with the Intel processors (Hardy 2014). Watson IoT, on the other hand, has formed multiple strategic partnerships which it categorizes under applications, cloud, device, gateway, network, silicon and sensor, as well as system integrator partners (IBM n.d.).

5.1.4 Software governance

Following the division presented in the platform literature, the software governance principles are divided in this section under three categories: decision rights, formal and informal control, and pricing models. In the case solutions, the decision-making power regarding the core functionalities is principally centralized in the R&D departments of the case companies according to the interviews. The development of these functions is naturally directed by the customer needs, but the final decision-making power resides on the IIoT software provider. Especially early adopters might nonetheless affect the development of the solution significantly via feedback. Kone for instance reported in the interviews that some of its requests are now commonly available features in the Watson IoT.

Although IIoT software providers are strictly governing the development of the solutions in general, third-party developers are principally given the freedom to build their applications as they wish. Certain quality requirements are however set by the MindSphere and Predix solutions for applications which attempt to be deployed in the public market places of these solutions. Before the release in the marketplace, the applications are reviewed, and precise instructions are given for the marketing material posted in the marketplace[4]. Additionally, the IIoT software providers might recommend certain quality control processes for users which employ third-party solutions:

'Of course, if we endorse a specific agent to deliver an application for a certain end customer or machine manufacturer, we recommend that quality control is also incorporated in the process. [These processes] verify how the application is developed and how it is documented.' (Current Siemens employee)

To control the access to the IIoT solutions and the development tools, the case solutions have generated various models. Watson IoT, for example, allows anyone to experiment with the services by simply creating an account at their website. MindSphere, on the other hand, requires third-parties to fill in an application before granting them access to the developer tools. In the Watson IoT's model, third-parties can flexibly join the ecosystem whenever they want, while the MindSphere model enables the enhanced pre-selection of the developer candidates.

The access control principles are further supported by the formal agreements which regulate the relationship between the IIoT solution provider and third-party developers and set the boundaries for the usage of the solution. Many of the formal agreements are unrestrictedly available on the Internet, but they are often relatively complicated[5]. For example, in the case of Watson IoT, the agreement consists of multiple files, as there are separate agreements for the IBM Cloud development services, Watson IoT services, and multiple other services the developer wishes to use.

For the pricing, there seems to be no coherent industry practice yet, as each case company has chosen fairly different pricing models for their services. Watson IoT offers a 30-day free trial, after which the monthly pricing is based on the volume of data

---

[4] See e.g. MindSphere Operator Cockpit https://documentation.mindsphere.io/resources/pdf/operator-cockpit-en.pdf?download=true (retrieved May 28, 2018)

[5] See e.g. MindSphere Master Customer Agreement https://legal.apps.mindsphere.io/previousVersion/legal/documents/documents-aus/MSPH_MMCA_AUS_en_1.1.pdf (retrieved May 28, 2018); IBM Cloud Services terms http://www-03.ibm.com/software/sla/sladb.nsf/sla/saas?OpenDocument (retrieved May 28, 2018); Predix Customer Agreement https://www.predix.io/legal/customer-agreement-us (retrieved May 28, 2018)

handled via the software. In addition, the selected security level, which was discussed already in section 5.1.1, affects the pricing. MindSphere, on the other hand, has a similar data-based pricing model but is additionally charging fixed monthly fees based on the number of user accounts and one-time charges for physical connectivity equipment orders. Last of all, Predix is offering multiple pricing structures for individual accounts and more comprehensive enterprise accounts. For both account types, there are both fixed and usage-based pricing models available.

Even though the case solutions have chosen various pricing models, none of them seems to provide distinctly differentiated pricing modes for users and third-party developers. These groups are thus primarily following the same data-driven pricing models which grant no subsidies for any of the parties. On top of the basic usage fees, users must pay additional fees for the applications they use either on a one-off basis or more recurrently. The application prices for the users ultimately reflect the data-processing costs of the application developers:

'In a way, there is a chain. If we sell a component that is subject to a charge and uses for example a certain database, -- the price of the [database] service is deducted from our price.' (Current employee of a startup developing applications for IIoT platforms)

5.1.5 Interoperability

The interoperability of an IIoT system consists of two levels: interoperability with IT systems in general and interoperability with other IIoT systems. Interoperability with other IT systems is important, because the information associated with the smart, connected products is currently stored within multiple IT systems (Kang et al. 2016). In addition to the IIoT systems, the product data is collected in legacy systems, such as PLM and ERP software. In order to benefit from the full set of data, the IIoT systems must be able to retrieve and exchange data with the supplementary IT systems as well. Interoperability with other similar systems, on the other hand, was considered more thoroughly already in section 2.3.

The case material suggests that there are currently some connections between the IIoT solutions and the other enterprise IT architecture, but the comprehensive integration is still considerably unfinished. Most of the integration modules in the case systems are created for the needs of a certain customer, and standardized interfaces to the most common business software are still under development. From the case solutions, IBM seems to be the pioneer in IT system interoperability at least in terms of its own software solutions, as the company is aiming to embed all its cloud services on top of one solution, the IBM Cloud:

'In order to get the maximal value of the data, we must have the capability to combine data from multiple sources. [The combination of data] is of course possible via APIs also when it is located in different places. However, we see that the most efficient solution is to have the data in one platform.' (Current IBM employee)

At present, the IIoT solutions are principally built in terms of the existing IT architecture. Even though the IIoT systems are revolutionizing the operations of the industrial users, the existing IT architecture of these companies is frequently extremely complex and rigid. Therefore, it is rather unfeasible or completely impossible to change the existing IT architecture to serve the purposes of the IIoT solutions more proficiently:

