TAMPERE UNIVERSITY OF TECHNOLOGY

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SENSOR-BASED SERVICE ENABLERS IN ENGINEERING FIRMS

Master of Science Thesis

Prof. Miia Martinsuo has been appointed as the examiner at the Council Meeting of the Faculty of Business and Technology Management on November 5th 2014.

ABSTRACT

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Service innovation has attracted the attention of several industries and researches. Progresses in information and communication technologies have provided the opportunities to create innovative service solutions. Sensor-based solution is one of the significant research areas in the service business that has gained considerable importance over the past decade.

Previous researches which study the sensor-based service solutions usually do not cover multiple factors in different stages of the solution development and the opportunities in business to business (B2B) cooperation. Therefore, this research concentrates on sensor-based service enablers in B2B cooperation, particularly in the engineering firms. The goal is increased understanding on companies' use of sensor-based solutions in enabling new service business. The research methodology was multiple case studies. Four engineering firms participated in this research. Semi-structured interviews were conducted, audio recorded and transcribed, and the data were content analyzed. A workshop was also held with case companies to discuss the results and verify the findings.

The results of thesis showed that generating new turnover is the most important value driver of manufacturers and increasing the machine uptime is the main value driver of customers. The research explained the necessity of co-developing the solution with customers. The research studied opportunities in utilizing the collected data, especially for improving maintenance and product development. The importance of launch plan was another topic which showed that choosing the proper early adopters, involving sales people and informing them about all capacities and benefits of the new solution and providing after-sales support for customers can enhance the chance of success in commercializing the new solution. The thesis also studied how sensor-based solutions and the collected data enable the engineering firms to provide services efficiently.

PREFACE

About two years ago, I moved to Finland to start my Master degree. Living and studying abroad not only taught me valuable knowledge and skills about Business and Technology but also changed my personal life significantly. Now, when I look at all ups and downs during my study, I believe that it was an excellent learning process for me.

Writing this thesis was an interesting experience that could not be achieved without help of several people. First, I would like to thank my advisor Miia Martinsuo for her invaluable support and guidance through the research process. Second, I would like to thank all case companies' representatives for their cooperation and participation in this research. I also want to thank my colleague Olli Ahvenniemi, who helped me in the interviews and workshop.

I owe my greatest thank to my family, my mother, father, and sister for their continuous support and encouragement. I also want to thank my special friends who have provided me with all the love, care and the support when I have needed them the most. Without you, this would not have been possible.

Tampere, December 20th, 2014

Khadijeh Momenikouchaksaraei

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ABBREVIATIONS

B2B	Business to business
FOS	Fibre optic sensor
IoT	Internet of Things
M2M	Machine-to-machine
RMS	Remote monitoring system
RFID	Radio-Frequency Indentification

1. INTRODUCTION

1.1. Background

Businesses are no longer limited to the products; service sector grows rapidly and provides new sources of income for many companies. Actually, the economies of the world is changing from agricultures and manufacturing to the service business. It means the percentage of the workforce in the service sector has grown rapidly (Spohrer & Maglio, 2008). This trend has increased the importance and necessity of research in the field of service innovation.

In today's business to business (B2B) environment, a supplier cannot be successful only by focusing on its products but it needs interactive contacts between the company and its customers. According to Grönroos (2011), a business customer value is not only dependent on the main product. The value comes from the whole range of relationships between the customer and the supplier that support the effective use of the main product. Thus innovative services play an important role in providing business effectiveness for the customers.

Defining and innovating new services cannot be achieved only by indoor R&D. Customer collaboration is vital in B2B context. Customers provide a wide range of skills, competencies, interests and knowledge (Blazevic & Lievens, 2008). Acquisition of this information can happen in different ways. Blazevic and Lievens (2008) believe that majority of the innovation researches focus on face-to-face meetings, interviews, focus groups and surveys. Gathering information by this ways can be costly, time consuming and ineffective when considering a B2B environment with all networks and interrelationships. Actually, monitoring all installed-bases in different customers' sites needs a more advanced method. Technology development provides new opportunities for acquiring required data and information from the customer. Advances in sensors and communication technology have led to effective collection and transmission of data and subsequently transform it to reusable knowledge (Westergren, 2011).

Over the past years, utilizing sensors and sensor networks in the industrial sector has become very demanding in different business environments. Sensors are applied in several domains including defense, public security, energy management, traffic control and health care (Wehner, 2011). Sensors make an effective link between physical world and the system and lead to a stable and reliable operation (Kirchner et al., 2008).

This thesis studies the sensor-based services in engineering firms. Sensors are used widely in several industrial environments. They are mainly used to gather data from different elements of the system, from a particular component to whole industrial plant. Data gathering are usually done by placing sensors close to the target part and then transmitting the data to the processing system (Salvadori et al., 2009). The transmission can be done by a wired or wireless communication infrastructure. There are various types of sensors and they can measure and control several attributes like thermal, mechanical and electrical quantities such as temperature, strain, pressure, vibration, current and voltage (Bogue, 2011).

Several studies have reviewed the sensor applications in different industrial components such as measure the in-cylinder pressure of an internal combustion engine in real time (Sion & Atkinson, 2002), fault detection in motors (Gomes et al., 2013), monitoring wellhead and heat exchanger pressures on a Norwegian offshore oil platform, measuring the water flow in a turbine hall at a UK power plant, measuring pressure and temperature of fuel delivery on an Australian bitumen plant, controlling the cooling water flow and pressure in an American flat-rolled steel mill, asset tracking and logistics applications (Bogue, 2010), tool condition monitoring (Kurada & Bradley, 1997).

There are multiple technologies that use sensors to provide some services such as radio-frequency identification (RFID), machine-to-machine (M2M) communication, wireless sensor networks (WSNs), remote monitoring system (RMS) and so on. All these systems have some similar elements but they have some differences in the level of automation and functions. This study tries to define the mentioned technologies but sheds light particularly on remote monitoring system as the most typical solution that enables services in industrial firms.

One of the main applications of sensors in industrial environment is condition monitoring. It means applying advanced technologies in order to evaluate condition of equipment and predict potential failures (Vogl et al. 2009). Applied sensors can monitor parameters such as vibrations, temperature, power consumption and liquid levels (Owen et al., 2009). For instance, vibration monitoring sensors are used in several kinds of rotating and reciprocating components such as shafts, bearings, gears and fan blades. These sensors can be placed in engines, pumps, electric motors, generators, compressors and gear boxes. They can determine the start of a probable failure (Bogue, 2013).

Another application of sensors in engineering sector that has a considerable effect on service business is remote monitoring system (RMS). The RMS helps service provider to monitor products from distance and gather data to create services based on data analysis and improve their understanding about product utilization (Westergren, 2011). RMS enables service innovation because manufacturing firm can access valuable data from their products which are installed in customers' sites and provide new service opportunities that will lead to increased total customer value.

Despite a large number of studies concerning sensors and their applications in the industrial sectors, there is a shortage in the area of deployment of sensors to provide innovative services in B2B cooperation. Actually, most of the researches are focused on using sensors to monitor the plant process and control the quality of the product in the production line. Application of sensors for monitoring the installed-bases in the customers' locations has been studied in some researches. However, researches on current or potential services based on them have been limited.

1.2. Objectives of the study

The research focuses on sensor-based services in B2B cooperation. It concentrates on developing integrated sensor-based solutions, particularly in the engineering firms. Therefore, the main research question is …

> *How can a company utilize sensors to enable services in the engineering firms?*

The main research question is broken down into the following questions:

1. *What are the value drivers for developing sensor-based services in engineering firms?*
2. *What are the opportunities for utilizing collected data from sensor-based services in engineering firms?*
3. *How do companies differ from each other, in their approaches towards sensor-based solutions and related service innovations?*

The thesis has two purposes. First, theoretical goal is to increase the understanding of the use of sensor-based solutions to enable new service business for engineering firms. Second, the goal of the case studies is to evaluate the situation of deployment of sensor-based services in Finnish engineering firms.

1.3. Research context

The thesis is a prestudy for a bigger research proposal for the FIMECC's (Finnish Metals and Engineering Competence Cluster) research program, called Service Solutions for Fleet Management (S4Fleet). The project will be focused on the management of complex service delivery systems for distributed fleet in an efficient and flexible manner. The department of Industrial Management is the main influencer of this study.

The context of this thesis is in Finnish engineering firms. The data for the empirical study is gathered from four companies in engineering sector. The scope is to find out the state-of- art of Finnish engineering firms in sensor-based service solutions and also evaluate their value drivers for developing sensor-based services.

To answer the research questions of this study, two research strategies are implemented including searching the literature and interviewing experts. Literature review is done for fulfilling the theoretical aim of the study and also designing a suitable framework for the interviews.

1.4. Scope of the thesis

The thesis focuses on B2B cooperation and studies the current issues and opportunities to develop sensor-based services in a business and deliver them to another business; thus, customer market and application of sensors in that domain is not included in the current study. The thesis also concentrates on engineering firms and tries to study the possible sensor-based services for installed bases. Therefore, other types of companies and industries are out of scope of this thesis. This thesis takes a managerial perspective to sensor-based solutions and relies on interviews primarily with managers. A broader analysis within the companies, for example, from a technology and customer interface perspective is left as a topic of further study.

1.5. Structure of the thesis

The thesis consists of six chapters. The chapter after the introduction is literature review. The first part of the literature review focuses on developing new services. After that the sensor-based services are studied to understand value drivers for sensor-based services and state-of-art of these solutions in literature. The literature is reviewed in order to achieve a comprehensive understanding of the main topic of the study and to build a theoretical foundation for the empirical section.

The third chapter concentrates on the research methodology. It describes the research strategy of the thesis and also companies which are going to be studied in the empirical section. The methods for data collection are clarified in this chapter. Finally, it explains the way of analyzing the gathered data.

Chapter four presents the results. It contains the result of multiple case studies and the related analysis. After reviewing the result, the discussion chapter examines how the results are linked to the prior studies. It shows the overlaps between the result of case studies and literature review and also the main differences. It also examines how the objectives of the study are met. Conclusion as the last chapter reviews the academic and managerial contributions of the thesis. The limitations of the thesis as well as ideas for future researches are explained in this chapter.

2. LITERATURE REVIEW

2.1. Developing new services

2.1.1. Shifting toward service business

Today economies in many countries and especially western economies are based on services (Nijssen et al., 2006). For example, in 2008, almost 77% of the gross domestic product in Australia and 80% in the United States were generated by service activities (O'Cass et al., 2013). Service business has also achieved the main role in many manufacturing firms. According to Chesbrough and Spohrer (2006), service parts of GE and IBM are growing fast in a way that the IBM Global Service Business creates the majority of the IBM's revenue. These dramatic changes in the contribution of production and services in global economies and particularly in industrial environment prove the necessity of studying service business and its related concepts in more details.

Shift toward service business means shifting from a goods-dominant (G-D) logic to a service-dominant (S-D) logic. G-D logic states that value can be created by producing goods and distributing them in the market to earn money and/or goods. Thus, producers and customers have separate roles in value creation. On the other hand, S-D logic does not consider distinct roles for producer and customer but it is based on interactions between them to create value (Vargo and Lusch 2008).

Change to S-D logic is inevitable in many industries; especially in today's global business environment. Industries are expanding their businesses beyond their plant boundaries and have customers, suppliers, and other plants in several countries. Shifting to a global business changes many aspects of a business. One of the key factors to keep the production efficient and maintain the customer satisfaction in a global context is services. Customers expect effective services and maintenance from suppliers regardless of the distance between them.

A high quality product is no longer the only expectation of a customer; Quality and efficiency of services are other important parameters for a customer. Küssel et al. (2000) identify four requirements to achieve customer satisfaction regarding to the provided services including global service availability, low costs, quick response time, and high quality. In other words, companies can differentiate their offerings by these measures. The greater influence of services than the price or even the functionality in buying a product comes as no surprise to many business firms (Küssel et al., 2000). Fading traditional purchasing criteria and highlighting new methods of differentiation has changed the status of competition in different markets.

A company which accepts service logic is responsible for the customer's practices and business processes. It means they provide extended offering to the customer that leads to create value from the core process. Therefore, the supplier provides business effectiveness instead of operational efficiency (Grönroos, 2011). The service provider needs to achieve a deep understanding of the customer's business to be able to provide the right service solutions which can enhance the value of the delivered products.

2.1.2. Integrating services and products

Integrating services and products or in other words developing innovative product-related services attracts substantial attention in many industries (Lenfle and Midler, 2009). Companies usually deliver products to several customers that call it installed base. Oliva and Kallenberg (2003) define a product's installed base as the total number of products currently under use. Customers need several product or process-related services to utilize a product effectively that call installed base services. Integrating these products and services can provide value for both suppliers and customers.

An integrated solution is a bundle of physical products, services and information. The combination of these parts provides more value than offering them separately. These solutions fulfill a specific functional need of the customer and are long-term oriented and cost effective (Brax and Jonsson, 2009). Firms can achieve competitive advantage through these product-related services and differentiate their offerings from other competitors.

There are several reasons to integrate services and the product. First, manufacturers can achieve considerable revenue from an installed base of products (Oliva and Kallenberg, 2003). Services can facilitate the sales of products (Brax, 2005). Generally, services have higher margins than products. For example, Fiat makes double-digit margin from its service business that is considerably higher than margin of its car production (The Economist, 2000). Services are also more reliable source of revenue because they are not highly dependent on the economic cycles and subsequently the investment and equipment purchases (Oliva and Kallenberg, 2003). Actually, companies can create different cash flows through provided services and thus balancing the effects of economic cycles (Brax, 2005).

Second, customers need more services than before (Oliva and Kallenberg, 2003; Brax, 2005). Several reasons may cause this situation; firms are forced to downsize to have a flexible business (Oliva and Kallenberg, 2003). Therefor they may not have enough resources to allocate to the service activities. Companies try to have specific core competencies (Oliva and Kallenberg, 2003). While this strategic approach can concentrate the firm on its main objective and enhance its productivity, it may limit the required capability of a firm in other areas like services. Increased technological complexity leads to higher specialization (Oliva and Kallenberg, 2003). Thus, companies require outsourcing the service activities to the suppliers or service providers who have more technological knowledge and skills.

Third, services increase customer relationship (Brax, 2005). Keeping the contact with customers after selling and installing the product is a critical task for the manufacturers. Providing integrated solutions can enhance this relationship and increase customer satisfaction and loyalty. It makes a good opportunity for selling more products and services to the customer in the future.

Fourth, services are less visible and more labor dependent than products. These special characteristics can increase the competitive advantage of a company because competitors cannot imitate services easily (Oliva and Kallenberg, 2003). Actually, nowadays due to high competition in market, a new product can be profitable for a short time before entering the similar products to the market. Competitors are monitoring the market continuously and producing the same product with enhanced features. By integrating services with products, a company can reduce the chance of imitating by other competitors because achieving the logic and required skills of a provided service is a tough work.

The last but not the least, services create growth opportunities in matured markets (Brax, 2005). Growing an installed base is very difficult for equipment manufacturers. Therefore, companies have to develop services to maintain growth. For example, Otis sold about 100,000 new elevators and escalators while provided services for more than 1.5 million of installed base (Harvard Business Review, 2008).

2.1.3. Innovative service solutions

Manufacturing firms seek to find new value sources because physical products no longer lead to competitive advantage. Therefore, they try to add new services, combine services with products and offer integrated solutions to enhance their competitive advantages (Brax and Jonsson, 2009). Companies need to provide services that differentiate their total offering from other players in the market. This ability of driving a market requires great concentration on innovation in service solutions.

Creativity and innovation in services is a must in today’s business. Companies should be able to “think for the customer” and offer more value to them (Kandampully, 2002). It means service providers should analyze the customers’ businesses continuously to identify the current requirement of customers and respond to them. More importantly, they should be able to predict future needs of customers based on current information. Innovative services provides several benefits to a company include increasing the profitability of existing offering, attracting new customers, improving current customers’ loyalty, developing new market opportunities (Menor et al. 2002), improving or changing the image of company, providing a platform for introducing future products (Storey and Easingwood, 1999).

Creativity in service offerings can be done in several ways. den Hertog et al. (2010) define service innovation as:

> *A service innovation is a new service experience or service solution that consists of one or several of the following dimensions: new service concept, new customer interaction, new value system/business partners, new revenue model, new organizational or technological service delivery system.*

This definition shows that almost all possible innovative service solutions are intangible. As it has been mentioned before, intangibility make it hard for the competitors to imitate the service solutions but and it also make it hard to measure how much the innovation is successful and effective.

It also shows that that offering new service functions requires several function management domains. According to den Hertog et al. (2010)’s dimensional model of service innovation, those required functions include sales and after sales services, partnering, mergers and acquisitions, and procurement, finance strategy, human resource management, technology, information and communication technology, and marketing strategy. Furthermore, service function interacts with internal and external customers, several networks, alliances and partners. Among these connections, external networks have a great importance in terms of achieving the required capabilities and knowledge to fulfill customer requirement (Kandampully, 2002).

In spite of extended opportunities for service innovation, most of the researches in innovation domain are focused on products (Nijssen et al., 2006). Innovation is clearly an important factor for most companies to do business in today’s hostile markets. New product development has been recognized vital for companies’ competitive advantages for several years; however services as one undisputed sources of income need to receive the same attention. Products and services have different characteristics. Figure 1 shows the main characteristics of services (Nijssen et al., 2006; Wolak et al., 1998).

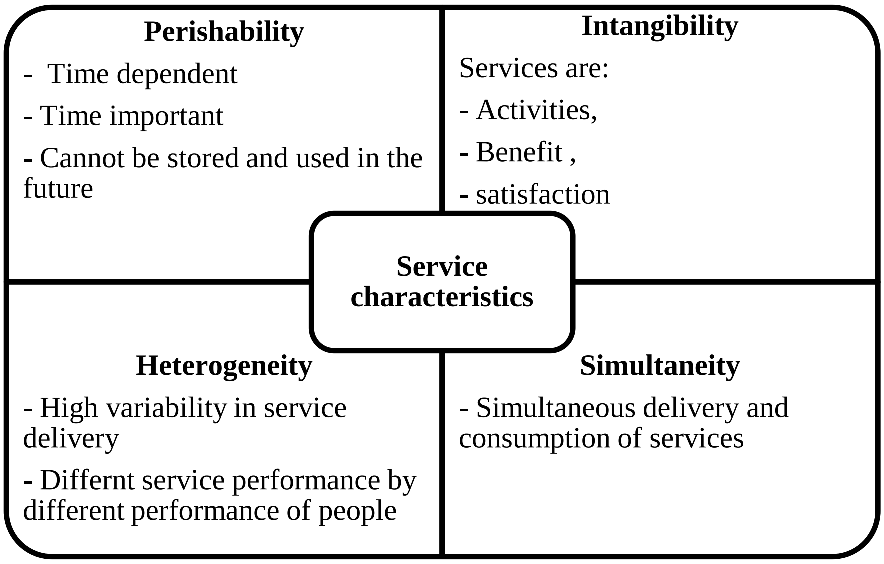

Figure 1. Main characteristics of services (Adapted from Nijssen et al., 2006 and Wolak et al., 1998)

The highlighted characteristics of services in Figure 1 lead to different ways of development of products and services. Nijssen et al. (2006) studied similarities and differences between successful companies in New Product Development (NPD) and New Service Development (NSD). The result of their studies is presented in Table 1.

Table 1. Similarities and differences between successful NPD and NSD firms (Adopted from Nijssen et al., 2006)

Similarities	Differences
Strong commitment to innovation	Higher interaction between NSD and service delivery than the relationship between NPD and production
Well-structured innovation efforts	Higher need to fit between the new service and existing systems than in a production context
Allocate considerable resources	Smaller role and influence of the R&D department in service development
Align the cultures and systems to the innovation processes	

Among all specific characteristics of services, close relationship with customers is vital in service innovation. One of the key elements for offering innovative services is interacting with customers (Kandampully, 2002; Galloug and Weinstein, 1997; Hipp and Grupp, 2005). There are many terms for this relationship such as interface, interaction, co-production, 'servuction', socially regulated service relationship, service relationship (Gallouj and Weinstein, 1997). Regardless of the used term, maintaining a continuous relationship with customers is considered as an important strategy. It helps the company to achieve the latest information about customer’s changes, needs and expectations (Kandampully, 2002). Providing suitable service solutions requires close collaboration between customers and manufacturers because the manufacturer needs to understand the production of the customer deeply.

A company needs to analyze all customer needs; not only the current requirement but also predicted needs in the future. Fulfilling these holistic needs is possible by mixing different products and services, offering new services or procuring required competencies via strategic alliances (Kandampully, 2002).

One of the key facilitators in service innovation is information and communication technologies. Information and communication technologies have become very helpful in service innovations. Through information technologies, the time and location between service provider and the customer are eliminated (Hipp and Grupp, 2005). Therefore, manufacturer can create a continuous relationship with customers in different locations and gather required data for further analysis. Sensors are among the most used components to acquire data in different business environment (Wehner et al., 2011). Sensor-based solutions have achieved considerable attention in service-related studies. Next chapter will focus more on this concept and presents several cases in service domain.

2.2. Sensor-based service solutions

The pervasive computing on the shop floor has resulted in a dynamic network of networked devices in manufacturing field, called Internet of Things (IoT). The concept was introduced after 2000 and it includes several related approaches (De Souza, 2008). IoT concept is about integration of various things into the Internet infrastructure flawlessly and securely, with using standard communication protocols (Mazhelis et al. 2013). IoT has four key components including sensing, heterogeneous access, information processing, applications and services (Chen et al., 2012). Internet-enabled things can be utilized in various domains from home appliances to smart grids and high-resolution asset and product management. They have several benefits such as facilitating or simplifying environment sensing and automated sensing (Mazhelis et al. 2013).

Several technologies and approach belong to IoT, such as wireless sensor networks (WSNs), remote monitoring system (RMS), RFID (radio-frequency identification), machine-to-machine (M2M) communication, machine type communication (MTC). These technologies have some differences in the level of each mentioned key components. The technologies that are going to study in this thesis are: RFID (radio-frequency identification), machine-to-machine (M2M) communication, and remote monitoring system (RMS) because these solutions are the most applied technologies or most discussed technologies in engineering firms. In this section, each of the mentioned technologies is explained briefly but the focus is on Remote Monitoring System. The main reason for this defined scope is related to the case companies and their current sensor-based solution which is closer to RMS.

2.2.1. Radio-frequency identification (RFID)

RFID is a technology to identify objects and people automatically. It facilitates the perception of objects by clearly labeling them with computing devices (Juels, 2006). Actually, it is a wireless sensor technology that detects electromagnetic signals (Domdouzis et al, 2007). The RFID system usually consists of three components: an antenna or coil, a transceiver (with decoder) and a transponder (RF tag) electronically programmed with unique information (Domdouzis et al, 2007). The RFID technology and its applications have achieved more attention compare to other approaches in IoT. Several key players in various industries has accepted and implemented this technology.

According to Zelbst et al. (2012), RFID's benefits can be categorized in three groups. First, the automational effect that makes the process more efficient. It reduces labor cost, improves inventory replenishment and reduces the required time to process shipping or receiving. Second, the informational effect that improves responsiveness, reduces waste and improves utilization of assets. These benefits are gained through the ability of the technology to collect, store, process and distribute information. Third, the transformational effects that comes from the ability of the technology to make process innovation and transformation, such as process redesign.

RFID technology has been utilized in several fields. Table 2 shows only some of these studied applications to present the possible opportunities in this field. The technology has also been applied in healthcare and transportation significantly

Table 2. Some of the studied applications of RFID

Industry	application	Author
Oil industry	Construction and maintenance of oil facilities: the correct assembly of the pipework systems	Domdouzis et al, 2007
Car production line	Correct placement of the components during assembly and tracking of the desired components	Johnson, 2002 Domdouzis et al, 2007
Retail industry	Tracking of returnable packaging and transport units with active RFID in the grocery supply chain	Alejandro et al., 2009
Manufacturing	RFID-based smart Kanban system for work-in-progress (WIP) management; A real-time manufacturing information system for controlling flows of information and materials of the entire shop-floor; Facilitating just-in-time (JIT) ordering	Zhang et al., 2008; Huang et al., 2008; Zelbst et al., 2012

Most of the studied applications of RFID are related to its effects on reducing inventory, flow of information in the shop floor and improving assembly process. There are few studies in the field of RFID's applications in services and the existing ones are more related to its application in service organizations like healthcare (Heim et al., 2009). However, RFID's industrial service applications have not been investigated considerably.

2.2.2. Machine-to-Machine (M2M) communications

Machine-to-machine (M2M) is about communications between computers, embedded processors, smart sensors, actuators, and mobile devices without or with limited human intervention (Chen et al., 2012). The foundation of M2M communication is based on two observations; first, a machine which is connected to a network of machines is more valuable than an isolated machine. Second, interconnection of several machines results in creating more intelligent applications (Lawton, 2004).

Both wireless and wired systems can communicate with other devices which have the same ability via M2M communication technologies (Chen et al., 2012). Following example can clarify the M2M paradigm. Imagine a fridge in a home which is part of a M2M network. The fridge can collect data about the number and state of items that it contains. The fridge can be connected via the internet to report the stock situation to a grocery store chain. Then the store can run a dispatch chain to restock food items in all the houses that it monitors (Chen et al., 2012).

The most recognized M2M's application is in the satellite navigation system. In this application, the M2M allow the transferring of the latest traffic information, useful location information to drivers on the road (Lu et al., 2011), remote control and monitoring activities, robotics and offsite equipment diagnostics (Lawton, 2004). However, today, M2M has been applied in various fields such as healthcare, smart robots, cyber-transportation systems, manufacturing systems, smart home technologies, and smart grids (Chen et al., 2012). Lu et al. (2011) categorized best known applications and benefits of M2M communication that are presented in Table 3.

Table 3. Typical applications and benefits of M2M communication (adopted from Lu et al., 2011)

Typical applications	Benefits
E-healthcare	Remote patient monitoring for better health-care
Smart home	Real-time remote security and surveillance
Environmental monitoring	Effective monitoring at low cost
Industrial automation	Remote equipment management for cost savings

The important characteristics of M2M communication is that machines could not only gather data about other devices but also, in some cases, take action based on the information. Actually, this attribute (no or limited human intervention) is the main distinction of M2M communication with wireless sensor network and subsequently remote monitoring system where the operators finally decide about required actions based on the collected data. The M2M literature is not as strong as other solutions such as RFID and it is more about the possibilities in this field than practical solutions and approaches. This issue is even more obvious in the industrial service business.

2.2.3. Remote monitoring system

Today's industrial environment utilizes several complicated equipment to produce their products. Lee (1998) believes that one of the main problems of many transplants is equipment's failure because identifying the cause of machine breakdown is difficult. The main reasons for this difficulty include system complexity, uncertainties and lack of suitable tools for finding and correcting failures. The expensive machines should work at high operation rates and low breakdown rate (Biehl et al., 2004). The unpredicted breakdowns in some parts of equipment can stop the operation and cause economic loss, in addition to the damage of the equipment itself (Hou and Bergmann, 2012). Therefore, companies need to develop services to identify the abnormal situation in machines and their causes. Furthermore, they should be able to predict and solve problem as early as possible to prevent discontinuous production.

According to Lee (1998), industries should utilize new information and telecommunication technologies to enhance the quality of services. Sensor-based systems as one of the most important advancements in this domain have helped companies to receive real time data from several machines, analyze them and do right actions in the right time. These technologies enable factories to monitor their products from anywhere in the world remotely. There are several terms for these kinds of systems in literature and industries. Remote monitoring system (RMS) is a term that will be used in this thesis. Figure 2 shows a simple presentation of remote monitoring system.

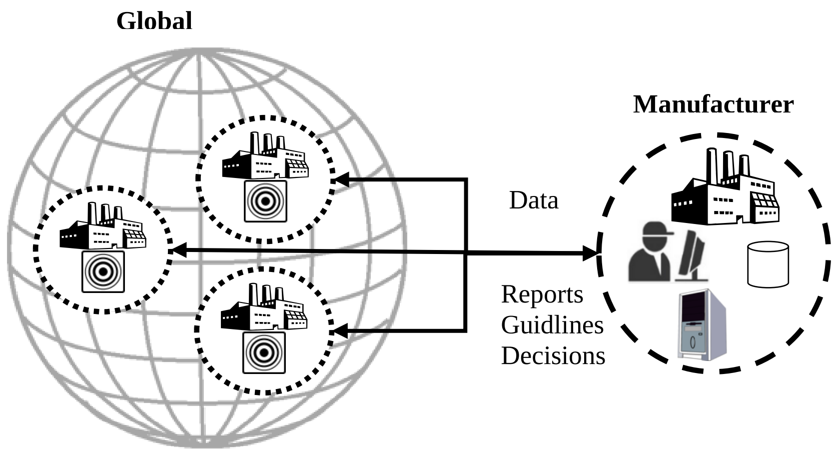

Figure 2. Simple illustration of RMS

One of the most influential applications of sensors in industrial environment is Remote Monitoring System (RMS). A RMS is a collection of sensors and data transmitters which are placed on the products and enable the manufacturer to provide remote monitoring services (Westergren, 2011). The system consists of several technologies including sensors that gather data, networks that transmit data to a repository, and analytical and operational rule systems which are responsible for storing, retrieving, analyzing and visualizing data as well as making recommendations and making alarms (Jonsson et al., 2009).

The sensors embedded in the system provide real time data about equipment like the current status, unusual use and any signs of breakdown (Westergren, 2011). Sensors are installed on critical components of different equipment in one or multiple plants. This capability provides the opportunity to have a global remote service center to diagnose numerous production systems and their components across several organizational boundaries (Jonsson et al., 2009).

RMS or as called by Lee (1998) “tele-service engineering systems” can evaluate the performance of products in the customer’s site, manufacturing equipment, and quality of production and in general productivity of the plant which are located in different places. With help of RMS a service provider can monitor equipment which is installed locally in the customer site and analyze machine data (Westergren, 2011). By applying remote monitoring system, existing boundaries between different sites are blurred. When the system can analyze data of multiple locations, it provides a valuable set of information and knowledge. It helps the technicians to learn from the past occurrences and diagnose failure proactively (Jonsson et al., 2009).

The specific characteristics of digital data including accuracy, timeliness, volume, multi-dimensionality and extended time-span help the remote monitoring system to represent the production status in the best way (Jonsson et al., 2009). The gathered digital data through sensors can be computed in several ways and thus provide variable valuable analysis. It makes the decision making faster and less dependent to the location (Vogl et al., 2009).

While proactive maintenance is one of the key applications of remote monitoring system, it has also some other important functionalities in the service domain. As it has described in the previous section, identifying customer needs and providing suitable and on time offerings are among the main concerns of manufacturers. Tracking and monitoring all machines and components and subsequently, increased knowledge of products, is a key competence for the service provider (Jonsson et al., 2009).

RMS provides different opportunities for firms to innovate and create value including both internal and external process innovation (Westergren and Holmström, 2012). Westergren (2011) considers RMS as not only a driver but also an enabler of service innovation because this system can transfer a manufacturer to a service provider. The manufacture can keep its real time contact with its customers after leaving the factory.

Continuous monitoring and gathering data can provide an excellent ground for manufacturer to create new services.

Considerable progress in the field of internet and mobile communication leads to a rapid development of remote monitoring systems (Wang et al., 2007). For example, Mori et al. (2008) explain that remote monitoring and maintenance systems in Japan connect over 8000 machine tools worldwide.

2.3. Value drivers for remote monitoring system

The perceived benefits of RMS are definitely the key driver to accept this system from both manufacturer and customer. Figure 3 shows some of these benefits for both groups.

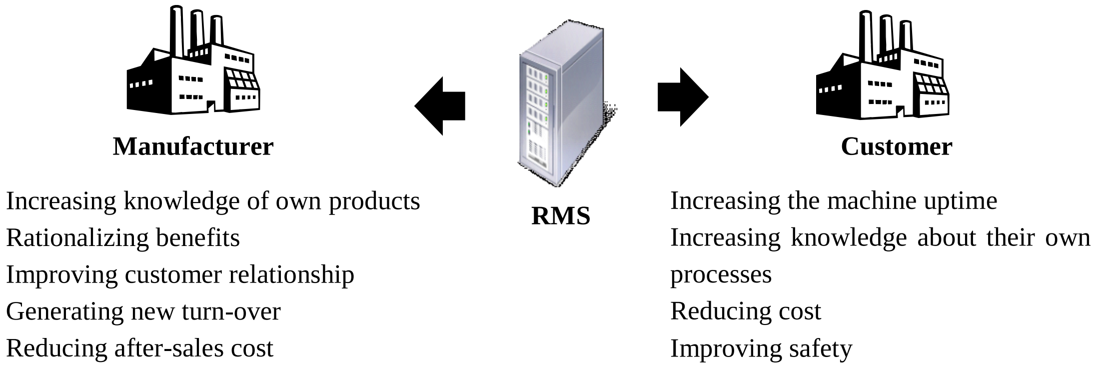

Figure 3. Value drivers of RMS for manufacturers and customers (Adopted from Jonsson et al., 2008; Westergren, 2011; Westergren and Holmström, 2012; Küssel et al., 2000; Biehl et al., 2004; Wang et al., 2007; Wu et al., 2006)

Remote monitoring system can provide several benefits and opportunities for manufacturers. First, the manufacturer can increase its knowledge of products by gathering and analyzing data through RMS (Jonsson et al., 2008; Westergren, 2011). This knowledge is valuable for product development (Westergren and Holmström, 2012). They can realize the way that customers use their product and the improvement areas for further development.

Second, rationalizing benefits is another advantage of RMS. Rationalizing benefits is related to the reduced cost during implementation and warranty phases. First, during implementation phase, the manufacturer can reduce the time and cost through remote supporting of the service personnel of the company who works on the customer site by the service personnel in the headquarters. Second, during warranty phase, remote monitoring system enables the service personnel to do minor services without going to the customer place and thus reduce the travelling cost. In a case that providing services is not possible from distance, the service provider can analyze the failure through the remote monitoring system before visiting the installed base. This evaluation reduces the invested time and cost in the customer site (Küssel et al., 2000).