'After all, there are quite rarely situations where the whole [IT] stack is remodeled in terms of IoT. Mostly the basic use case is such that we build an IoT platform, take the capabilities of the IoT world into practice, and integrate those to the existing, either on premise or cloud solutions.' (Current IBM employee)

The interoperability of IIoT systems with other similar systems is a remarkable issue, as the smart, connected products are surrounded by a multitude of other products. These other products are practically always supplied by multiple manufacturers which might support completely different technologies and IIoT systems. Unless the various IIoT systems are able to communicate with each other, it is impossible to achieve an overall understanding of the product system:

'If we consider a factory which includes many different machines, it does not bring much value for the customer if each machine supplier brings their own little cloud, because they are all separate systems.' (Current Siemens employee)

The interoperability of various IIoT systems further facilitate the provision of diverse industrial services. Many industrial companies offer maintenance services which are not only limited to the products they manufacture but also serve other similar products from a broad range of manufacturers. Kone, for instance, is providing maintenance services for all types of elevators irrespective of the original manufacturer. IIoT system interoperability enables the transfer of data from one service operator to another, attracting more alternative suppliers to the market.

At the product level, interoperability is enforced by both MindSphere and Predix by allowing products from other companies besides Siemens and GE to join the system. Third-party products might however suffer from lower performance levels, as the solutions are primarily optimized for the offering of these particular companies (Lavid 2017). With Watson IoT, such problem does not exist, as IBM is not providing any industrial products and all products connected to the system are thus provided by third-parties.

At the system level, the integration of different IIoT systems is rare at the moment. Both IBM and Siemens however mentioned in the interviews that they are not aiming to create a closed system, and standardized interfaces to other IIoT systems can be expected in the near future. In addition, there are also some collaboration initiatives between the case solutions which are not directly linked to the most basic data collection services. MindSphere is for example bringing IBM Watson's analytic capabilities to its system (Siemens 2016). These analytic capabilities strengthen the offering of MindSphere but do not jeopardize the competitive edge of either solution.

5.1.6 Data

Various companies have collected data from their products and processes for decades, but the introduction of smart, connected products has raised the amount of data to a completely new level (Chen, Chiang and Storey 2012). Even though many of the technologies for data management have existed for a long time, companies are only now starting to implement these technologies in a large scale (Fitzgerald 2013). The massive data quantities and new technical implementations provoke several questions and challenges in the IIoT industry which are considered more comprehensively in this section.

In legal terms, the data produced by the smart, connected products cannot be owned, but it can be managed (Ailisto et al. 2015; Rajala et al. 2018). Data is conventionally managed by the owner of the product or service which generates or stores the data, as this entity has the ability to restrict the access of other entities to the data either physically or with other means (Ailisto et al. 2015). Many other agents in the supply-chain are additionally interested in the data, as they aim to improve their solutions and processes. These agents include among others raw material suppliers, machine manufacturers, distributors, service and software providers and financial institutions. (Rajala et al. 2018)

At present, the case solutions provide limited tools for the data management and access control, but the uncertainty of the general data management principles is great at the industry. The industrial users are speculating who ultimately controls their data and under which conditions they could give other entities access to the data. Similar to traditional supply and value chains, data creates sequences in which it flows from the product users to the product manufacturers and even further to component and raw material suppliers and other industry agents. As the number of agents in the network increases, the management of data becomes more and more difficult:

'Another question, a more difficult question is that if such value chains arise, who ultimately owns the data. There is currently no clear answer for that in the customer interface. A good example was from a conversation related to the paper industry. The paper machine manufacturer was considering that when they send a paper machine to a factory and the hyper care phase of the machine ends, who owns the data accumulated

by the paper machine. This inevitably complicates the transformation of the manufacturing industry to the service business.' (Current employee of IBM)

The case solutions have taken a neutral position in the data management discussion, as they give the users the full power to control their data. Watson IoT and Siemens for example allow the users to select independently which points of data they gather and store in their IIoT services. Siemens has also taken a step further by publicly announcing that MindSphere does not collect data from the users in an unstructured manner (Siemens 2017b).

From the user perspective, the industrial companies are accustomed to protect their data and knowledge very prudently in order to maintain their competitive advantage. Even though the nature of some datasets has evolved from mere transactional data to more indifferent monitoring data, the uncollaborative data sharing policies seem to follow the industrial companies to the era of smart, connected products and the Industrial Internet:

'If we talk about industrial companies which make significant business, they are fairly sensitive about who can access the data.' (Former employee of an IIoT platform startup)

One reason for the reluctance of industrial companies to share their data is the absence of proper incentives for such action. The massive quantities of data the companies possess create enormous opportunities, but only few companies have so far managed to design successful business models around data:

'If we can refine the data further, so that it becomes something else than information, so that it starts to create profits, -- sharing the data might become attractive.' (Former employee of an IIoT platform startup)

In the current practice, if data is shared, it is mostly given out for free. Kone for example provides users snap shot data about the status of its elevators for free but does not have prominent models for selling larger data sets. The historical monitoring data from the elevators is retained within Kone, although third-parties can retrieve it by recording the snap shot data. This practice creates unnecessary overlaps which could be avoided if

Kone decided to share the historical data in some format and created a suitable business model around it.

The establishment of proper business models around data requires companies to separate the business-critical data from the non-critical data. Industrial companies are understandably willing to share only their non-critical data to which the prospective business models must therefore be based. Another factor encouraging companies to categorize their data is the fact that it is no longer feasible to apply the same rigorous protection processes to all pieces of data as the total amount of information is so massive (Kaminski, Rezek, Richter and Sorel 2017). By categorizing the data, companies can focus the most demanding security measures only to the business-critical part of the data which saves the resources of the company.