Third, customer relationship can be enhanced considerably by applying remote monitoring systems (Küssel et al., 2000). Monitoring the installed base can help the manufacturer to better understand the customer, improvement areas in their own product and current and/or upcoming needs of the customer. This constant involvement with the customer leads to improved services and products and consequently enhances the customer relationship.

Fourth, new turn-over is another benefit of remote monitoring system (Küssel et al., 2000). As it has described, remote monitoring enables the manufacturer to identify different requirements of the customer and provide suitable services. Furthermore, they can provide integrated service solution to the related customers by analyzing the data from several customers. The new service solutions can be new sources of income for the manufacturer.

Fifth, remote monitoring system can decrease cost of after-sales activities. This benefit of RMS has become very important in today's global business where customers are no longer belonging to a limited geographical area. While this extended market help the firms to increase their turn-over, it can make some problems in providing required services. The companies need to establish some branches in each area or send their experts to different locations regularly that increase the cost of services for the service provider. RMS can save 20% to 30% of after-sales costs. This cost saving is very important for small and medium-sized manufacturers because they can reduce the cost of travelling and provide efficient services to their global customers (Biehl et al., 2004).

On the other hand, customers benefit from remote monitoring system too. One of the main expected benefits of RMS for the customer is increasing machine uptime and speeding up the production process by reducing unplanned production stops. It also results in more efficient and streamlined process (Jonsson et al., 2008; Westergren, 2011; Westergren and Holmström, 2012; Wang et al., 2007; Wu et al., 2006).

The collected data can also increase the customer's knowledge about its own processes (Westergren, 2011; Westergren and Holmström, 2012). The customer can access information about each component and processes and realize the bottlenecks, miss-use of equipment and other important factors in its production process.

RMS can also reduce costs in the customer site (Westergren and Holmström, 2012; Wang et al., 2007). Cost of unplanned stops in the production line can be reduced by continuous monitoring through RMS and do the proactive maintenance. This is highly important in continuous process industries. According to Biehl et al. (2004), RMS could save about 60 billion dollars a year in American continuous process industries like chemical and oil companies. Reduce the cost of services is more important for the customer after the warranty time because customers usually have to pay all costs of services and maintenance in this phase (Küssel et al., 2000; Jonsson et al. 2008). RMS can help them to identify problems earlier and do required actions before the big breakdown in their systems.

The last but not the least benefit for the customer is improving safety in the plant (Wu et al., 2006). Changing in pressure, temperature, rotating speed and other parameters of different parts may result in awful sequences. If the customer cannot predict these risks, it may threat the labors in the production line. RMS can increase the awareness of customers about any abnormal situation in their systems that may cause safety problems in their sites.

Table 4 shows the map of value drivers which have been highlighted in several researches. As it can be seen from Table 4, increasing knowledge of own products is the most cited value drivers for the manufacturers. Gathered data from customers' sites provide several opportunities for the manufacturer to develop their own products. On the other hand, reducing cost seems to be the most important value drivers for the customers. Cost saving is usually the main motivation of customers to accept new solutions from the suppliers.

Table 4 also shows that the frequency of customer's value drivers is more than manufacturers in literature. Most of the researches in the field of sensor-based solutions are focusing on effects of these solutions on the customers' operations and try to highlight how the customers benefit from these systems. However, as explained in this section, sensor-based solutions can create several values for the manufacturers too. Focusing more on these value drivers can provide more forcing drivers for manufacturers to seek opportunities to develop sensor-based solutions.

Table 4. Map of value drivers of sensor-based solutions

	Jonsson et al. 2008	Küssel et al., 2000	Biehl et al., 2004	Westergren, 2011	Westergren and Holmström, 2012	Wang et al., 2007	Wu et al., 2006
Manufacturer's value drivers							
Increasing knowledge of own products	√			√	√		
Rationalizing benefits		√					
Improving customer relationship		√					
Generating new turn-over		√					
Reducing after-sales cost			√				
Customer's value drivers							
Increasing the machine uptime	√			√	√	√	√
Increasing knowledge about their own processes				√	√		
Reducing cost	√	√	√		√	√	
Improving safety							√

2.4. Current applications of remote monitoring system

Remote monitoring system helps companies to do condition monitoring. Condition monitoring is based on sensors that can measure several parameters of equipment like vibrations, temperature, power consumption and so on. (Owen et al., 2009). Owen et al. (2009) define condition monitoring as continuous analysis of affected parameters of a machine to provide early notice of reliability problems. In the past, condition monitoring was limited to the industries which would incur high economic loss or safety issues due to equipment failure. However, today many industrial firms apply condition-based solutions such as aerospace, military, power generation, shipping, mining, papermaking, petrochemicals, water supply and offshore oil and gas (Bogue, 2013).

The applied sensors for condition monitoring can be wired or wireless sensors. Wireless sensors are attracting more applications because they do not need the expensive wiring and also can be placed in more suitable location that cannot be done by wired solutions like on rotating components (Owen et al., 2009). They can also be installed and maintained more easily (Gomes et al., 2013). Another key benefit of wireless sensors is the possibility to install them where no power is available (Bogue, 2010). Table 5 shows some of the techniques of condition monitoring and their applications.

Table 5. Techniques of condition monitoring and their applications (Adopted from Bogue, 2013; Bogue, 2011; Vogl et al., 2009; Sion and Atkinson, 2002; Gomes et al., 2013; Kurada and Bradley, 1997; Huang, 2014; Everall et al., 2000)

Technique	Applications
Vibration monitoring	shafts, bearings, gears and fan blades, in engines, pumps, electric motors, generators, compressors and gear boxes
Acoustic emission technique	pressure vessels, storage tanks, offshore rigs, heat exchangers, pipework, reactors and nuclear power plant
Thermal techniques	circuit breakers, transformers, distribution panels and bus bars
Monitoring the metallic particles	gas turbine engines, helicopter gearboxes, marine and other diesel engines, wind turbine gearboxes, hydraulic systems
Measuring the in-cylinder pressure	combustion engine
Monitoring the torque	electronic motors
Electrical signature analysis	electronic motors
Pressure sensing	automotive sector: engine management, fuel delivery, stability and emission control systems , monitoring tyre pressure; military and aerospace sectors
Proximity sensors	tool condition monitoring
Cutting force signals	tool condition monitoring

Vibration monitoring is one of the most applied techniques of condition monitoring. It can be used for several rotating components and equipment including shafts, bearings, gears and fan blades, in engines, pumps, electric motors, generators, compressors and gear boxes (Bogue, 2013). For example, accelerometer is the most suitable sensor for measuring high frequency vibrations or velocity and displacement sensors are appropriate for low frequency vibrations (Vogl et al., 2009). The transmitted data from the sensors can be applied to analysis the changes in the frequency of vibration and detect early damage in the components (Bogue, 2013).

To monitor frequencies that are above the audio range, and are usually caused by cracks, fiber breakage or delamination in composites, the acoustic emission (AE) technique is applied. Some components and structures that can be monitored with AE are pressure vessels, storage tanks, offshore rigs, heat exchangers, pipework, reactors and nuclear power plant (Bogue, 2013).

Many failures in mechanical and electrical equipment lead to an increased temperature in the components. Thus, thermal techniques are widely used for condition monitoring. One of the thermography instruments is microbolometers sensors. They can be placed on electrical components such as circuit breakers, transformers, distribution panels and bus bars to detect loose contacts, corroded nuts and bolts and broken conductor strands. In case of mechanical equipment, this technique can detect breakdowns like tightening bearings in motors and pumps or blockages in pipework (Bogue, 2013).

One applied technique of condition monitoring to detect early warning of failure in the components is monitoring the metallic particles which are generated by wear processes in lubricants. Analyzing different attributes of these particles such as size, shape and their quantity shows the condition of the component. This method is practical for monitoring components like gas turbine engines, helicopter gearboxes, marine and other diesel engines, wind turbine gearboxes, hydraulic systems (Bogue, 2013).

Measuring the in-cylinder pressure of an internal combustion engine is one of the studied applications of sensors for condition monitoring. The continuous monitoring of the pressure allows the experts to identify any possible knock, misfire and other failures as early as possible and thus lead to increase the efficiency of the engine (Sion and Atkinson, 2002).

One of the main sources of power usage in industrial plants is electronic motors. According to Gomes et al. (2013), electronic motors consume two-thirds of electricity in the industrial sector. Thus developing monitoring systems can be very helpful to optimize the operation of motors. There are different techniques to monitor the motors for example monitoring the torque. It is critical parameters that can be estimated from the motor electric signals. Monitoring torque can reduce motor failures and losses in the production. It can also be used to estimate motor efficiency which is an important factor for reducing power consumption (Gomes et al., 2013). Another method for motor monitoring is electrical signature analysis. This method analyzes the variations in voltage and current signals to relate the signature characteristics with electrical and mechanical conditions. Vibration analysis is another way to monitor the motors. It uses accelerometers and monitor parameters like displacement, velocity, and acceleration to detect faults in motors (Gomes et al., 2013).

Pressure sensing is another application of industrial sensors. Pressure sensors are based on micro-electromechanical systems (MEMS) in almost all cases. This system allows the sensors to achieve high performance and measure a wide range of pressure. For example, these sensors are used in automotive sector for engine management, fuel delivery, and stability and emission control systems and to monitor tyre pressures. The more expensive types of these sensors are used in military and aerospace sectors which use high performance MEMS pressure sensors (Bogue, 2013).

Tool condition monitoring is one of the important applications of sensors in the industry sector. It has direct effect on the cost of production and the quality of parts. Sensors can optimize the performance of machine tool by gathering related information about machine, process and part. Specially in the case of unsupervised centers, utilization of sensors can reduce time and improve quality of the parts. For instance, cutting tool as a common tool in manufacturing can reach to end of its life due to gradual wear or edge failure. These defects have direct effects on the surface quality of the machined part. Different sensors can be applied to monitor the efficiency or predict the life of the cutting tool like proximity sensors and cutting force. Proximity sensors can measure the change in the distance between the edge of the tool and the part to estimate tool wear. Cutting force signals is also used for condition monitoring. In this method, a dynamometer is placed on a tool holder to monitor the cutting force. The force sensor signal can measure the required force and detect the best time to replace the tool (Kurada and Bradley, 1997).

After reviewing different techniques of condition monitoring, it is good to study a sensor type that has attracted considerable focus both in studies and industries: fiber optic sensor (FOS). According to Huang (2014), the main reasons for this popularity are their small size, cost-effective, immunity to electro-magnetic interference and ability to work in harsh environment. FOSs can measure several parameters such as thermal, mechanical and electrical quantities like temperature, strain, pressure, vibration, current and voltage (Bogue, 2011).

Among all the mentioned parameters, monitoring temperature has been applied more successfully and there are more manufacturers for this type of FOS (Bogue, 2011). Bogue (2011) has studied several temperature sensing applications of FOS such as:

- Monitoring transformer temperatures
- Medical (e.g. in vivo) temperature sensing
- Cooking temperature monitoring

- Monitoring temperature of power lines and underground cables
- Temperature (fire) monitoring in tunnels
- Gas and liquid pipeline leak detection
- Monitoring reactor vessel temperatures
- Monitoring temperature in oil wells and boreholes

For example, a developed FO strain sensors can sense both temperature and strain. They can be used in several industries and civil engineering applications to monitor different parts and structures such as reactor vessels, pipelines, wind turbine blades, bridges, buildings and dams (Bogue, 2011).

Another used attribute of commercial FOS is the magneto-optical Faraday effect that can be applied in the power and process industries. They are applied to measure high voltage and currents. Some applications include monitoring voltages in electrical substations and the current in overhead distribution lines, controlling currents in aluminum smelters and the electrolytic processes in metal production, and locating faults in high voltage, underground cables (Bogue, 2011).

A studied application of FOSs has been done by Smart Fibers company. They installed their Optical Fiber Strain Sensor System on a 42ft cruising yacht. During the production, the sensors were embedded in the composite laminate. Via this system, they could monitor loading during tracking and gybing. The collected information helps the designers to better understand the structural performance and subsequently improve composite design, in-service performance of composite structures and finally expand the market for this type of structure. They can also use this accurate data to remove unwanted weight and unnecessary strength (Everall et al., 2000).

2.5. Case studies of remote monitoring system

Application of information and communication technology in the industry has achieved significant attraction. There are considerable numbers of researches that study the use of sensor-based solutions in several domains. Westergren and Holmström (2012) summarize some of the main studies in the field of remote sensing, including:

- Use of smart machines within the pulp and paper industry (Zuboff,1988),
- Use of GIS in India (Puri, 2007),
- Undersea oil well maintenance (Østerlie, Almklov, and Hepsø, 2012).

Pan et al. (2008) also highlights some studies and applications of remote diagnostic systems in different industries:

- Creating a web and virtual instrument based machine remote sensing monitoring and fault diagnostic system to diagnose motor conditions of a cooling tower, (Tse and He, 2001)
- Implementing case-based reasoning on a remote diagnosis system to monitor the conditions of a die-attaching machine (Huang et al., 2002)

Wang et al. (2007) have mentioned some other applications of remote machine monitoring and diagnosis, including:

- Diagnosing a scanning electron microscope via internet (Caldwell et al., 1998)
- Using a multi-agent technology to create a web-based fault diagnostic and learning system (Ong et al., 2001)
- Using a web-based remote monitoring system for open NC devices (Yuan et al. 2004)

In this section, some specific cases in the field of sensor-based solutions are explained. These examples mainly concentrate on the manufacturer-customer relationship and application of remote monitoring systems to provide suitable services to the customer.

One of the first uses of communication and information technology was happened in America in 1975 where a data transfer system was designed to decrease the cost of service department. However, it was not a successful implementation at that time because of low transfer speed, poor quality of data transfer and weak communication infrastructure (Küssel et al., 2000).

A Swedish company called PowerDrive is a good example of RMS implementation. Actually, PowerDrive, like most of other manufacturer, has provided fieldwork services for its customers. That needs service technicians to visit the customer's site and do the required services. This type of providing services is quite expensive and sometimes inefficient. As a manufacturer of hydraulic systems, PowerDrive has tried to create new business value by providing after-market services based on data analysis of RMS (Westergren, 2011). Through sensors which are installed in the motor, the RMS collects data about performance and condition of hydraulic motor like pressure, temperature, speed, oil quality and flow (Westergren, 2011). When something unusual is detected, the technicians are informed by an automatic alarm via SMS or email which shows the problem information (Jonsson et al., 2009). Therefore, service technicians do not have to visit the customer on site for all kinds of problems.

The RMS enables the company to create a more structured and efficient service process. It also helps the PowerDrive to review and analyze its products and use it in their product development endeavor. The last but not the least benefit for PowerDrive is the possibility to understand how their customers operate and utilize the product (Westergren, 2011). One of the advantages of the system for PowerDrive's customers is to understand how their operators utilize the product. For example, a warranty claim of a customer was reviewed by PowerDrive based on the data from the remote monitoring system and they found out that the work routines had to be changed in the customer site (Jonsson et al., 2009).

Mori et al. (2008) explain a remote monitoring and maintenance system (RMMS) for machine tools. Through this system, the manufacturer can access to the CNC unit of an installed base in the customer place. When there is a need for a service from the manufacture, the machine tool sends a service request automatically via email. Then the service personnel of the manufacturer analyze the status of the machine tool through RMS. They can also do the preventive maintenance by the developed monitoring system. The mentioned system monitors different parts of the machine tool like spindles and NC batteries. Service personnel analyze the indexes that can show the predicted lifetime of the components. For example, the rotation number of the spindle or the machine tool usage time for the CNC battery can provide useful data for the manufacturer to identify the necessity of a preventive maintenance. The result of developed RMMS shows the increased operating rate and decreased downtime. Actually, the average operation rate was increased from 60% in 2005 to 70% in 2007. On the other hand, the average downtime rate which was 1.5% in 2005, declined to 1% in 2007.

Xerox has also developed a remote sensing technology to monitor copiers and do the required services and maintenance in its service center through data transmission via phone lines (Biehl et al., 2004). PrInteract, Xerox Remote Services, is a group of optional services that are performed based on the XPresso™ platform (Xerox.com). Figure 4 shows some of the main features of this system.