In the interviews, many comments suggested that most of the industrial companies are still missing the understanding of the potential of data. The companies are mainly concentrating on what they themselves can achieve with the data instead of considering the potential benefits of it for third-parties. By considering the needs of other companies as well, industrial companies could develop new, significant business areas and possibly improve their own processes and products via external innovation.

5.2. IIoT industry challenges and suggested actions

Based on the results presented in the previous sections, it can be concluded that the IIoT software market is still in its early phases and involves many challenges which slow down the development of the market. This section summarizes the most remarkable challenges and derives corrective actions to these challenges from the platform literature. The corrective actions are considered from the perspective of both IIoT solution providers and users. The fundamental challenges and corrective actions are collected in Table 5 and each of them is explained more thoroughly in the following chapters.

Table 5: Fundamental challenges of the IIoT industry and suggested actions for the IIoT solution providers and users.

Challenge	**Suggested actions for IIoT solution providers**	**Suggested actions for IIoT users**
Small number of complements and high level of customization	• Improve modularity of basic architecture • Consider which complements to develop by one's own • Create attractive incentives and pricing models for complementors	• Consider thoroughly which functions require customized software
Uncertainty of the purpose of IIoT	• Create attractive pricing models for the users	• Continue investing in IIoT experiments • Act as a reference • Train top management and other employees of the potential benefits of IIoT
Dominance of IIoT software providers	• Facilitate third-party involvement in decision-making • Streamline application processes for third-parties • Simplify agreement structures	

Challenge	Suggested actions for IIoT solution providers	Suggested actions for IIoT users
Low level of interoperability	• Develop standard integrations for other business software • Develop common data structures	• Integrate IIoT solutions to other business software
Reluctance to share data	• Agree on data management principles • Create supporting technologies for data sharing	• Agree on data management principles • Separate business-critical data from non-critical data • Develop profitable business models around data

The first challenge the IIoT industry is facing is the small number of complements which is not sufficient to complete the current offering of the core IIoT solutions. The existing solutions concentrate on only certain layers of the IIoT stack, so they would need partners and complementary applications to cover the remaining layers. At the moment, the IIoT providers compensate the lack of complements by customizing the core components based on customer needs. This practice however aggravates the original problem, as the resources devoted in the creation of customized solutions cannot be employed to the development of the more general components and the overall ecosystem. In the ideal platform model, complements would eliminate the need for customized components, as the users could configure their IIoT solutions simply by selecting the adequate combination from the core components and the complements[6].

To solve the complement issue, actions are required from both IIoT solution providers and users. From the IIoT provider perspective, the first action is to improve the

[6] Compare to e.g. smart phones which are configured by the users by selecting the applications that fulfil their varying needs on top of the basic product.

modularity of the software solutions and create more simple interfaces so that third-party developers can more easily integrate their solutions to the system. As discussed in section 2.1.2, simple interfaces decrease the barriers of entry for complementors and thus stimulate the adoption rate. Second, IIoT providers should more rigorously consider which complements they develop themselves and which they leave for complementors. In an immature market, it might be reasonable for the IIoT solution providers to develop more complements than they would in a more established market and thus try to increase the confidence of the users in the growth of the ecosystem (Eisenmann, Parker and Van Alstyne 2009, p. 149). Finally, IIoT providers should test distinct pricing models for complementors and users in order to create sufficient incentives for complementors to join the ecosystem. Different pricing options are explained in more detail after the next fundamental challenge. IIoT users, on the other hand, can help to reduce the number of customized components by considering their requirements thoroughly and determining in which occasions they essentially need customized components and in which occasions standard components suffice.

The second fundamental challenge of the IIoT industry is the uncertainty of the industrial users on the purpose of IIoT. In the cases, the uncertainty appeared as the hesitance of industrial companies to experiment with IIoT solutions and as the lack of proper reference customers. Combined, the first and second challenge indicate that the IIoT industry is evidently suffering from the chicken-and-egg problem at present (see section 2.1.3). Both users and complementors lack the courage to fully invest in the IIoT market, because there are not enough participants on the other side of the market.

In order to solve the chicken-and-egg problem, the IIoT solution providers must figure out a way to attract at least one side of the market to the platform so that the other will follow as well. One of the tools the platform providers can use to attract potential users or complementors is pricing. Platform providers can subsidize the key participants while collecting profits from the other segments of the market (see section 2.1.4). At the IIoT industry, the pricing is currently based principally on data volumes so the IIoT software providers could for example consider lowering the data processing fees for complementary products in order to make their business models more profitable. Users, on the other hand, could be charged a bit more for the basic infrastructural services to compensate the possible losses in the complementor business.

The existing IIoT users, on the other hand, can stimulate the market best by continuing to invest in the IIoT solutions. With these investments, IIoT software providers can employ more resources on the development of the software and speed up the development process. In addition, the existing users can actively share insight on how they use the IIoT solutions and in that way act as an example and reference for other companies. Finally, the IIoT users must educate the executives and other employees about the benefits of the IIoT to ensure the organizational and top management support for new IIoT initiatives.

The third fundamental challenge is the dominance of IIoT solution providers in the decision-making processes. As the results in section 5.1.4 present, the IIoT solution owners principally dictate to which direction the core elements are developed and who is allowed to enter the platform. These principles drastically limit the independence of third-party developers and decrease their motivation to participate in the ecosystem. In addition, the current model further increases the unsteadiness of the complementor businesses, as they are highly dependent on the core solution but cannot know how it will evolve in the future.

To solve this challenge, IIoT software providers should consider if they could involve third-party developers and their feedback more in the decision-making processes and in the development of the core components. For example, the IIoT software providers could create structured feedback processes for third-parties which would then be used in the development decisions. Moreover, third-party entry applications could be reviewed to evaluate their necessity and make the entry process as straightforward as possible. Finally, third-party developer agreements could be simplified to clarify the division of responsibilities between the IIoT solutions provider and third-party developers. Example can be taken from the consumer platforms which currently provide substantially simpler agreements for third-parties[7].

The fourth fundamental challenge is the lacking interoperability of IIoT systems with other IIoT and IT systems. The existing IIoT software solutions are mainly utilized for internal purposes by the industrial users, thus resembling the internal platforms or Intranet solutions of the platform literature (Gawer 2009a; Ailisto et al. 2015). As internal platforms, these solutions increase the efficiency of single firms but affect only marginally at the industry level or in general. Originally, the IIoT solutions were envisioned to be universal systems that combine multiple industries. In order to achieve this objective, the existing IIoT solutions must improve their interoperability with other systems so that they do not become lonely islands besides the other IT architecture.

To mitigate the fourth challenge, IIoT solution providers should develop standardized integration modules to other IIoT solutions and business software. Via these integration modules, data could be transferred effortlessly between different systems. Furthermore, IIoT solution providers should aim to develop common standards for the data produced by the smart, connected products in order to ensure the usability of the data in multiple applications. As the amount of data increases, it might be difficult or completely impossible to convert the data to another format or transfer it to another service in the future. Users, in contrast, should actively try to integrate the IIoT solutions with the other business software they use so that they can exploit all the data they have collected in multiple systems.

The fifth and final fundamental challenge is the reluctance of industrial companies to share their data. By refusing to share their data, industrial companies drive themselves into silos which limit open innovation and collaboration as well as force companies to reinvent the wheel. The reluctance to share data is linked to the ambiguous data management principles which are currently a big question mark for the IIoT industry

[7] See e.g. Apple https://developer.apple.com/terms/ (retrieved August 31, 2017)

operators. As explained in section 5.1.6, the IIoT industry is currently lacking universal principles and agreement structures for the management of data.

To promote data sharing, IIoT industry agents should first create and agree simple data management principles to determine who can innately access the data produced by a certain smart, connected product. Based on these principles, IIoT software providers should create tools which support the management and sharing of data. IIoT users, on the other hand, should create models to separate their business-critical data from the non-critical data in order to distinguish which data they can share and which not. On top of the aforementioned instruments, industrial companies can start to build business models which turn data sharing profitable in the long run.

6. Discussion

This study has contributed to the platform literature by examining the contemporary IIoT platforms from the platform perspective. A general overview of the industry was first formed by studying the typical operating principles of the existing IIoT solutions, after which five fundamental challenges of the industry were distinguished by comparing the current operating principles with the present platform literature. The managerial implications of the study consist of the suggested actions for the five identified challenges. To benefit from the existing platform knowledge, the prevailing IIoT software solutions should tackle the identified challenges by implementing the suggested actions in their daily operations.

As the previous sections suggest, the IIoT industry is currently very fragmented, and no solution or design has yet achieved a dominant position. Market fragmentation reduces the willingness of the industrial users to engage and invest in a certain solution, as the future of the entire market is exceedingly uncertain. Many industrial companies are thus waiting for the market to settle before committing to any far-reaching decisions. Complementors, on the other hand, are faced with complex governance principles which complicate their market entry. Consequently, the IIoT industry is at present primarily supported by a few industrial early adopters and the initial investments of the IIoT solution providers.

The prudence of the IIoT users is however understandable, as the early decisions and commitments might have significant effects to their business in the future. As the volume of data produced by the smart, connected products increases, the significance of the IIoT solutions increases. The industrial companies may risk losing substantial amounts of data or business opportunities if their original choices in the IIoT field turn out to be wrong. The risk of system and supplier lock-in is particularly high with the prevailing, highly customized systems which interoperate poorly with other IIoT solutions.

In order to develop industry-wide systems, IIoT solution providers and industrial users should start emphasizing external integration and ecosystem value instead of focusing on internal resource control and optimization (Van Alstyne, Parker and Choudary 2016). With external integration, IIoT solutions can boost positive network effects which ultimately determine the dominant design. The transformation from internal platforms to industry-wide systems is unlikely to happen overnight and is more probably gradual and partial (Cusumano 2010b). In order that this transformation can occur, IIoT software providers must open up their solutions to a certain extent and increase the interoperability of various systems.

One alternative for the implementation of an industry-wide system is that one IIoT software system becomes an industry standard that is utilized by most of the companies. Such centralization is however unlikely within the B2B environment, as the B2B companies are more conscious than consumers about the risks of giving control of the overall system to one company or a small subset of industry agents. The dependency on a single system is seen as a threat, because system failures or malpractices may compromise the whole business of the users. None of the existing IIoT providers seem to have the power to take over the full market. In the interviews, the setting for instance at the building management field was described as follows:

'There is a chance that someone would take the control of the big picture. At present and for many years, nobody has taken such a role. There is no such a dominant player who could be the backbone.' (Current Kone employee)

In this study, IIoT industry was mainly considered from the platform perspective, assuming that the platform model would be the best option for the industry. Taking into account the multiple challenges IIoT industry currently encounters, a viable option would also be that the platform model established in the consumer context would not be as directly applicable in the B2B environment. In the consumer context, the users have for example been much more amenable to give data for the platform providers in order to receive better service. Companies, on the contrary, are much more precise on what data they share and who they share it with. The fundamental differences of the consumer and B2B environment might therefore oblige the IIoT solution providers to revisit the platform principles in order to find the suitable ones for the B2B context and to develop new practices to substitute the inappropriate ones.