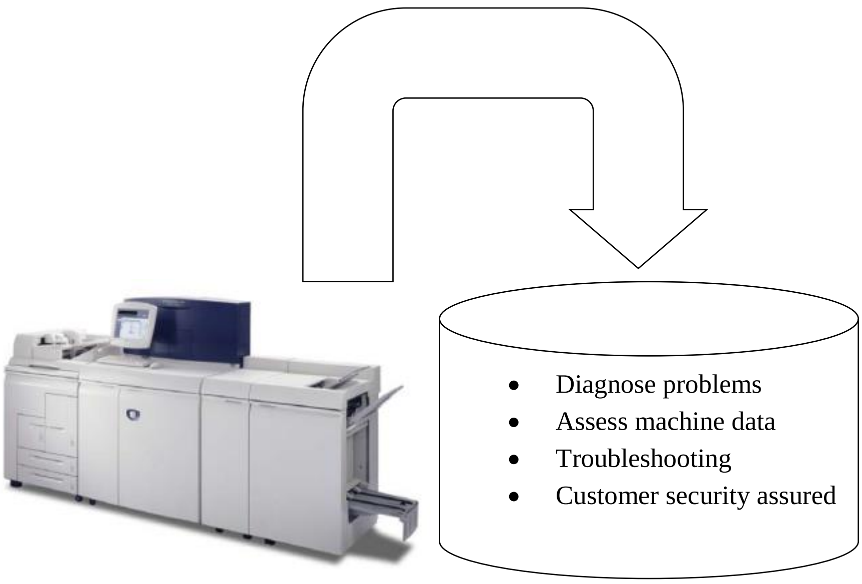

Figure 4. prInteract, Xerox Remote Services (Adopted from Xerox.com).

The services can be performed in two ways for Xerox's customers. Call for assistance is one option that can transfer machine data on demand. Automated remote monitoring the system is another option that can be performed for Xerox Nuvera (Xerox.com).

Hewlett-Packard is another example which monitors the hardware installed in the customer place. Based on its remote monitoring system, HP identifies required preventive maintenance and sends technicians or the required parts before machine breakdown (Biehl et al., 2004). HP Insight Remote Support (IRS) and HP Proactive Care can help the customer to mitigate risks, reduce cost and focus on their business. These systems provide almost 100% accurate diagnostic. All Information is sent to HP call center staff. They can log in remotely and identify the problem and decide whether the problem can be resolved immediately or it needs an onsite visit. Customers also receive periodic proactive advice and reports about critical areas in their business (hp.com).

An American company called Honeywell has developed remote monitoring systems for chemical plants to monitor both equipment health and abnormal situation. Through these complex systems, the customer can monitor all facilities in a central control room. The Honeywell can also monitor the customers' equipment remotely from its main office (Biehl et al., 2004). Cellu Tissue Holdings, Inc. is one of the customers of Honeywell that produces a combination of internally converted tissue products, machine-glazed paper and tissue hard rolls. The company has applied Honeywell's remote monitoring for its paper machines. Through this system, Honeywell technicians are notified about any abnormal changes in key performance variables. The technicians can access the system to understand the problem better and they can connect to the customer's technicians and help them to solve the problem. Therefore, it is possible for the customer to reduce or even eliminate system downtime (Honeywell.com).

A research project in Switzerland that called NePESM (New Paradigms for Embedded Systems Management) in association with ABB Corporate Research Ltd (Switzerland) resulted in a remote diagnostic and monitoring system for railway equipment. The system provides web pages for monitoring and maintenance of the equipment. The maintenance system is installed on the vehicles and makes it possible for the service personnel to monitor all of them from their office and allow remote diagnosis and monitoring (Nieva, 1999). Figure 5 shows the architecture of this system.

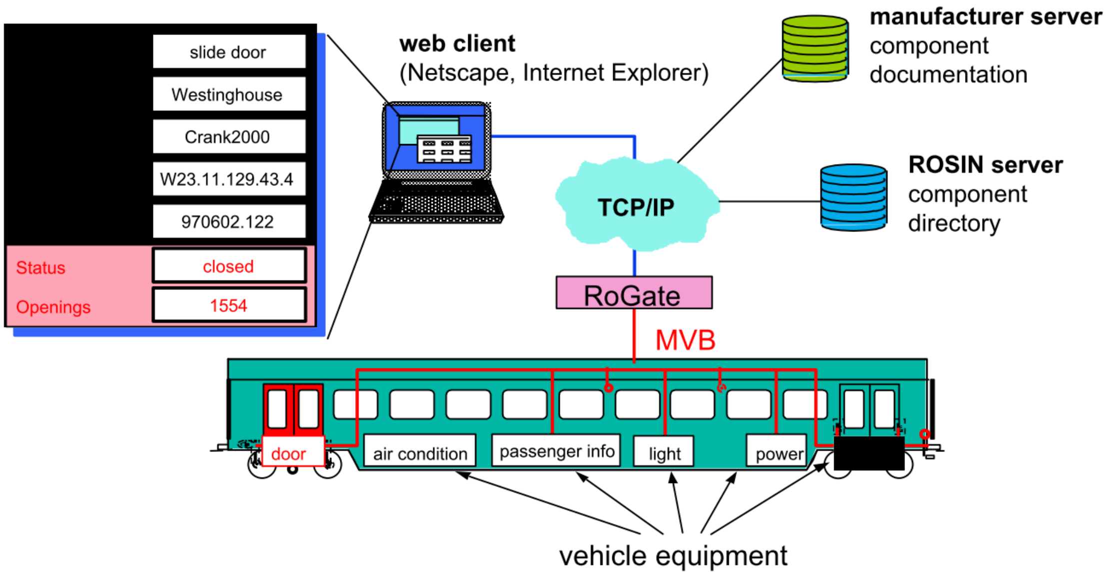

Figure 5. System architecture of remote diagnostic and monitoring system (Adopted from Nieva, 1999)

As shown in Figure 5, there is an element in the system called RoGate (Railway Open GATEway) that is connected to a fieldbus. The fieldbus interconnects several devices such as sensors and PLCs which are installed on equipment like doors, brakes and HVAC. The main part of the RoGate is the GLASS server, which is a remote monitoring system based on Internet technology. In this server, each vehicle or equipment has a proxy object which retrieves the actual data from the equipment. The component documentation like web pages, Java applets, etc. is usually stored in a manufacturer web server. The manufacturer registers its web pages in a known server (ROSIN server) by giving to the server the component identifier and the hyperlink of its documentation. The server offers a means to get this documentation from the Internet (Nieva, 1999).

Another practical example of sensor-based solutions can be found in a crane manufacturer which provides cranes for the ships. Traditionally MacGregor Cranes send the technicians to the ship to collect information about the condition of the crane. As this way of providing services was expensive for both service provider and the customer, MacGregor Cranes developed a remote monitoring system to monitor the cranes in different sites. Sensors are placed on the crane to transfer the data about condition of the crane to the crane control system. The sensors measure several attributes such as temperature, pressure, speed and the time of use. For example, when the pressure decreases, it might be sign of breakdown in some parts of the crane. In addition to these urgent problems, MacGregor Cranes can analyze different parameters and provide preventive maintenance to the customers. Furthermore, the company can use the collected data to identify the potential problems in its products and try to avoid them via product development. MacGregor Cranes and its customers achieve several advantages from the system including minimizing operational hold-ups, reducing the complexity of information handling, reducing language problems between technicians of the company and customers (Jonsson et al., 2008).

The last case study in the field of sensor-based solutions is LKAB, an international high-tech mineral group in Sweden. The company has installed sensors in all parts of the production line to improve its equipment monitoring and preventive maintenance. The company has invested in remote-control operations considerably; it increased its investment from 3 million SEK in 2003 to 11 million SEK in 2004. Investing in sensor technology was one of the main parts of this investment. They have increased the number of measuring parameters from 3 to 33 and the number of points of measurement from about 100 to more than 15000 during 20 years. Now, LKAB can collect real-time data such as temperature, oil pressure, and vibrations from all parts of the production line (Westergren and Holmström, 2012).

The most important characteristic of the LKAB case study was the establishment of a joint-venture company called MCC (Monitoring Control Center) by LKAB in 2003. This collaboration was between LKAB and two of its long-term business partners, Sandvik and SKF. Sandvik was the main supplier of mining equipment for LKAB and SKF had developed an advance solution for remote equipment monitoring. Companies had different motivations to join this network. Sandvik could access to data and measurements from its equipment and use it for future product development. SKF had this opportunity to apply its remote monitoring system and develop its methods and technology. LKAB could structure its maintenance organization. By accessing to real time data from all equipment, they could monitor the status of all machineries and identify any abnormal situations and equipment failures. Therefore, they could decrease the number of unplanned production stops and improve the efficiency of the production line (Westergren and Holmström, 2012).

2.6. Critical analysis of prior studies and research gaps

Section 2.2.2 and 2.2.3 shows different applications of sensors and sensor-based solutions in industries. Study about application of sensors has been achieved considerable attention during the last decade and it has been grown significantly; the majority of previous studies in this topic have been done in the last five years. Thus, it is necessary to analyze these papers to understand their context, methodology and research gaps for current study. Table 6 and 7 show the result of the researches analysis respectively about applications of sensors in industrial firms and remote monitoring system.

Table 6. Analysis of prior studies about application of sensors in industrial firms

Autors	Primary focus	Methodology	Key findings for current study	Research gaps for current study
Kurada and Bradley, 1997	Tool condition monitoring	Review	Application of different sensors for tool condition monitoring	Real case studies B2B service applications
Everall et al., 2000	Fibre optic sensors (FOSs)	Review	Application of FOSs for load monitoring and improve the structural performance	B2B service applications
Sion and Atkinson, 2002	Measuring cylinder pressure	Review	Application of sensors for measuring cylinder pressure and improving performance	Real case studies B2B service applications
Owen et al., 2009	Self-powered wireless sensors	Review	Application of sensors for condition monitoring	Real case studies B2B service applications
Vogl et al., 2009	Design and manufacturing of vibration sensors	Review	Application of vibration sensors for condition monitoring	Real case studies B2B service applications
Bogue, 2010	Wireless sensors	Review	Application of wireless sensors	Real case studies B2B service applications
Bogue, 2011	Fibre optic sensors	Review	Applications of commercially available fibre optic sensors (FOSs)	Real case studies B2B service applications
Bogue, 2013	Sensors for condition monitoring	Review	Sensor-based techniques and their applications	Real case studies B2B service applications
Gomes et al., 2013	Wireless sensor networks (WSN)	Review and quantitative analysis	Application of WSN for monitoring motors	Real case studies B2B service applications
Huang , 2014	Fibre optic sensors (FOSs)	Review and quantitative analysis	Characteristics of FOSs	Industrial applications Real case studies B2B service applications

Table 7. Analysis of prior studies about remote monitoring system

Autors	Primary focus	Methodology	Key findings for current study	Research gaps for current study
Nieva, 1999	Architecture of remote diagnosis and monitoring system	Case study	Applications of sensor-based solutions in a real industrial case; Different components of RMS and its process	Other service applications than predictive maintenance
Biehl et al., 2004	Comparison of the U.S., Japanese, German remote repair, diagnostics, maintenance (RRDM) system	Review	Applications RMS in different industries; Value drivers of RMS	Other service applications than predictive maintenance
Wang et al., 2007	Architecture of remote machine maintenance system	Review and case study	Applications of RMS in different industries	Other service applications than predictive maintenance
Jonsson et al., 2008	Value creation through remote monitoring system	Case study	Applications of sensor-based solutions in a real industrial case; Value drivers of RMS	Other service applications than predictive maintenance
Mori et al., 2008	Architecture of remote monitoring system	Case study	Operation process of RMS in a real industrial case	Other service applications than predictive maintenance
Pan et al., 2008	Architecture of remote online machine condition monitoring system	Review and case study	Applications of RMS in different industries	Other service applications than predictive maintenance
Jonsson et al., 2009	Impacts of remote diagnostics systems on boundary-spanning	Case study	Applications of sensor-based solutions in a real industrial case; Identifying applicable services based on sensor-based solution	More details about how to utilize collected data
Westergren, 2011	Open innovation in IT-enabled services	Case study	Applications of sensor-based solutions in a real industrial case; Identifying applicable services based on sensor-based solution	More details about how to utilize collected data
Westergren and Holmström, 2012	Value network in open innovation	Case study	Applications of sensor-based solutions in a real industrial case; Value drivers of RMS for different players in a network	More details about how to utilize collected data

Most of the current works about sensor-based solutions are using literature review as their main methodology. These studies are usually more technical and have less focus on business values of the solutions. However, there are some valuable case studies which focusing on remote monitoring system but they are usually single case studies that try to analyze some aspects of the solution in a real case. The multiple case studies can help to figure out various opportunities in this field and to show differentiation in offerings and the reasons behind them. This thesis tries to fulfill this shortage and cover different aspects of remote monitoring system via multiple case studies. The upcoming chapters show the results of cases and discuss about existing and potential opportunities by doing cross-case analysis and comparing the findings with prior studies.

All reviewed sensor-related researches and specially the case studies shows that most research attention has been aimed toward two main applications of sensor-based solutions: preventive maintenance and product development. Condition monitoring through sensor-based systems and subsequently executing preventive maintenance has achieved considerable attention in researches and also companies. Using collected data through sensor-based systems to develop current or new products has been mentioned in several researches. However, it was rarely highlighted as the main application of sensor-based systems. The most studied application in almost all researches was preventive maintenance. This thesis investigates other opportunities for utilizing collected data via multiple case studies.

The role of customers in developing the remote monitoring system and the initial launch plan for the innovative solution has not been studied significantly in the prior studies. However, there are some researches about open innovation in RMS and its benefits and challenges but the number of those studies and specially number of case studies are not sufficient to have a broad picture of different cooperation possibilities in this area. The remote monitoring system literature also does not cover launch process of this innovative service solution. Current thesis tries to focus on this aspect of service development too and show the existing ideas towards these concepts and also use the applicable findings of prior studies in similar fields.

3. RESEARCH METHOD AND MATERIAL

3.1. Research strategy

This research was implemented as a qualitative research in the form of case study. To understand how companies utilize sensor-based services and to analyze their value drivers, case study was seen necessary. Case studies are used to better understand complex phenomena or hidden phenomena (Gummesson, 1993). The case study method is more relevant when the researcher wants to explain holistic view of real-life situation and explain some present circumstance such as how or why some phenomenon works (Yin, 2009, p. 4).

The research was done based on multiple case studies to avoid uniqueness and artificial conditions (Yin 2009, p. 61). The main benefit of multiple case studies is the provided opportunity to verify the results of first case in other cases. This will enable the researcher to generalize the findings (Saunders et al., 2009, pp. 146-147).

3.2. Case companies

Four case companies were studied in this research. All companies are engineering firms and operate in Finland. All selected companies are big international firms which have large global installed-base. These characteristics make them good examples for the objective of this study. The fictional names Company A, Company B, Company C and Company D are used in this thesis to secure the anonymity. Main information of the case companies are shown in Table 8.

Table 8. Information of case companies

	Company A	**Company B**	**Company C**	**Company D**
Industry	Engineering	Engineering	Engineering	Engineering
Net sales (million euros)	<100	>1000	<100	<100
Employees	<1000	>10 000	<1000	<1000

Company A is a technology firm that provides equipment and services to a specific industry. The company is the global market leader in the several market segments. The company has a broad range of project deliveries from complete production plants to individual machines and equipment. The provided services include maintenance and spare parts services, modernizations and consulting and business development. Services bring about 30 percent of the net sales to the company.

Company B is a global market leader in supplying technologies and services to different industries. The scope of service activities ranges from delivering spare parts to long-term full maintenance services. Services provide about 40 percent of net sales. A total net sale of Company B is much greater than other three case companies.

Company C offers advanced systems to several industries. The provided solutions can be standard or customized. This company also offers wide range of services like start-up services, availability services and modernization services. Services generate about 30 percent of the company's turnover.

Company D is a medium-size company which is a subsidiary of a larger corporation. The company supplies part of the manufacturing system to its customers. The company is specialized in building turnkey projects to its global customers. Like the first and second case company, Company D also offer broads selection of services to its customers. Services generate 20 percent of the company's turnover.

As illustrated in Table 1, Company A and Company C have quite the same size; Company D is in the same size category but the business unit included in this study is medium-sized. Company B is much bigger than the other companies in terms of net sales and number of employees.

3.3. Data collection

One important aspect in doing case study is selecting the most appropriate data generation method. The applied research methods in this research are using existing material and interviews. First, existing material includes everything that is stored in media such as books, research reports, computer data bases, brochures, films, photos and more (Gummesson, 1993). Websites of the companies were one of the sources for this study. All pages, brochures and annual reports were studied to find the relevant information regarding to the topic of the research. These sources used as supporting material to design and improve the questionnaires for interviews. The literature review was also conducted to increase the understanding about the topic and illustrate the state-of-art in literature. It also has direct effect on the interview structure.

Second, qualitative interview is the most common method to generate data in case study research. Interview can be divided into formal and informal interviews. Formal interviews can be done by questionnaires while informal or qualitative interviews are more similar to a conversation (Gummesson, 1993). In this research, the formal interview has been conducted. Empirical data was collected through semi structured interviews. The interview structure was developed based on literature review and existing material of case companies. The interview questionnaire was improved based on the received feedback from the supervisor of the thesis. The interview questionnaire had some similar themes for all case companies. It has also some different questions based on the situation of the companies towards sensor-based services. The questions are illustrated in Appendix 1. The interviews were conducted in October and November 2014. A workshop was also held with all companies in December 2014 to discuss the result of interviews and compare them to the prior studies.

In total, 8 interviews with 12 interviewees were performed. The interviews lasted between 35 to 80 minutes with an average of about 55 minutes. The detailed information of interviews is shown in Table 9. Most interviews were conducted on site, which provided a good opportunity to know the interviewees' working environment. The interviews were audio recorded and transcribed.