To clarify the suitability of the platform model in the B2B context, additional research is still needed. Further research should explore what kind of modifications are required to the existing platform models in order to increase their applicability in the B2B context. An especially interesting question is how industrial companies can find the balance between maintaining their competitive advantage and supporting open innovation ecosystems. Another important question consists of the data management rights: who should have the right to manage certain data and to whom it would be beneficial to grant the additional access to the data?

References

Ailisto, H., Mäntylä, M., Seppälä, T., Collin, J., Halén, M., Juhanko, J., Jurvansuu, M., Koivisto, R., Kortelainen, H., Simons, M., Tuominen, A., & Uusitalo, T. (2015). Finland – The Silicon Valley of Industrial Internet. Publications of the Government's analysis, assessment and research activities 10/2015.

Anderson, S. W., & Dekker, H. C. (2005). Management control for market transactions: The relation between transaction characteristics, incomplete contract design, and subsequent performance. Management Science, 51(12), 1734-1752.

Anderson, P., & Tushman, M. L. (1990). Technological discontinuities and dominant designs: A cyclical model of technological change. Administrative science quarterly, 604-633.

Adner, R., & Levinthal, D. (2001). Demand heterogeneity and technology evolution: implications for product and process innovation. Management science, 47(5), 611-628.

Asthana, P. (1995). Jumping the technology S-curve. Ieee Spectrum, 32(6), 49-54.

Baldwin, C. Y., & Clark, K. B. (2000). Design rules: The power of modularity (Vol. 1). MIT press.

Baldwin, C. Y., & Woodard, C. J. (2009). The architecture of platforms: a unified view. In ed. Gawer, A., Platforms, Markets and Innovation (Chapter 2), p. 19-44.

Benbasat, I., Goldstein, D. K., & Mead, M. (1987). The case research strategy in studies of information systems. MIS quarterly, 369-386.

Boudreau, K. (2008). Opening the platform vs. opening the complementary good? The effect on product innovation in handheld computing. HEC Wording Paper. Retrieved August 23, 2017 from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1251167

Brousseau, E., & Pénard, T. (2007). The economics of digital business models: A framework for analyzing the economics of platforms. Review of network Economics, 6(2).

Caillaud, B., & Jullien, B. (2003). Chicken & egg: Competition among intermediation service providers. RAND journal of Economics, 309-328.

Chander, A. (2013). How Law Made Silicon Valley.

Chen, H., Chiang, R. H., & Storey, V. C. (2012). Business intelligence and analytics: from big data to big impact. MIS quarterly, 1165-1188.

Creswell, J. W. (2018). Qualitative inquiry & research design: Choosing among five approaches (4th ed.). Los Angeles: SAGE Publications.

Crook, S. & MacGillivray, C. (2017). IDC MarketScape: Worldwide IoT Platforms (Software Vendors). International Data Corporation (IDC).

Cusumano, M. (2010a). Technology strategy and management: The evolution of platform thinking. Communications of the ACM, 53(1), 32-34.

Cusumano, M. (2010b). Cloud computing and SaaS as new computing platforms. Communications of the ACM, 53(4), 27-29.

Cusumano, M. A., & Gawer, A. (2002). The elements of platform leadership. MIT Sloan Management Review, 43(3), 51.

De Reuver, M., & Bouwman, H. (2012). Governance mechanisms for mobile service innovation in value networks. Journal of Business Research, 65(3), 347-354.

De Reuver, M., Sørensen, C., & Basole, R. C. (2016). The digital platform: a research agenda. Journal of Information Technology, 1-12.

De Weck, O. L., Roos, D., & Magee, C. L. (2011). Engineering systems: Meeting human needs in a complex technological world. MIT Press.

Drath, R., & Horch, A. (2014). Industrie 4.0: Hit or hype? [industry forum]. IEEE industrial electronics magazine, 8(2), 56-58.

Eisenhardt, K. M. (1989). Building theories from case study research. Academy of management review, 14(4), 532-550.

Eisenmann, T. R., Parker, G., & Van Alstyne, M. (2009). Opening platforms: how, when and why?. In ed. Gawer, A., Platforms, Markets and Innovation (Chapter 6), p. 131-162.

Evans, D. S. (2003). Some empirical aspects of multi-sided platform industries. Review of Network Economics, 2(3).

Evans, P. C., & Annunziata, M. (2012). Industrial internet: Pushing the boundaries. General Electric Reports.

Fitzgerald, M. (2013, January 28). An internet for manufacturing. MIT Technology Review, 116(2), 71-72. Retrieved May 29, 2018 from https://www.technologyreview.com/s/509331/an-internet-for-manufacturing/

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. Qualitative inquiry, 12(2), 219-245.

Garcia-Swartz, D. D., & Garcia-Vicente, F. (2015). Network effects on the iPhone platform: An empirical examination. Telecommunications Policy, 39(10), 877-895.

Gawer, A. (2009a). Platform dynamics and strategies: from products to services. In ed. Gawer, A., Platforms, Markets and Innovation (Chapter 3), p. 45-76.

Gawer, A. (Ed.). (2009b). Platforms, markets and innovation. Edward Elgar Publishing.

Gawer, A. (2014). Bridging differing perspectives on technological platforms: Toward an integrative framework. Research Policy, 43(7), 1239-1249.