Table 9. Interview details

	Company A	Company B	Company C	Company D
Interviews	3	3	1	1
Respondents	4	3	4	1
Average length	45	45	80 min	45 min

3.4. Data analysis and validation

All recorded interviews were transcribed by an external service provider. The researcher also reviewed all transcriptions to find and correct any mistakes or gaps. The data analysis consisted of three steps. First, interview transcriptions were grouped and coded in some categories (Saunders et al. 2009, p. 492). Categorization was done based on the interview structure. Second, after categorization, data of each case company was analyzed. Third, a cross-case analysis of interviews was performed to find similarities and differences between case companies. This comparison tried to illustrate a scale for identifying the current situation of each company toward sensor-based services as well as their plans and expectations for the future.

The data validation was done in three stages. First, the results of interviews were reviewed and validated by all companies. Some parts of the report were modified based on the companies' feedback; however, these modifications were mostly focused on confidentiality and did not reduce the accuracy of the data. Second, a workshop with the case companies was used to validate interview data. Finally, the full manuscript was sent to the case companies for final verification and validation of the analysis results.

4. RESULTS

4.1. Company A

Company A is a Finnish technology company in a specialized industry which provides production machineries as well as required services for maintaining and further developing the machineries. The company's offerings cover broad range of projects including complete production plants, production lines, individual machines and equipment, automation, machine vision applications and measuring technology.

Besides manufacturing in Finland, the company has also two other plants outside of Europe, several technology services centers, sales offices and agents in different geographical areas. The company is the dominant player in Finland with some local competitors who are concentrated on specific technology areas. It is also one of the global market leaders in different business areas. However, it has some competitors in each market segment that have a global approach and have advanced technology.

Company A has a broad range of customers from big industry groups to very small companies. They are located in different parts of the world such as Europe, Latin America, Africa, Asia and North America. One of the main benefits of the company for its customers is its extensive products and services; the company can cover the total scope. A manager says: *"We are known to be quite expensive but the customers have been willing to pay for something more, for our technology."*

4.1.1. Basic information of Service business

Types of services

The share of services has been increased during the last years and now it is about one-third of total net sales of the company. A manager explains: *"Service business has been gradually growing and I believe it will continue that way."* Services in Company A include maintenance and spare parts services, modernizations, consulting and business development. The service offerings are customized based on customers' preferences and have different levels with different scope of responsibility for the company. A manager explains: *"In our industry we have not really seen that our customers would outsource all those service operations. They want to keep quite a bit in their own hands but in those areas where they are not skillful enough, they will outsource them to us."*

Service delivery process

There has been a traditional service delivery in Company A; a manager describes the situation: *"With new customer it is more selling the services and with the existing customers it is more responding to their needs"*. The process of service delivery usually starts from the customer. Each big customer has an account manager who is responsible for the entire relationship with that customer. Based on the customer's request and the situation, the account manager initiate a quotation process or ask for a maintenance specialist to join him and prepare a proposal to that customer or he may pass the information of needed spare parts to the spare part department of the company.

However, this process has been changed and become more automated; CMMS, computerized maintenance management system is the new way of managing service process in Company A. The need, its content, required work and schedule are entered to the system and the work order is made. There is also a connection to the ERP system of the company. Besides responding to the random calls from the customers, the company also does regular inspection. The inspection helps the company to know the current situation of installed base and propose any required maintenance works. A manager says: *"In some cases a client does not see a need itself. Our job is to help them to see the need."* The company is currently trying to improve the CMMS. A manager adds: *"At the moment it is quite difficult to have reports from the existing system, moreover we cannot supply all the needed information to the client."*

Process of identifying customers' expectations

Company A tries to use different channels to understand customers' needs and expectations. However, most of them are based on general understanding of customer's business. Providing the customers with complete production system helps the company to go deep in the customers' organizations and their daily processes. A manager describes: *"We are talking with the customers on the management level, operator level and anything in between. Also, during the installation, we have start-up guys who are very practical workers and then we have sales guys and after-sales managers and the top management who is talking to the customers, more or less regularly. So we believe that we get a fairly good understanding what they are doing, why they are doing, what are their bottlenecks, what are their challenges and so on."*

Existing knowledge about the technology and machines is also another general way to predict the current and future situation of the installed based. A manager adds: *"We know how those sub processes and machines are supposed to perform because we sell those machines. We need to know what is the capacity of the machine, what is the recovery, what is the uptime compared to downtime and so on. Also, we have some ideas about those numbers in old machines."* Therefore, when they get the production information from customers' sites, they can estimate whether that line works properly or not.

Inspection is another channel to get required data from the customers. All findings from inspections are recorded during the visits including all measures and observations. However, a manager believes that it is not utilized in the best way: *"we collect a lot of valuable information but at the moment we do not have such kind of system in use to provide reports"*.

Remote monitoring system is a new way of accessing to the production data in customers' sites. This data can be collected from installed bases but it is not utilize in the best way to predict customers' expectations.

4.1.2. Basic information of the sensor-based solutions

Current stage of the solution

Company A has already developed a remote monitoring system to monitor the installed bases in some customers' sites. Today, the company can access few installed bases and can see online or offline what happens in the delivered machineries. The system is still in early phase of development. A manager says: *"We need to admit that we do not really know what to do with that information but we see there are both short-term and long-term opportunities in collecting information."*

The company supply small scale IT-system with the machineries. The system can collect data from the customers' production lines and provide some sort of reports about uptime, downtime, and recovery and productivity numbers. These reports can help the company to compare the measure from one period to another period. However, Company A cannot access to customers' production lines or those reports whenever they want; their customers decide to get the access to the company. The customer can open the connection to the system and then Company A can observe and control the required functions.

Initial motivation to develop the solution

The first motivation for developing a remote monitoring system has been formed some years ago and it is rather vague who was the initiator of this idea and what was the reason for developing the system and expectations at that time. However, it seems one of the reason to activate this concept in the company was result of some benchmarking of other Finnish companies. A manager explains: *"We just started to think that it might be a good idea to do some kind of measuring and evaluation."* There has been also some customers who have demanded some kind of support to manage the machineries and keep them running. A manager explains the situation: *"nowadays the equipment is so complicated and high-tech that many customers do not have the in-house skills to* *keep them up and running. They realized that. So, based on that fact, they have asked us for something and now this is the answer to that demand."*

4.1.3. Value drivers of developing sensor-based solutions

Value drivers of manufacturers

There are several value drivers of sensor-based solutions for Company A. One of the main value drivers is generating revenue. The company wants to create new business opportunities and increase the revenue of the service business.

Improving the relationship with customers is another important value driver. The company wants to tie their customers to the services and increase their willingness to buy from the company in the future. A manager explains: *"We hope that the customers learn to rely on us better so they know we are able to make the living for them easier."*

The remote monitoring system can also provide the opportunity for the company to understand what is going on at customers' production lines. A manager says: *"By understanding what is going on there, we are able to provide the right service at the right time."*

Cost-saving is another value driver for developing remote monitoring system. It will reduce the unnecessary service visits. If the company can evaluate different situations remotely and can provide some instructions for the customer to solve the problems, they can save the cost of travelling.

Perceived value drivers of customers

Saving cost is one of the important perceived value drivers of the customer. Company A believes that the customers can benefit from the system by minimizing or optimizing the maintenance cost. Customers also value those solutions that ensure them that equipment are running smoothly and reliably and therefore increase their uptime.

4.1.4. Data utilization

Right now, the most important use of the collected data via remote monitoring system is improving maintenance. The company wants to monitor the installed bases to evaluate their performances, predict the future and do proactive maintenance in order to increase the uptime of the production line.

The company also sees the usability of the collected data in R&D efforts in its perspective. A manager explains: *"Those are valid information that R&D people can utilize them when they develop our systems and machineries so that they are running better in the future."* Another manager of the company approves the benefit of the collected data in the company's R&D. However, he did not see it as a main usage of the collected data. He says: *"We are not manufacturing the washing machine that we spent couple of months to develop them and then sell thousands of them. No, we sell just couple of similar machines per year."* Therefore, the collected data from the customers cannot have a direct effect on development activities.

Considering the collected data as a sellable material is one of the interesting perceived usage of the remote monitoring system in Company A. Actually, they hope that their global platform in the future can help them to provide a reference data for their customers. They need to put a huge amount of information into the right format and turn it to a sellable material. A manager describes: *"We can tell them anonymously these are your competitors and this is your level comparing to your competitors and there is a potential for your improvement".*

4.1.5. Different approaches in developing the solution

Cooperation in supply network

The system is mostly developed in-house. The company has some subcontractors but it did not outsource the development to them. A manager says: *"The project management of R&D has always been in our own hands."*

Launching the solution

Today, the remote monitoring system has been installed in ten customer sites and also in a specific product. The general strategy of the company is to test the system with few customers and then apply it in a broader context. A manager says: *"Perhaps we have to pick those strategic customers."*

The company has not launchd the system to all current and potential customers but they are doing several activities to be able to launch the system in the future. They receive feedback from the customers about how the system works and can be improved in the future. They are talking with some identified specific customers who can be potential users for this system. The company has developed some kind of portable system to go to the customers' sites and show them how they are able to measure equipment and what kind of information they are able to collect from the machine. They are also working on the front-end system to be able to get nice looking information and reports from the system.

However, the company believes that the system should become reliable and more importantly it should have some proved value added for the customers before trying to launch it widely. As a manager explains: *"We need to be more accurate, we need to have more testing and we need to have more experience about how it works because by launching something which does not work in a proper way, you screwed up the thing and you can screw up it only once."*

4.1.6. Risks, changes and possibilities

Problems and risks

Insuring data security of the customer is the biggest problem of Company A. It has been the biggest concern and obstacles for developing the system further and faster. A manager explains: *“There were several times when we were talking with production management, general management or maintenance management of our customers about the remote monitoring system. They thought and said this will be great. But as soon as we started talking about the practical realization of this solution, then the IT Manager came into the picture and jeopardized everything.”* Generally, the customers hesitate how the company is going to use the collected data and what is the risk of accessing those data by their competitors. The customers may also see the risk of being taken over by the company in the future. Besides these immaterial risks, there are also some material risks. A manager describes: *“The material side is more or less that if you have A and B and there is a connection between them, so there is always a risk that it is not connected.”* Therefore, the reliability of the system and infrastructure can be another risk.

The company has done a study about the willingness of the customers about the remote monitoring system. The result shows that the bigger the customer, they have more concerns about this system. However, the smaller customers were more willing to accept that. A manager adds: *“I do not know what is going on and what would happen if we really start to implement the system but at least, during those interviews, smaller customers were more open than the big ones.”*

The company hopes to find some new technical solutions to keep required data separate from other customers’ data. Therefore, it can provide a less risky environment for its customers. Making the customers confident about the system needs also time. The company believes that the customers will learn during the time when they hear about remote monitoring from different sources and find it as a trend in the industry. A manager says: *“They will know if they are trying to fight against it, anyway it happens. So someday I think they are ready to take the first step and maybe give a chance for us.”*

The company also thinks that one of the most effective ways for convincing the customers is selling the idea and actually the benefits of the system. A manager explains: *“If the benefits and specially the economic benefits are shown to the customers, they will be willing to accept the solution.”*

Changes in business model

Change in business model of Company A is an important issue that attracts the company’s attention but they have not studied or developed any alternatives for this purpose. Today, the services are normally sold based on hours or spare parts. However, one of the managers thinks this new type of services (remote monitoring system) cannot be easily sold based on traditional measures. He adds: *"Our revenue and our profit will be dependent on something more intangible"*. The company needs a business model which depends on customers' performance or production volumes or downtimes or etc. It means the model can enable them to value the activities rather than hours or spare parts.

Future development

As mentioned before, the company does not use the collected data efficiently now. Actually, they believe that they do not have enough information to be able to provide some value added for the customer and the own company. Many kinds of measurements require additional sensors. On the other hand, they do not tend to add more sensors to their products to receive more data from the customers because it is costly and they want to figure out some business with the collected data before adding extra sensors. A manager says: *"So, it is like chicken and egg problem".*

Improving the front-end system to is another development area of the company. The system needs to be improved in a way that it can generate useful information and reports based on the collected data.

4.2. Company B

Company B is a global developer and supplier of services and technologies for some specific industries. However, this study only focuses on one of the business areas of the company. Therefore, whenever it is mentioned Company B, it means that specific business area.

The company has a wide product offering and covers all scope of the production lines. High expertise is one of the most important characteristics of the company. They are experts not only in mechanical fields but also in service, maintenance and automation. Therefore, the company can offer wider scope of know-how to the customers than other competitors. Actually, Company B is one of the big players in each of its industrial markets. It is also has a strong market position in the service business. The company has some global competitors in each business segment. Besides these big players, there are also many small local companies who compete in the service business.

The company has a wide range of customers. Some customers are acting globally, some others are doing business in one continent and also family-owned companies who have couple of mills or even only one mill. A manager explains the situation: "*So more or less we have all types of companies but of course the biggest total volume comes from the big companies who have several mills."*

4.2.1. Basic information of Service business

Types of services

Services generate about 40 percent of the total net sales of Company B. It has been a growing market during the last ten years and, based on the market analysis, it will continue to increase. The company provides different services to its customers including spare part, consumable, maintenance, process technology support, automation and modernization.

Most of the services are customized for each customer. A manager explains: *"Usually it sells better if you have a customized package that customers feel that it is exactly for their needs and not something that comes from some product catalogue."* However, the company tries to make the process as standard as possible to have an appropriate cost-level. Therefore, they define some modules that are quite well standardized and then make a customized package by adding some new elements to make it fit better for the purpose.

Service delivery process

The company has both kinds of reactive and preventive maintenance. The company receives many contacts from the customers to repair a broken part or solve some kinds of quality problems. A manager says: *"That is when they call us. They need a person who is able to do anything on that piece of equipment."* These emergency issues consists a huge portion of maintenance activities. An employee explains: *"It is hard to say how big the percentage is but the majority of maintenance activities are reactive on our side."*

For some specific components, with a determined life time, the customer contact the company before the deadline and the component is shipped from the customer site to the company workshop to finish the maintenance and then is shipped back to install on the machine. There also some maintenance activities that are done in the customers' places. The company tries to be more proactive in its service business. An employee explains: *"That is why we do more marketing on new technologies. We visit the customers and discuss with them and we also participate in trade fairs and that kind of things."*

Process of identifying customers' expectations

Company B tries to understand customers' expectations through several ways. They use public source of information to get general information and global view. To achieve more specific knowledge, they interview with the customers to get feedback and receive their opinions about their current and future works. This process usually is done manually. In the next level, sales people who meet the customers, receive feedback and save it in a platform to be available for future analysis.

Although these processes help the company to have a general view of the customers' needs and satisfaction towards the existing products and services but predicting their expectations is more or less common sense. A manager explains that sometime the company faces to some difficulties in predicting and defining the suitable package for the customer: *"Very often, we are offering too much. That means that the price tag is too high. Then the customer is asking the same offering from our competitor and they claim to deliver the same delivery with a cheaper price. However, in real life they do not offer the same quality. On the opposite side, there are some situations that we do not know what to offer."*

4.2.2. Basic information of the sensor-based solutions

Current stage of the solution

Today, Company B does not have sensor-based services in order to monitor its installed bases but it has a specific component with embedded sensors. Customers control and use the collected data from the component for condition monitoring purpose. Actually, the customers want to make all related decisions by themselves. Therefore, if the company wants to sell some kinds of sensor-based services to monitor the machineries remotely, they need to provide added value for their customers. A manager describes the situation: *"It is not that easy to change it. We should have some kind of special programs or different offering from existing ones to be able to sell it."* Therefore, the basic idea is to optimize the current maintenance program through sensor-based solutions.

Initial motivation to develop the solution

The first idea for developing the system was initiated inside the company about ten years ago. Technology improvement was an important driver to develop sensor-based or IT-based solutions. Observing the possible activities of the competitors in this field was also effective in activating the company in defining a development project. A manager explains: *"We have defined a couple of business cases. Then we have started the first steps including what should be the platform and how to utilize collected data."* Customers did not have a significant effect in initiating the development. A manager says: *"We need to create this kind of opportunity to our customers. They do not figure out or realize it by themselves necessarily."*

4.2.3. Value drivers of developing sensor-based solutions

Value drivers of manufacturers

As described before, Company B is a global company who competes against global players as well as small ones. Differentiation is one of the value drivers of developing sensor-based solutions for the company. The company wants to show that their offering have something special comparing with the competitors. A manager emphasizes: *"We need to have this kind of differentiation from normal offers."* An employee explains that even if it would not possible to get money for the sensor-based solutions, we could use it as marketing tool. He adds: *"It is difficult to get money from this technology but we can sell a bigger package including both traditional services and sensor-based services and get more sales from them."*

Cost-saving has not been an important value driver for the company. Actually they seek to create new business based on the innovative service. A manager explains: *"In this type of solution, we are definitely looking after increasing business volume and profits from the new solution. This increase should bring the payback of the development investment."*

Perceived value drivers of customers

Improving performance and cost saving are considered as key value drivers of customers to accept sensor-based solutions. Company B wants to make the working process better for the customer by implementing sensor-based services. A manager explains: *"The processes and the volumes which they are producing are very large. Therefore, even a small improvement, anywhere in the process, brings quite considerable amount of money for the customers."*

Access to a reference data is the other perceived customer value driver. The company can give more information via sensor-based services to the customers in return of the collected data from them. This benefit is more important for small customers. A manager says: *"The small customers do not have a reference data at all. So, accessing to the reference data can be a motivation for them."*

4.2.4. Data utilization

Company B is looking for all opportunities to find different ways of utilizing collected data. It will include maintenance but it will not limit to it. Actually, they want to create business out of the collected data but it is not clear how to achieve to this goal right now. A manager explains: *"The analysis of data is not really bringing direct payback. We need some extra sales based on this data."*

The first step that the company has taken in utilizing data is about forecasting consumables and not the maintenance. However, a manager says: *"From my perspective it is more important to utilize the data in maintenance than consumables."*

Company B also believes that he collected data can be useful in product development process. If the collected data from several installed bases show that there is something in the process that does not work effectively, then the company can use this data as an input in product development process.

The collected data could also be useful in sales and marketing affairs. The company can explain the problems in the products, its effects on the customer's process and the developed product. These effects can be calculated in terms of money and show the customers how much they are going to save by buying the appropriate services or developed product. An employee explains the situation: "*I guess it helps us when the product is ready and we want to launch it to the market. It gives you the appropriate tool for marketing because in this industry you always need something to show in statistics or based on real data. That is basically the only thing which you can really sell it. Otherwise, they feel like nice to have it but they do not buy it or they do not pay a good price for it."*

4.2.5. Different approaches in developing the solution

Cooperation in supply network

The remote monitoring system has not yet developed in Company B but all the current efforts are coordinated by R&D of the company. A manager adds: *"That is how we normally bring in new technologies."* In the past, these kinds of developments were usually done in-house but it seems that the company feels the necessity of having partner in this project. An employee explains the situation: *"We do not have enough expertise to develop the system so we will have cooperation with others."* There are also some potential subcontractors to help the company to develop the system but they are trying to evaluate more alternatives. A manager says: *"There are some possibilities but I am not sure if everything can be solved by them. Probably there must be more than one partner."*

The company wants to develop the network of potential partners and do benchmarking. There are some big names in this area such as Intel, Nokia and IBM which provide some systems called industrial internet. These companies have a big platform and all kinds of related products. However, working with these big companies might be hard in terms of flexibility. There are also many smaller companies which might be more flexible to cooperate with them. The company also considers other types of partnerships. An employee explains: *"We could also do partnerships with other machine building companies that are not our competitors. So we could do cooperation with them and we could use same kind of technologies and platforms."*

Launching the solution

The company supposes to offer the new system gradually and in a smaller customer scale. A manager says: *"Yes, that is our normal way to go; first in a smaller scale and if that shows successful in the small scale we enlarge it."* The company will select some customers, at least in the first phases. The company will do the trials and find the business models together with these customers. After developing a ready concept, they will expand it to other customers.

The first target group of the customers can be those with more relationship with the company. One of the employees thinks that starting with the bigger companies is easier and they can build a bigger business with them. He explains the situation: *"Small companies do not often work with us in a continuous way. However, they will have to be involved in the development at some level."* On the other hand, a manager considers smaller customers as a better target segment for the remote monitoring system. These smaller customers can benefit from the system by benchmarking and find their position against other competitors. He adds: *"In the current situation, our bigger customers are not interested in the new system at all because they believe, right or wrong, they already have the knowledge."*

4.2.6. Risks, changes and possibilities

Problems and risks

The main risk of the remote monitoring system for Company B is data security. Getting access to the customers' production lines create some risks for the customers such as change settings, illegal accessing to the data and even environmental and property damages. An employee explains the situation: *"Mostly, I do not think they are very open. There are companies that they have said they will not allow others from outside to access their automation networks."*

Data encryption is a possible solution to mitigate this risk. An employee explains: *"Some years ago, there was a similar project with some big customers with the similar risks. They did not allow access to their systems. They provided a certain way to access their network through encrypted tunnels and then they had all kinds of tracking systems which showed a list of the users who could be access and all logs. Therefore, they could follow up. Then there was also an audit to review all parts that were going on."* The employee thinks that the similar approach would help the company to achieve customers' acceptance. The company should be open for customers' audits. They can also use a third party auditor to do all auditing process.

Changes in business model

Company B considers the need for changes in the business model but they have not studied the possibilities and requirements. Actually, they are in the stage of awareness right now. An employee explains: *"We have not really started to study about it. In the future, we have to create new business models but it is lacking today."*

Future development

Since Company B has not developed the sensor-based solution yet, creating the remote monitoring system is the main development plan of the company.

4.3. Company C

Company C is a manufacturer and suppliers of advanced systems. Besides the headquarters which is located in Finland, the company has subsidiaries in Europe, North America and Asia. The company's offering range from single to factory-wide systems. It delivers both standard and customized solutions to the customers.

The company has several types of competitors from big companies which deliver quite the same offering to local players which can deliver small-scale solutions and do maintenance. Due to the nature of Company C's business, its business partners can also be their competitors. As the company has different business areas, it has different market positions in each of them. The share of company is even less than one percent in a market and at the same time it has a very strong position in the other market. A manager explains the situation: *"Since the company's main competitive advantage is related to its advanced technology and systems, the bigger and more complicated is the system then the bigger is our market share. Actually, when we go to the complicated systems, there is not that much competition in that area."*

Company C has a wide range of customers; starts from very small local machine shops to huge companies. Therefore, they have completely different needs and expectations. A manager explains: *"For big companies, you need to fill all kind of papers in order to deliver something. For the smaller companies, it is the owner who decides what happens and it is so easy. But of course the business potential with the large companies is quite big."*

4.3.1. Basic information of Service business

Types of services

The company offers different services to its customers including maintenance, extensions and modernization. The market of service business can be divided in four areas: America, Asia, North Europe and Central Europe. Each area has a service area manager who has different service managers in different countries. Each service manager has a team of technicians. They are responsible to contact the customers and sell the service offering.

Share of service business for Company C is about 20 percent. The service business is a growing business for the company. Specially, share of extensions and modernization has been increased in the past years. A manager explains the situation: *"Approximately 80 to 90 percent of our systems are extended in some points of their life time."* Another manager adds: *"The lifetime of the system is quite long; it might be 30 years. So customer might change the machine tools several times during the lifetime."*

Service delivery process

Service delivery process of Company C contains both reactive and proactive activities. The company receives several ad hoc requests from customers to solve some urgent problems. The company tries to move its service delivery process to a proactive process. The company has different agreements to do periodic maintenance and suggest required action to the customers to avoid sudden downtime or shutdown. A manager explains: *"One important matter is checking different technical solutions to provide the proactive solutions but the other key matter is the mindset."* The company is trying to change its delivery process more and more to have less ad hoc services and more proactive solution.

Process of identifying customers' expectations

Company C uses different ways to identify customers' needs and expectations. Talking with the customers, inspection and feedback from customer relationship management are some of the main means of receiving this information. However, most of these methods, give a common sense to the company and it is not a well-defined process. The company also receive considerable amount of data remotely that can be useful in this context but they do not utilize it efficiently today.

4.3.2. Basic information of the sensor-based solutions

Current stage of the solution

All deliveries of Company C are equipped with a possibility to have a remote connection. It collects the data in a central location and then the company can access to the data remotely. Using remote monitoring system is an efficient way of doing maintenance for Company C. A manager explains: *"Almost seven out of ten cases can be solved through the remote connection."* The remote monitoring system or as it called in Company C "tele-service solution" has a graphical user interface which help the customers to control the system. When there is a problem, it notifies the user with some error messages. Then the customer might solve the problem by themselves or contact the company to support and do the maintenance. The process of service delivery via tele-service is agreed with the customer. Thus, the customers know the contact persons, how they connect remotely and how the service is done. These contract-based customers can call the company as many times as they want. A manager explains: *"Operator does not need to get an acceptance from his supervisor to contact us because costs have been already agreed. So it is very easy for them to contact us. Otherwise, they need to ask acceptance for what we invoice based on the hourly rate."*

However, the data are not collected centrally and automatically. In most cases, it is the customer who decides whether utilize this feature or not. A manager describes the situation: *"Customer calls us, we take the remote connection and we start to analyze the* *problem."* Company C also has some contracts with some customers, who have good relationships with the company, which let the company to check the customer's systems remotely before the periodic visits. Therefore, they can select the right serviceman and prepare the serviceman with right parts to go to the customer' site. However, it is not the mainstream. A manager explains the situation: *"For example, if we have around 250 contracts globally, then more than 100 of those contain a tele-service component. Out of those tele-service agreements, five to ten percent have the proactive approach and let us to check something beforehand. Usually it is reactive."* Although the remote monitoring system is helping the company to do its maintenance efficiently but the reactive nature of the current system decreases the optimum utilization of the remote system. A manager says: *"It depends on the customer. Some customers realize the problem immediately and some others do not realize it after many weeks. The longer they wait, the worse the problem will become and it will be a very tricky situation at the end."* When the operator keeps getting warning messages about some problems in the system and he decides to ignore that warning, it might cause to a breakdown or shutdown. Then, the customer contacts the company to do some urgent maintenance for them. It means they change the proactive system to a reactive one.

Initial motivation to develop the solution

The first initiatives for changing the service delivery process in Company C have started about 15 years ago. Due to huge number of phone calls from customers to solve several problems, designers were not able to do their main jobs. Therefore, the company decided to dedicate one person to do answer the customers' questions and problems. The manager continues: *"Then the need has grown and more people have come in to have this service. We have started to realize that this is a business potential and we can invoice customers for this service."*

4.3.3. Value drivers of developing sensor-based solutions

Value drivers of manufacturers

Improving the customer relationship is one of the main value drivers for Company C. A manager says: *"We do not need to wait couple of months and after the problem becomes too big, we send several guys on-site. We can call the customer and say that last week we corrected this and that problem in your system and you are welcome."*

Saving cost is another value driver of remote monitoring system. Offering required service via remote monitoring system cause less cost for the company than answering the ad hoc request of the customers.

Remote monitoring system can also help the company in marketing and sales. The company can add value to its offering by showing their ability to respond them at any time. A manager explains: *"When you are trying to sell a new system, especially if the* *customer does not have previous experience of our specific solutions, then we must prove to customer that we are able to support him, in case of something is happening middle of the night. He can always call the tele-service."*

Creating new business potential is another key value driver of Company C. The remote monitoring system helps the company to be more connected to the customer. Therefore, they can understand what the customer is doing and what is going on there. A manager describes: *"So we have more constant connection. Therefore we could see that they are investing in some new systems and we are already there and are ready to offer some related solutions to them."* The company can also provide additional services to the customers like system analysis and suggesting next steps to improve their performance. For example, they can suggest customers to upgrade the system or add some components to their production line. Hearing these advices from the service unit might have a better effect on the customers. A manager explains the situation: *"Our service people are always considered as trustworthy partners for the customer. So if our service man says that this component is going to die, customer believes him and he will buy a replacement. However, if our sales man says the same suggestion, the customer might not believe it."*

The company can also benefit from the system by differentiate its offering and being competitive. The competition is getting harder and the company needs to have a developed version of its remote monitoring system to compete in its advanced-context markets. A manager explains: *"We are somehow ahead of competition now because nobody has really developed this kind of things before."*

Perceived value drivers of customers

Increasing the availability of the production line and shortening the downtime are the main perceived customer values for Company C. Due to the specific products of the company, if it faces any problems, it will affect all connected machineries. Thus, hourly cost of downtime is quite high for Company C's customers. By implementing remote monitoring system, the company can solve the problem faster and without need to send service people to its global customers.

4.3.4. Data utilization

The most of the data that is collected remotely is case-specific and it is related to a troubleshooting case. They are used for analyzing a problem on a customer's site and doing the appropriate maintenance. However, the company has huge amount of collected data and log files over the years but it do not analyze the whole installed bases. Actually, analyzing is a manual work at the moment and they need to review the log files to find suitable data. A manager adds: *"we have a lot of data but not so much information."*

The company has not used the data for the product development purpose yet but they consider the possibilities in this field. Standard solutions are the main areas which can be developed by collected data from installed-bases. The company supplies a considerable number of same machines around the world. In this case, if they see an error is repeating in most of deliveries, then they understand that it is systematic problem and should be solved in the next version of the product. Actually, the company has already done it for a specific product. A manager explains: *"We are developing a new version and new generation of that product and the collected data was helpful in this case"* However, he continues: *"but it is not a daily task that we are doing at our company."*

One of the managers also thinks that the collected data can also be useful in complicated systems because the company could see how the systems are running by the customers. He explains: *"Customers are running a system in different ways. We can understand which features they are using or utilizing and which they are not. That could give us a better picture of where to concentrate or what to do in the future."*

4.3.5. Different approaches in developing the solution

Cooperation in supply network

The system has been mostly developed in-house. However, previously the company with some other Finnish companies participated in a project about initiatives in service business which has become helpful for defining and developing the remote monitoring system.

The customers have not had a direct effect in the development of the system but their requirements for response times or know-how have had indirect influence on the system. A manager explains: *"We have lots of customers who are really demanded in a way that we have been pushed to develop our offering. Our customers are almost always number ones in their fields."*

Launching the solution

The tele-service solutions are offered to all customers. However, they might have different prices depend on the level of solution. For example a simple system needs only couple of hours per month but more complicated systems might use hundreds of hours monthly. The response time also has effect on the price of the solution. Some customers need responding even at midnight but some others want only daytime service.

4.3.6. Risks, changes and possibilities

Problems and risks

Many customers of Company C are very sensitive to the remote connection. They want to know who is allowed to connect and they want to control when the connection happens. The company has some customers whose business field needs high security. These customers are worried about safety issues and do not allow any instant connection without their permission and their monitoring. A manager explains the situation: *"They usually have their own policies, which we need to adapt because they are big companies and they are not going to change because of our company. So we need to take that into account and find the best possible solution."*

Changes in business model

The business model of the company has been changed during the years. Services have been considered as cost centers in Company C but now it is considered as a business unit which not only generates cost but makes profit. Today, the company thinks about how to generate more profit by its tele-service solution. A manager describes the situation: *"In our strategic agenda, we are evaluating different business models at the moment. We think what our business model is in future. Process is ongoing now but we have not made a decision yet."*

Future development

Currently the company measures the motions and accuracy of the system. However, they want to measure more parameters in their systems. They have investigated in some sensors which can measure several things. By adding more sensors, the company can enrich the collected data and have the right and useful data. A manager says: *"I think that something like that is needed to be able to really do the proactive service and be able to predict what is going to happen and when it is the good time to do some actions."*

4.4. Company D

Company D is a well stablished company, specializing in turn-key deliveries of specific systems and components to some particular plants. The company has three business divisions and each of them serve a unique industry and purpose. Therefore, company has three different market and customers. For one business area, the market is mainly located in Europe. However, for another markets, the market is the whole world. The customers are both public and private companies. There are not many competitors for Company D in Europe but the competition is tough. Since the company is not well-established in other continents, the players in those areas are not considered as competitors by the company.

4.4.1. Basic information of Service business

Types of services

The service business of Company D generates 30 percent of its turnover and it is increasing over time. The profitability of services is better than project business so the company tends to increase the share of service business. A manager explains: *"That is one aspect that we are considering in our business development now to find out how to improve our capabilities to increase service businesses in terms of a volume and also profit."*

The company offers various services to its customers including maintenance support, spare parts supplies, testing and inspection services and modernization. The industries that use Company D's technology always have to do process continuously. Therefore, doing maintenance and taking care of spare parts and consumables are very crucial for the customers. A manager explains: *"We take care that the machine is up and running seven days a week and 24 hours per day."*

The company has various service packages. Each service package requires different level of support from the company and different levels of responsibility from the customers. For the high level package, customers do not need to have their own resources to do maintenance. However, in other service packages, customers need and want to do some parts of maintenance by themselves or only purchase consumables and spare parts from the company.

Service delivery process

The company has long-term relationship with most of the customers. Thus, the customers contact some people in the company who they know. The company also has some internet tools that customers can send their questions and ask services. Then the service people make some quotations and offer some services to the customers. A manager explains the situation: *"There are quite old-fashioned methods that people face some problems then they contact us and send us a request to make an offer. However, there are almost none advanced, service infrastructure at the moment."*

Besides these ad hoc contacts, the company also does inspections in the customers' sites. Actually, due to the specific characteristics of the industries which use Company C's technology, they need to be checked continuously to identify the need for fixing or replacement. This makes the inspection as an important part of the service package. The service people visit the customer's site and make a proposal for the customer which explains the areas that works good as well as bad condition areas that need maintenance. Again, due to the particular characteristics of the customers' industries, the maintenance should be done in a specific season and the technology should be in the perfect condition in other seasons.