Gawer, A., & Cusumano, M. A. (2002). Platform leadership: How Intel, Microsoft, and Cisco drive industry innovation (pp. 29-30). Boston: Harvard Business School Press.

Gawer, A., & Cusumano, M. A. (2008). How companies become platform leaders. MIT Sloan management review, 49(2), 28.

Gawer, A., & Cusumano, M. A. (2014). Industry platforms and ecosystem innovation. Journal of Product Innovation Management, 31(3), 417-433.

GE. (2015). 2014 annual report of GE. Retrieved June 22, 2017 from https://www.ge.com/ar2014/assets/pdf/GE_AR14.pdf

GE. (2018). 2017 annual report of GE. Retrieved May 16, 2018 from https://www.ge.com/investor-relations/ar2017/downloads

Germany trade and invest. (2017). Industrie 4.0. Retrieved July 24, 2017 from https://industrie4.0.gtai.de/INDUSTRIE40/Navigation/EN/Topics/industrie-4-0.html

Ghazawneh, A., & Henfridsson, O. (2010). Governing third-party development through platform boundary resources. In the International Conference on Information Systems (ICIS) (pp. 1-18). AIS Electronic Library (AISeL).

Ghazawneh, A., & Henfridsson, O. (2013). Balancing platform control and external contribution in third-party development: the boundary resources model. Information Systems Journal, 23(2), 173-192.

Eisenhardt, K. M. (1989). Building theories from case study research. Academy of management review, 14(4), 532-550.

Hagiu, A. (2014). Strategic decisions for multisided platforms. MIT Sloan Management Review, 55(2), 71.

Hagiu, A., & Yoffie, D. B. (2009). What's your Google strategy?. Harvard Business Review, 87(4), 74-81.

Hagiu, A., & Wright, J. (2015). Multi-sided platforms. International Journal of Industrial Organization, 43, 162-174.

Hardy, Q. (2014, October 9). G.E. opens its big data platform. The New York Times. Retrieved June 23, 2017 from https://bits.blogs.nytimes.com/2014/10/09/ge-opens-its-big-data-platform/?_r=0

Hein, A., Schreieck, M., Wiesche, M., & Krcmar, H. (2016). Multiple-case analysis on governance mechanisms of multi-sided platforms. In Multikonferenz Wirtschaftsinformatik (pp. 9-11).

Hitt, M. A., Keats, B. W., & DeMarie, S. M. (1998). Navigating in the new competitive landscape: Building strategic flexibility and competitive advantage in the 21st century. The academy of management executive, 12(4), 22-42.

IBM. (2016). 2015 annual report of IBM. Retrieved June 21, 2017 from https://www.ibm.com/investor/financials/financial-reporting.html

IBM. (2018). 2017 annual report of IBM. Retrieved May 16, 2018 from https://www.ibm.com/annualreport/2017/assets/downloads/IBM_Annual_Report_2017.pdf

IBM. (n.d.). Discover IBM Business Partners to help with your IoT solution. Retrieved August 22, 2017, from https://www.ibm.com/internet-of-things/partners/find-a-partner/

Industrial Internet Consortium. (2017). The Industrial Internet of Things Volume G1: Reference Architecture. Version 1.8, IIC:PUB:G1:V1.80:20170131. Retrieved September 3, 2017, from http://www.iiconsortium.org/IIRA.htm

Jacobides, M. G., Knudsen, T., & Augier, M. (2006). Benefiting from innovation: Value creation, value appropriation and the role of industry architectures. Research policy, 35(8), 1200-1221.

Jansen, S., & Cusumano, M. A. (2013). Defining software ecosystems: a survey of software platforms and business network governance. Software ecosystems: analyzing and managing business networks in the software industry, 13.

Juhanko, J., Jurvansuu, M., Ahlqvist, T., Ailisto, H., Alahuhta, P., Collin, J., Halen, M., Heikkilä, T., Kortelainen, H., Mäntylä, M., Seppälä, T., Sallinen, M., Simons, M., & Tuominen A. (2015). Suomalainen teollinen internet – haasteesta mahdollisuudeksi. Elinkeinoelämän tutkimuslaitos.

Kang, H. S., Lee, J. Y., Choi, S., Kim, H., Park, J. H., Son, J. Y., Kim, B. H. & Do Noh, S. (2016). Smart manufacturing: Past research, present findings, and future directions. International Journal of Precision Engineering and Manufacturing-Green Technology, 3(1), 111-128.

Kaminski, P., Rezek, C., Richter, W., & Sorel, M. (2017, January). Protecting your critical digital assets: Not all systems and data are created equal. McKinsey&Company. Retrieved May 29, 2018 from https://www.mckinsey.com/business-functions/risk/our-insights/protecting-your-critical-digital-assets-not-all-systems-and-data-are-created-equal

Kenney, M., & Pon, B. (2011). Structuring the smartphone industry: is the mobile internet OS platform the key?. Journal of Industry, Competition and Trade, 11(3), 239-261.

Kone. (n.d.). Taking services to the next level. Retrieved August 24, 2017, from http://www.kone.com/en/stories-and-references/stories/taking-elevator-services-to-the-next-level.aspx

Kotiranta, A., Seppälä, T., Tahvanainen, A. J., Hemminki, M., Mattila, J., Sadeoja, S., & Tähtinen, T. (2017). Roadmap for Renewal: A Shared Platform in the Food Industry (No. 74). The Research Institute of the Finnish Economy.

Kude, T., Dibbern, J., & Heinzl, A. (2012). Why do complementors participate? An analysis of partnership networks in the enterprise software industry. IEEE transactions on engineering management, 59(2), 250-265.

Lambert, F. (2016, February 15). Tesla is implementing a new custom end-to-end platform called 'Tesla 3DX' to ramp up for the Model 3 and Tesla Energy. Electrek. Retrieved Aug 31, 2017, from https://electrek.co/2016/02/15/tesla-3dx-model-3/

Lavid, D. (2017, February 7). Considering GE Predix or Siemens MindSphere? How to Evaluate Supervised Machine Learning Solutions for Predictive Asset Maintenance. Retrieved Jun 23, 2017 from http://www.presenso.com/single-post/2017/02/07/Considering-GE-Predix-or-Siemens-Mindsphere-How-to-Evaluate-Supervised-Machine-Learning-Solutions-for-Predictive-Asset-Maintenance/

Manner, J., Nienaber, D., Schermann, M., & Krcmar, H. (2012). Governance for Mobile Service Platforms: a literature Review and Research Agenda. In ICMB (p. 14).

Mattila, J., & Seppälä, T. (2017). Distributed Governance in Multi-Sided Platforms. Washington DC, United States: Industry Studies Association Conference.

Menon, K., Kärkkäinen, H., & Gupta, J. P. (2016, July). Role of Industrial Internet platforms in the management of product lifecycle related information and knowledge. In IFIP International Conference on Product Lifecycle Management (pp. 549-558). Springer, Cham.

Parker, G., & Van Alstyne, M. (2017). Innovation, openness, and platform control. Management Science, forthcoming.

Pelino, M. and Hewitt, A. (2016). The Forrester Wave™: IoT Software Platforms, Q4 2016. Forrester Research.

Pfister, S., Koehler, A., & Hellweg, S. (2009). Assessing the environmental impacts of freshwater consumption in LCA. Environmental science & technology, 43(11), 4098-4104. Pisano, G. P., & Teece, D. J. (2007). How to capture value from innovation: Shaping intellectual property and industry architecture. California Management Review, 50(1), 278-296.

Pon, B., Seppälä, T., & Kenney, M. (2014). Android and the demise of operating system-based power: Firm strategy and platform control in the post-PC world. Telecommunications Policy, 38(11), 979-991.

Pon, B., Seppälä, T., & Kenney, M. (2015). One ring to unite them all: convergence, the smartphone, and the cloud. Journal of Industry, Competition and Trade, 15(1), 21-33.

Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. Harvard Business Review, 92(11), 64-88.

Porter, M. E., & Heppelmann, J. E. (2015). How smart, connected products are transforming companies. Harvard Business Review, 93(10), 96-114.

Prakash, A., & Hart, J. A. (Eds.). (2003). Globalization and governance. Routledge.

Rajala, R., Hakanen, E., Mattila, J., Seppälä, T., & Westerlund, M. (2018). How Do Intelligent Goods Shape Closed-Loop Systems?. California Management Review, 60(3), 20-44.

Rink, D. R., & Swan, J. E. (1979). Product life cycle research: A literature review. Journal of business Research, 7(3), 219-242.

Rochet, J. C., & Tirole, J. (2003). Platform competition in two-sided markets. Journal of the European Economic Association, 1(4), 990-1029.

Rogers, E. M. (2010). Diffusion of innovations, fourth ed. Simon and Schuster.

Romano Jr, N. C., Donovan, C., Chen, H., & Nunamaker Jr, J. F. (2003). A methodology for analyzing web-based qualitative data. Journal of Management Information Systems, 19(4), 213-246.

Rong, K., Lin, Y., Shi, Y., & Yu, J. (2013). Linking business ecosystem lifecycle with platform strategy: a triple view of technology, application and organisation. International journal of technology management, 62(1), 75-94.

Ruutu, S., Casey, T., & Kotovirta, V. (2017). Development and competition of digital service platforms: A system dynamics approach. Technological Forecasting and Social Change.

Seawright, J., & Gerring, J. (2008). Case selection techniques in case study research: A menu of qualitative and quantitative options. Political Research Quarterly, 61(2), 294-308.

Seppälä, T., Halén, M., Juhanko, J., Korhonen, H., Mattila, J., Parviainen, P., ... & Ruutu, K. M. M. S. (2015). Historiaa, ominaispiirteitä ja määritelmä.

Shrouf, F., Ordieres, J., & Miragliotta, G. (2014, December). Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm. In Industrial Engineering and Engineering Management (IEEM), 2014 IEEE International Conference on (pp. 697-701). IEEE.

Siemens. (2016, December 13). Siemens and IBM to bring Watson Analytics to MindSphere. [Press release]. Retrieved August 15, 2017 from www.siemens.com/press/PR2016120102DFEN

Siemens. (2017a). 2017 annual report of Siemens. Retrieved May 12, 2018 from https://www.siemens.com/investor/pool/en/investor_relations/Siemens_AR2017.pdf

Siemens. (2017b, April 11). Is all data being collected unstructured? [Online forum comment]. Retrieved August 14, 2017, from https://community.plm.automation.siemens.com/t5/MindSphere-FAQs/Is-all-data-being-collected-unstructured/ta-p/402489

Sudarsan, R., Fenves, S. J., Sriram, R. D., & Wang, F. (2005). A product information modeling framework for product lifecycle management. Computer-aided design, 37(13), 1399-1411.

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. Research policy, 15(6), 285-305.

Terzi, S., Bouras, A., Dutta, D., Garetti, M., & Kiritsis, D. (2010). Product lifecycle management–from its history to its new role. International Journal of Product Lifecycle Management, 4(4), 360-389.