Process of identifying customers' expectations

Understanding the customer's expectations highly depend on the relationship between the company and its customers. As described before, the company has a long-term relationship with its customers that help them to know the customers and their needs. A manager explains: *"It is quite surprising how much it depends on person-to-person dialogue and long relationships".* Another source of information for the company is people who travel to the customers' sites and check their production lines and talk with them. However, the collected information also depends on people and their relationships.

4.4.2. Basic information of the sensor-based solutions

Current stage of the solution

The company has not developed sensor-based solutions yet. Actually, they are in the early phase of development and start studying about the possible solutions. Before starting any action plan for developing these solutions, the company needs to include it in its strategy. A manager continues: *"First, we should have that in our strategies. Then, it gives us the background and required support to really make actions and do operations".*

Based on the company's research, it seems that the competitors do not have sensor-based solutions. A manager explains the situation: *"There are some companies that have announced some solutions but we have not found it in reality. Maybe they use it in some specific small cases but it is not a common way of doing business"*. However, the company knows that it would be a big threat if a competitor commercialize these advanced service solutions earlier and become the leader.

Initial motivation to develop the solution

The service delivery process and solutions in Company D has been the same for a very long time. Today, the company is interested to find out how they can improve their capabilities in this area. A manager describes the situation: *"The way we have done service business is providing us very good profits and very good turnover but the world is changing and customers are changing so they would like to be served in a different way in the future."* Cost efficiency is another motivation for the company. They want to integrate new technologies into their products to reduce the need for inspections and decrease the related costs. Another motivation is the competition pressure. If in the future, some competitors can do the services in a more professional and efficient way, they can increase the profit. In this case, the company with old-fashioned service business will lose profit.

4.4.3. Value drivers of developing sensor-based solutions

Value drivers of manufacturers

The main value driver for the company is to increase the volume of the service business and to increase the profits. A manager explains: *"By utilizing our existing business model, increasing the volume means increasing the people. We understand that it is not the right way to do. We should find out some methods that by adding 20 percent more people we can double the business."*

Perceived value drivers of customers

Improving safety is very important for Company D's customers. The company needs to assure customers that the people, process and machineries are safe. A manager adds: *"There is always threat of explosions in those industries"*. The sensor-based solutions can help the company to monitor the technology continuously and identify the need for any kind of maintenance as soon as possible. Another value driver for the customers is that their sites are running continuously and without downtime. By remote monitoring system, the company can guaranty its customers to maintain the delivered technology in the perfect shape and running.

4.4.4. System utilization

Current and possible use of the collected data

The company has not studied about possible use of the collected data yet.

4.4.5. Different approaches in developing the solution

Cooperation in supply network

The company has not decided about how to develop the solution but one of the managers thinks that customers can be effective partners in development process. He also considers the possibility of cooperating with third parties to generate more useful reports from the collected data. He emphasizes: *"So there are room for different players."*

Launching the solution

The company has not analyzed how to launch the solution or how to select the target market yet.

4.4.6. Risks, changes and possibilities

Problems and risks

Maintaining the security is a very important factor for the customers. The customers accept the direct access to their system when there is something wrong and they need the technology supplier to fix the problem. However, when everything goes smoothly, they do not want the technology supplier to follow the process parameters in their systems. Illegal access to the data by third parties is also another risk that may harm both customers and the company.

Another risk of these solutions is losing the personal touch and close relationship with the customers. A manager explains: *"We should make sure that it is still there. The advanced methods should be built on the existing model so that the customers feel that they get served better."* For instance, the analytical reports based on the collected data through the remote monitoring system can be sent to the email of the customer's responsible service man and he can direct the service delivery process. In this way, the company can integrate the long-term relationship with the advanced automatic solutions.

Changes in business model

The company senses the necessity of changes in the business model. However, this area has not studied well now and actually it is part of the further development of the system.

Future development

Since Company D has not developed any kind of sensor-based solution yet, the all required steps of developing the solution is considered as future development of the company in this field.

4.5. Cross-case analysis

This section completes the results of this study. It compares four companies in each defined criteria and shows their main differences and similarities. It also includes the result of the workshop that was held with all case companies.

4.5.1. Basic information of service business

Service business is a growing business for all companies and constitutes more share of turnover over years. Share of service business in Company A and Company D are quite similar, about 30 percent of turnover. Company B with 40 percent and Company C with 20 percent of turnover have the highest and lowest service shares. All companies offer rather similar services to their customers. See more details in Table 10.

Service delivery processes in case companies have some similar attributes. Reactive maintenance is a key part of the service delivery for all companies. It means, case companies receive numerous ad hoc requests from their customers and they need to respond to these sudden problems as soon as possible. On the other hand, all companies try to reduce the number of these unplanned services by applying preventive maintenance. Regular inspection and periodic maintenance are part of the service plan of all case companies. However, preventive maintenance has a bigger role in Company A and Company C. Company B and Company D are trying to change the current situation and to concentrate more on preventive maintenance.

Table 10. Basic information of service business

	Company A	Company B	Company C	Company D
Share of services	30%	40%	20%	30%
Types of services	Maintenance, spare parts, modernizations, consulting and business development	Maintenance, spare part, consumables, process technology support, automation and modernization	Maintenance, extensions and modernization	Maintenance, spare parts, testing and inspection and modernization
Process of service delivery	Computerized maintenance management system (CMMS); Reactive maintenance; Preventive maintenance	Reactive maintenance (more); Preventive maintenance	Reactive maintenance; Preventive maintenance; Remote monitoring system	Reactive maintenance (more); Preventive maintenance
Process of Identifying expectations	General understanding; Inspection	General understanding; Information from CRM; Feedback from sales people	General understanding (more); Remote monitoring system	General understanding; Inspection

Company A has a computerized maintenance management system called CMMS that helps the company to manage the service delivery process automatically. The company also has a remote monitoring system but it is not used in the daily service delivery process actively. However, Company C applies its remote monitoring system for the maintenance purpose actively. The system is called tele-service and helps the company to diagnose problems in the customers' machineries remotely and do the required maintenance without traveling to the customer's site, if it is possible, or choose the right service men with right tools and spare parts to visit the customer.

Almost all case companies use their common sense to understand customers' expectations. It means there is not a well-defined approach to identify customers' needs and expectations. Companies are more dependent to their close relationship with customers and their deep knowledge about the industry and the technology. Company A and Company D use the inspection as an effective way to observe customer's business and identify the potential needs and opportunities. Company B uses the available information from the customer relationship management and also the feedback from the sales people to detect current shortages and opportunities as well as the future possibilities. Company C tries to utilize its RMS to find out the customers' needs but the system is still more applied for the maintenance purpose so common sense is also the main way of identifying customers' expectations in Company C.

4.5.2. Basic information of the sensor-based solutions

The main sensor-based solution in all case companies is remote monitoring system. Other types of solutions do not exist or are not at a level that worth to mention. Case companies are in different stages of system development that is explained in Table 11.

Table 11. Basic information of the sensor-based solutions

	Company A	Company B	Company C	Company D
Types of sensor-based solutions	RMS	RMS	RMS	RMS
Current stage	Developed system; Access few installed bases; Needs customer's permission	Early phase of development; One specific component with embedded sensors; Needs customer's permission	Developed system; Needs customer's permission (mostly)	Early phase of development
Initial development motivations	Benchmarking; Customers' needs	Technology improvement; Observing the possible activities of competitors	Customers' needs	Improve capabilities, Cost efficiency; Competition pressure

Below list explains the current stages of RMS in the companies and is sorted from the lowest level of development to the highest level.

- Company D is in the early phase. Actually it has just started to think about the concept and related aspects.
- Company B is rather in the same situation; the company has not developed a RMS but one of their specific component has embedded sensor that helps the company to measure some attributes. However, the company can access to the data only by customer's permission.
- Company A has developed its remote monitoring system but it has only access to few installed bases. This company can also access to the remote data only by customer's permission.

- Company C has the most developed system among the case companies. The RMS is part of the company’s service offering and they provide it to all customers. Customers are the decision maker about accessing to the installed bases remotely in most cases; for some customers the company can connect to the customers’ site before the periodic maintenance automatically. The company uses this opportunity to monitor the installed bases and plan for the service and maintenance efficiently.

Companies have had different initial motivations to develop RMS. Table 3 shows these motivations. Customers’ needs to receive better services and observing activities of competitors and other companies are the main common motivations for the case companies. However, customers’ effect was not very significant for Company B. Company D also has more internal motivations to develop the system.

4.5.3. Value drivers of developing sensor-based solutions

Companies’ value drivers to have a RMS are listed in Table 12. The first common value driver for all companies is creating new business. Company A and Company C identified the improving customer relationship as the second common value driver. The third common value driver is to increase current service sales and it is highlighted by Company B and Company C. Company B, in one hand, wants to sell a bigger package including traditional services and sensor-based services and on the other hand, the company wants to make a differentiation to its offers whereas Company C wants to show the ability of the company to respond to the requests quickly and at any time. Cost saving is the fourth common value that is mentioned by Company A and B.

Table 12. Value drivers of developing sensor-based solutions

	Company A	Company B	Company C	Company D
Value drivers of manufacturers	Generating revenue; Improving the customer relationship; Saving cost; Understanding customers’ operations	Creating new business; Marketing and sales purpose	Improving the customer relationship, Saving cost; Marketing and sales purpose	Increasing the volume of the service business
Perceived Value drivers of customers	Saving cost; Increasing the uptime	Saving cost; Increasing the uptime; Accessing to a reference data	Increasing the uptime	Improving safety; Increasing the uptime

The perceived value drivers of customers are rather similar for all companies. The first common value drivers of customers is increasing the machine uptime. The companies think that the most important matter for their customers are increasing the availability of the production lines, reducing downtime and running the production line smoothly. The second common perceived value driver is saving cost for the customers. Companies believe that customers can benefit from the system by reducing costs of unnecessary travels of the service providers and reducing cost of downtime. Accessing to the reference data is another perceived value driver of the customer that is highlighted by Company B. The company reasons that customers can take advantage of the global platform and the collected data and figure out their performance situation in compare with the other competitors. Company D also considers improving safety as an important value driver for its customers.

4.5.4. Data utilization

Case companies proposed some similar and different possibilities in utilizing the collected data that are presented in Table 13.

Table 13. Data utilization

	Company A	Company B	Company C	Company D
Current and possible use of collected data	Improving maintenance; Product development; Provide Sellable material as a reference data	Forecasting consumables; Improving maintenance; Product development; Sales and marketing	Improving maintenance; Product development	No comment

Improving the maintenance is the main similar usage of the collected data from the installed bases. The companies try to use the RMS to analyze the machineries automatically or by customer's permission and do the maintenance in the earliest possible time. However, companies do not use the collected data as an input for research and development but they accept the great opportunities in this field. Company A believes that if they can collect data from all their global customers, it can be an important reference data and they can sell it to the customers. Company B considers the use of the data in sales and marketing efforts. Analyzing the cost of existing problems in the previous version of a product by using the remote data can be an effective marketing tool to sell the developed product.

4.5.5. Different approaches in developing the solution

Case companies had quite similar approaches in developing and launching the solution that is shown in Table 14.

Table 14. Different approaches in developing and launching the solution

	Company A	Company B	Company C	Company D
Cooperation in network	Mostly developed in-house	Coordinated by R&D department; Searching for potential partners	Mostly developed in-house	Has not studied; possibilities of cooperation with customers and third parties
Launching services	Applied in two customer sites; Test the system with few customers	Gradually and in a smaller customer scale	All customers with different prices and levels	No comment

The remote monitoring system has been developed in-house in all companies. However, Company B wants to continue the development process in cooperation with some subcontractors and partners. The customers and suppliers have not had a direct role in developing the solution in all companies. However, Company D considers the role of customers in developing the system and also thinks about cooperating with third parties to have a better utilization of the collected data.

Both Company A and Company B decide to launch the system gradually and with a limited number of customers. Close relationship with the customers is the main criteria for the target customer group. Company B also thinks about the size of customers as another factor and tries to find out whether big customers are better to start with or smaller ones. Company C has a developed monitoring system and offers it to all customers with different service levels and prices based on the customers' requirements.

4.5.6. Risks, changes and possibilities

The companies explained several important matters about risks, required change in business models and future development. Those comments are summarized in Table 15.

Table 15. Risks, changes and possibilities

	Company A	Company B	Company C	Company D
Problems and risks	Data security	Data security	Data security	Data security; Losing the close relationship with the customers
Changes in business model	Needs to change; Have not studied or developed	Needs to change; Have not studied or developed	Needs to change; Evaluating different business models in the strategic agenda,	Needs to change; Have not studied or developed
Future development	Additional sensors; Figure out some business with the collected data; Improve the interface of the system	System development	Add sensors which can measure several parameters	System development

Almost all companies mentioned the data security as the main risk of the remote monitoring system. This risk has been mentioned by customers frequently and has acted as a barrier to further development and deployment of the system. Company D has also some concerns about losing the existent close relationship with its customers. The result of workshop also confirms the deep concern about data security in all companies. Monitoring the installed bases remotely may cause less site visits and face to face relationship between service men and customers.

Most companies recognized the need to change the business model. Companies A, B and D have not studied the different alternatives. Company A thinks that the earning logic should value the activities rather than service hours or spare parts. However, Company C has put this issue in its strategic agenda and is evaluating different business model to find the most appropriate one.

Companies detect some future development possibilities based on the current stage of their systems. For Company B and Company D, that are in the early phase of the development, the whole system development with all prerequisites and requirements is considered as the future development. Company A identifies the need for additional sensors to measure more parameters of the installed bases. The possible business with the collected data is another issue that the company wants to develop in the future. The company also wants to improve the interface of the current system. Company C’s main development idea is about using sensors in the installed bases which can measure several parameters at the same time.

5. DISCUSSION

This chapter presents the similarities and differences of the results of the thesis and prior studies. The answers to the main research questions of the thesis are explained in this chapter.

The main research question was broken down into the three questions:

1. *What are the value drivers for developing sensor-based services in engineering firms?*
2. *What are the opportunities for utilizing collected data from sensor-based services in engineering firms?*
3. *How do companies differ from each other, in their approaches towards sensor-based solutions and related service innovations?*

5.1. Question 1. Value drivers for developing sensor-based services

5.1.1. Value drivers of manufacturers

The main value drivers for manufacturers which have been identified in prior researches and case studies are sorted by decreasing order of frequency in Table 16. The outcome of case studies shows quite same results as literature review however with different level of importance.

Table 16. Comparison of value drivers of manufacturers in prior studies and case studies

Prior studies	Case studies
Increasing knowledge of own products	Generating revenue
Rationalizing benefits	Improving customer relationship
Improving customer relationship	Saving cost
Generating new turn-over	Marketing and sales purpose
Reducing after-sales cost	Understanding customers' operations

Generating new turn-over is the main value drivers of the case companies. However, companies have different viewpoints regarding to generate turn-over; some companies want to create new business via the sensor-based solution like selling reference data and some others want to the increase the volume of service business with help of technology. Küssel et al. (2000) confirms some parts of this finding. In his study concerning tele-service, he explains that machine manufacturers have the opportunity to expand their service sector for example preventive maintenance and acquire new turn-over. However, he did not discuss about possibilities of new business based on the collected data.

Improving the customer relationship has been pointed in both literature and case studies as an important value driver for the manufacturers. Relationship with customers can be enhanced considerably by applying remote monitoring systems (Küssel et al., 2000). The ability of company to identify problems even earlier than customers and respond to them in a proper time and manner can improve the customers' satisfaction. The remote monitoring system also provides this opportunity for the manufacturer to involve with customers constantly and identify current and upcoming customers' needs.

Saving cost is another mentioned value drivers in case studies. However, most companies believe that this is not the main stimulant in compare with creating new turn-over. Reducing after-sales cost has also been declared in Biehl et al. (2004) study which was about remote repair, diagnostics, and maintenance. The cost of establishing new branches and service centers in each area can be reduced significantly by using remote monitoring system. Based on his researches, manufacturers can save 20 percent to 30 percent of after-sales cost.

Some case companies also consider the role of remote monitoring system in improving marketing and sales. Actually, differentiation through RMS acts as a driver for those companies. They can add advanced solutions to their offer and show their ability to fulfill customers' needs efficiently. However, this driver can be somehow related to customer relationship but prior studies did not focus on marketing and sales specifically and they actually concentrate more on possible effects on other parts of a company.

Understanding customers' operations is another value driver that has been mentioned by some case companies. The constant connection with the installed bases is an opportunity for manufacturer to understand how they customer operate with their machineries and it can open some areas for improvement. This driver also has a connection with customer relationship but it is not discuss specifically in literature.

Küssel et al. (2000) also describes another value driver of remote monitoring system called rationalizing benefits. He explains that both in implementation and warranty phases the manufacturer can utilize the remote monitoring system to connect the service experts in the headquarters to the service men in the customer's site. This new way of connection not only reduce time and cost but also help the company to analyze the problem beforehand and equip the right service men with right tools. However, this benefit does not consider for case companies as a value driver but one company use this opportunity partially and analyze some customers' sites via RMS before going for preventive maintenance.