Tiwana, A. (2013). Platform ecosystems: aligning architecture, governance, and strategy. Newnes.

Tiwana, A., Konsynski, B., & Bush, A. A. (2010). Research commentary—Platform evolution: Coevolution of platform architecture, governance, and environmental dynamics. Information Systems Research, 21(4), 675-687.

Utterback, J. M., & Abernathy, W. J. (1975). A dynamic model of process and product innovation. Omega, 3(6), 639-656.

Van Alstyne, M. W., Choudary, S. P., & Parker, G. G. (2016). Platform revolution: How networked markets are transforming the economy--and how to make them work for you. WW Norton & Company.

Van Alstyne, M., & Parker, G. (2017). Platform Business: From Resources to Relationships. GfK Marketing Intelligence Review, 9(1), 24-29.

Van Alstyne, M. W., Parker, G. G., & Choudary, S. P. (2016). Pipelines, platforms, and the new rules of strategy. Harvard Business Review, 94(4), 54-62.

West, J., & Mace, M. (2010). Browsing as the killer app: Explaining the rapid success of Apple's iPhone. Telecommunications Policy, 34(5-6), 270-286.

Williams, Z. D. (2017, June 27). 450 Global IoT Platform Vendors Marks a New Record. IoT Analytics. Retrieved July 20, 2017, from https://iot-analytics.com/iot-platforms-company-list-2017-update/

Winig, L. (2016, February 18). GE's Big Bet on Data and Analytics. MIT Sloan Management Review, 57(3). Retrieved June 23, 2016 from https://sloanreview.mit.edu/case-study/ge-big-bet-on-data-and-analytics/

Yoffie, D. B., & Kwak, M. (2006). With friends like these: The art of managing complementors. Harvard business review, 84(9), 88-98.

Appendix A: List of interviews

For the purpose of the study, the following interviews were conducted.

Interviewee profile	**Date of the interview**
Current employee of Siemens	18.07.2017
Current employee of Siemens	02.08.2017
Current employee of IBM	14.08.2017
Current employee of Kone	17.08.2017
Employee of Kone, currently on a study leave	29.06.2017
Current employee of a startup developing applications for IIoT platforms	16.08.2017
Former employee of an IIoT platform startup	04.07.2017
Representative of the Aalto University Industrial Internet Campus	15.08.2017
Researcher specialized in enterprise IT architecture	25.08.2017

Appendix B: Frame of the interview questionnaire

Lifecycle and multi-sidedness

1. What kind of groups of agents are there operating on the platform? What kind of role does each agent have on the platform?

2. How many potential agents are there in each agent group? How many of these potential agents are currently using the platform? How many of the potential agents are using some other similar platform?

3. What kind of benefits do the agents reach by utilizing the platform?

4. How has the platform ecosystem been built so far? Which parties are critical for the development of the ecosystem?

5. What kind of benefits does the increased number of agents in certain group generate to the platform? What kind of downsides does the increased number of agents in certain group generate to the platform?

Architecture

6. At which levels of the IIoT industry stack (Figure B1) is the platform currently operating? Is the platform planning to broaden its operations to some other levels of the stack in the near future?

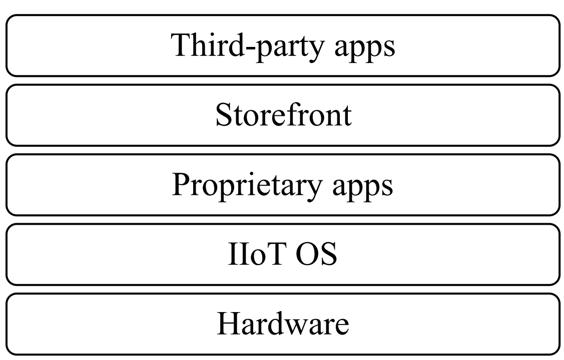

Figure B1: Simplified IIoT industry stack.

7. For which purpose is the platform currently used?
8. Of which features does the core of the platform consist?
9. Does the platform base its functionalities to some standards and if yes, which are those standards?
10. Are the applications on the platform mostly created by the platform owner, the platform users or some other third-party?
11. What kind of features are expected to be built on top of the platform by third-party developers?
12. What kind of interfaces is the platform providing to support third-party development?
13. What kind of applications has the platform owner built on top of the platform? What kind of role does the platform have in the complete offering of products and services provided by the platform owner?
14. To which extent are the platform solutions currently customized?
15. How is computing divided between the cloud and the edge on the platform?
16. What kind of role does the platform have besides the other IT architecture of the users?

Data

17. What kind of data is there on the platform?
18. How is data collected, handled and managed?
19. Who controls the data?
20. How willing are platform users currently to share their data? How do you expect the willingness of companies to share data to develop in the future?

21. How are immaterial rights and data privacy taken care of on the platform?
22. Does the regulation affect some activities on the platform and if yes, how does it affect?

Governance

23. Who makes the decisions regarding the development of the platform?
24. Who can enter the platform? Which criteria are used to screen the entrants?
25. What kind of agreements and licensing practices are there between the platform owner and the other platform agents?
26. How is the quality of the applications controlled on the platform?
27. What kind of processes are required from application providers?
28. How is the performance of third-party application developers measured?
29. What kind of pricing policy does the platform have? How much are each platform agent charged and why?

Openness and switching costs

30. Is it possible for the platform agents to use multiple similar platforms at the same time?
31. Which factors tie the platform agents to a certain platform?
32. Which factors facilitate switching between similar platforms?

Future

33. How do you see the platform to evolve in the future?