5.1.2. Value drivers of customers

The customers can have several value drivers to accept and apply remote monitoring systems. Those value drivers that are mentioned in prior studies and those that are identified during case studies are showed in Table 17.

Table 17. Comparison of value drivers of customers in prior studies and case studies

Prior studies	Case studies
Increasing the machine uptime	Increasing the machine uptime
Increasing knowledge about their own processes	Saving cost
Saving cost	Accessing to a reference data
Improving safety	Improving safety

Both literature and results of interviews show that increasing the machine uptime is the key driver for customers. Several researches show that RMS can reduce the unplanned production stops and increase the efficiency of the production process (Jonsson et al., 2008; Westergren, 2011; Westergren and Holmström, 2012; Wang et al., 2007; Wu et al., 2006). The case companies also affirm these findings and re-emphasize the importance of increasing the availability of the production lines for their customers.

Saving cost is another significant benefit that interviewees thought that will stimulate customers in applying RMS. Actually, reducing cost in customers' site has been mentioned several times in prior studies (Westergren and Holmström, 2012; Wang et al., 2007; Küssel et al., 2000; Jonsson et al. 2008; Biehl et al., 2004). Küssel et al. (2000) explains that this value driver plays an important role for customers especially after warranty phase when they usually have to pay all costs by themselves. All studies show that preventive maintenance and reducing unplanned stops through RMS has a significant effect on customers' production cost.

Improving safety is one of the value drivers of customers. This element has not mentioned noticeably in prior studies. However, Wu et al. (2006), in their study about web-based remote monitoring and fault diagnosis system, consider improving safety as one of the benefits of RMS. Most case companies also did not think that improving safety could be an effective motivator for their customers; actually, some of them produced advanced machineries that would stop automatically in case of any safety issues. However, safety was a very important matter for one case company and the company though that the RMS can help them to reduce risk of safety issue in sites and consequently provide some value added services to their customers.

Some case companies also open a new value driver for especially smaller customers that has not been mentioned in prior studies. Accessing to a reference data where customers can compare their performance and utilization rate with other competitors can be a good motivator for them. However, providing this database requires a global platform and more efficient use of collected data via RMS.

Westergren (2011) and Westergren and Holmström (2012) also mentioned the possible opportunities for customers to achieve more knowledge about their own production line through RMS. Actually, the customers can recognize how efficiently they use the product and any miss-use of machineries. This service can help them to solve related problems in their production lines and in improve the productivity.

5.2. Question 2. Opportunities for utilizing collected data from sensor-based services

One of the important matters in the field of sensor-based solution is how manufacturers can utilize the huge amount of the collected data through the system. Although this concept has been mentioned in some prior studies but it has not been discusses in detail in most of them. Case companies had some ideas about using collected data but most of them did not have a detailed plan about how to utilize the data efficiently. The suggested or applied methods are presented in Table 18.

Table 18. Comparison of use of data in prior studies and case studies

Prior studies	Case studies
Improving maintenance (preventive maintenance)	Improving maintenance
Product development	Product development
Understanding how customers use the equipment	Forecasting consumables
	Provide sellable material
	Sales and marketing tool

Improving maintenance was the main application of remote monitoring system for all companies. Most of the prior studies also confirm this application as the main use of remote data (Pan et al., 2008; Wang et al., 2007; Westergren, 2011; Jonsson et al., 2009; Mori et al., 2008; Biehl et al., 2004; Nieva, 1999; Jonsson et al., 2008; Westergren and Holmström, 2012). Through RMS the manufacturer is alerted about any problems or unusual changes in their installed bases. Then, they can analyze the system to understand the problem and help the customers to resolve it. However, the case companies do not use RMS as a pure preventive maintenance system. The need for customers' permission to access the system results in reactive actions rather than proactive maintenance.

Another identified use of collected data, both in prior studies and case studies, is in product development. Most of the case companies did not mention this usage at first but after opening the discussion about product development, they accepted the great opportunities in this area. The manufactures can use the collected data to detect the potential problems in its products and try to avoid them via product development (Jonsson et al., 2008; Westergren and Holmström, 2012; Jonsson et al., 2009; Westergren, 2011).

One interesting usage of collected data which was mentioned in case studies but has not been stated in prior studies is providing sellable material based on the collected data. Actually, companies want to build some business based on the collected data. Providing reference data to the customers is an identified example by the case companies. Manufacturers with global customers can access to a large database through RMS that shows several attributes of installed bases including their performance rates. This information can be helpful for the customers to determine their position in compare with their anonymous competitors.

The other identified usage of collected data by case companies is its use in sales and marketing. A case company suggested that the company can analyze the effect of the identified problems via RMS on the customers' production and try to evaluate the cost of problems. This calculated loss can be presented to the customers when the manufacturer wants to sell the developed version of the machinery. This way of utilizing the remote data has not been described in the prior studies.

One of the suggested uses of collected data in prior studies is about evaluating how customers use the installed base (Westergren, 2011). RMS provides this opportunity for manufacturers to analyze how the customer operates with the machinery. Therefore, they can identify any misuse of machinery by the customers and try to correct them. This data also becomes valuable when the customer claims about a deficiency in the product that is due to the wrong use of products by the operator not a problem in the product.

5.3. Question 3. Different approaches towards sensor-based solutions and related service innovations

5.3.1. Cooperation with customers

Most of case companies have developed or wants to develop the remote monitoring system in-house. It means the R&D of the company has the main role in developing the system. One company sees the possibility to work with subcontractors and partners who have the expertise in the technology and can help them to develop the system more efficiently. However, all case companies, except one of them, did not consider customers as important players in developing the system. According to Martin et al. (1999), understanding the important role of customers in a service offering and adjusting to this different role is one of the main obstacles in designing and integrating a business-to-business service innovation. Actually, as it has explained in section 2.1.3, the important role of customer involvement is the key difference of new service development to product development.

Innovation literature has focused on a rather new paradigm called open innovation. The increased opportunities of working with external partners have made the companies to start searching for resources from outside of their own areas to find innovative ideas and solutions (Lee et al., 2012). Customers are one of the main external resources for companies. They are the final users of products and services and achieving their satisfaction is one of the main success factors of the innovative solution. The customer involvement in new product development has achieved considerable attention in various studies. Lagrosen (2005) explains different possibilities of customer involvement in new product development. Customers can participate in different phases of the development process including only in the initial stage, only in the final stage or cooperating with the company in all stages of development. New service development has not been studied as same as new product development. However, this trend is changing and there are more researches which focus on this critical area. Customers can participate in the development by several ways. Martin et al. (1999) categorizes these methods:

- Specification of the service: the customer involves at varying levels to identify the nature and level of service offering;
- Pure co-production: the customer cooperates in some or all parts of the development, even they might be work as provider’s employees;
- Quality control: the customer participates in the entire course of service offering from development to on-going production of service offering and evaluating its quality level;
- Marketing: the customer helps the company to sell the service to other customers.

Neale and Corkindale (1998) suggest that in developing new technology, customers should have a very active role and cooperate with the provider in a joint development process. The suggested concept, co-development, requires the early participation of the customer in the development process. In co-development process, both company and the customer bring their expertise to the project; usually the customer helps in application of technology and the technology originator provides the core technology expertise. This process helps the company to consult the customer throughout the development process and subsequently maximize fit with customer needs.

The result of workshop with all companies confirms the important role of customers in developing the innovative services. First, the customer value should be defined with the customers. Then the solution can be co-created with customers. It can help the company to test and measure the new service in different customers’ sites with similar production lines and provide the opportunity to compare them and measure the values. During the discussion in the workshop, companies also emphasize on the possibility of co-developing with other companies from other industries. It helps the company to benchmark and use the ideas and experiences of other companies.

5.3.2. Launching innovative services

The way how the companies launch their innovative services can have a significant effect on the success or failure of the offering. Those case companies, who are in the process of development, propose to offer the remote monitoring system gradually and start with fewer customers. The most important factor for choosing the initial target group is the relationship between them and their customers. They think stronger relationship will increase the chance of acceptance and further success. The participants in the workshop also confirmed this approach and identified finding the right customers for piloting as an important issue in the launch process. They also explained use of these pilot cases as references for further expansion of the solution. References become very important when potential customers have some doubts about accepting the new solution. Ojanen et al. (2008) approve this finding and state that the customer relationship is a significant element in new service development. During launch of new services, some customers may not understand the new idea and its benefits, so the company should deal with customers who perceive the new offering is complex (de Brentani, 2001). de Brentani (2001) also considers a formal and planned launch program for the new service offering as one of the success factors of innovative new business services.

Lenfle and Midler (2009), in their study about the launch of innovative product-related services, consider new product launch as a basis for exploring the launch of innovative services. The launch of new product has two different processes including production ramp-up and the commercial launch of the product. Ramp-up is called to the final phases of the development process when the company starts commercial production at a low level of volume. The commercial launch is actually preparing the sales performance and it is usually related to the marketing and sales literature.

However, in the field of service business, it is not possible to separate production and marketing. The services are usually co-produced with the customers and therefore make it difficult to test the service before the sales process. It is also very difficult to correct defects in the service offering and change the customers' dissatisfaction (Zeithaml et al., 1990). The result of case study of Lenfle and Midler (2009) demonstrates the overlapping of three processes in innovative product-related services launch including the technical ramp-up of the service infrastructure, the design and implementation of the sales process, the need to explain to the customers and sellers the value and function of the service. They consider two complementary strategies to improve the launch process. First, the company should involve the sales personnel in the design process to prepare the launch, design the incentives, develop learning programs and so on. Second, the company should consider the after-sale process as a key process to support customer learning. Actually, it is very important to follow the customer's experience of innovation, help them to use it efficiently and increase the loyalty.

5.4. Sensor-based service enablers

Engineering companies provide various services to their customers. The main services of case companies have been mentioned in section 4.5.1. These services cover all maintenance and modernization activities, ensuring the customers that they would have continuous production with a high performance rate. Companies want to reach some objectives for each type of services to be able to support customers efficiently. Table 19 shows these services and the related objectives. This section explains how sensor-based solutions can act as service enablers and help firms to overcome emerged issues and reach the goal.

Table 19. Objectives of each type of services

Type of service	Objective
Maintenance	Reduce any unplanned breakdown
Spare parts and consumable	Identify needs and supply them on time
Modernization and extensions	Identify needs, provide accurate performance report and recommendations
Inspection	Choose right service people with right tools
Training	Identify the improvement areas in customers' operation

Maintenance. Sensor-based solutions provide the opportunity for firms to monitor their installed-base remotely and identify any unusual status in the machineries. They can analyze the problems thoroughly and find the proper way to solve it as early as possible and before the production shutdown. This increases the machine uptime and fulfills the main goal of the maintenance activity which is reducing the unplanned breakdown.

Spare parts and consumable. Monitoring the machineries via sensor-based solution enables the firms to recognize any obsolete or defective parts in the machine. The companies also can receive data from the embedded sensors about the status of consumable and determine how much they have been spent. Thus, they can supply the required spare parts and consumables proactively and prevent the possible breakdown.

Modernization and extensions. At various points of the machineries life cycle, the firms can integrate collected data from the system and provide performance reports for the customers. These types of reports identify possible needs to upgrade machines or production line and suggest recommendations for modernization and required extensions.

Inspection. Generally, the sensor-based solution reduces the need for on-site inspection considerably. It means manufacturers can do the inspection remotely with less cost. However, if the firm finds the necessity of site visit, the sensor-based solution enables the company to evaluate the installed base's status remotely and identify the possible problem areas in the production line. Thus, they can select the right service people to go to the customers' sites and equip them with right tools and spare parts.

Training. The collected data from the remote system can help the company to evaluate the problems in the machinery and detect any possible misuse of the machinery by the customers' operators. Thus, the company can prepare suitable learning program for the customers to train them the most efficient use of the equipment.

6. CONCLUSIONS

6.1. Responding to the research objective

The main research question which was stated in section 1.2 is …

How can a company utilize sensors to enable services in the engineering firms?

Companies can have different approaches to develop and use sensor-based solutions in their service business. This thesis provides several ideas and recommendations for the engineering firms. The findings of the thesis including results of literature review and case studies are presented in Figure 6.

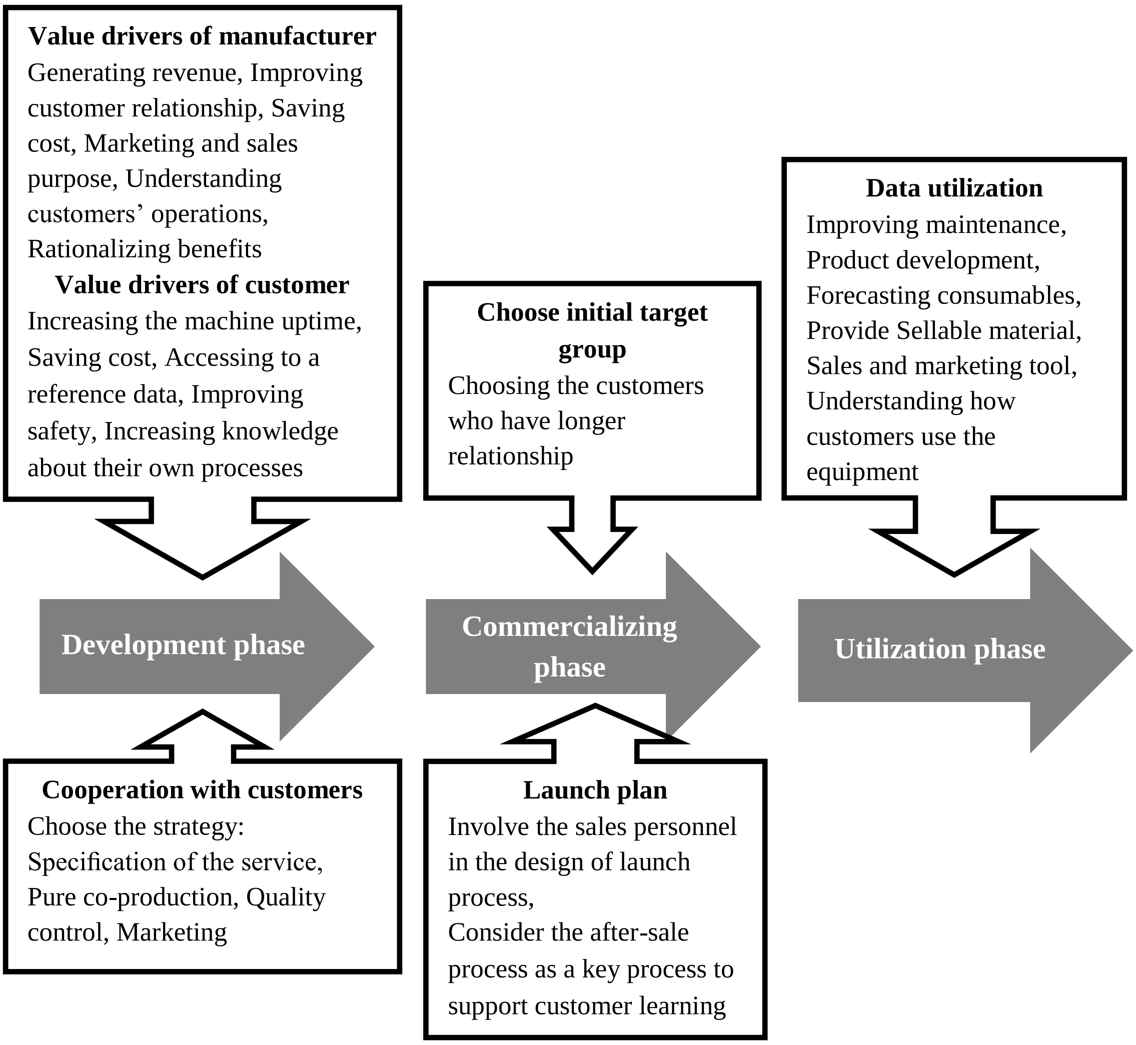

Figure 6. Framework for providing remote monitoring system

Identified value drivers of manufacturers and customers can help the firms in their developing processes; they must build a system to response to their goals and customers' needs. Manufacturers had various value drivers for developing the solution. The findings provide broader picture of the potential benefits of the solution that can be result in more commitment to develop the solution and also provide some initial ideas for potential ways to use the collected data. Identified value drivers for the manufacturers are generating new service business, improving the customer relationship, saving cost, helping in marketing and sales and understanding customers' operations. Rationalizing benefits is another value driver that has been suggested in prior studies which mentions the benefits of analyzing the installed-bases remotely before visiting the customers' sites. Identified value drivers of customers by the manufacturers can be also useful for the manufacturers to show how differently they look at their customers and their purposes. Provided value drivers of customers can help the manufacturers in their marketing and sales efforts and also in developing and utilizing the system in the most proper way. The value drivers can include, but not limited to, increasing the machine uptime, saving cost, accessing to a reference data, improving safety, increasing knowledge of customers about their own processes.

Another set of findings that can help the firms in the development phase is related to the cooperation of customers in developing the system. This thesis emphasizes on the important role of customers in developing innovative service solutions. The customers can participate in different stages of the development process from involving in some specific phases to joint development. The company can define the most appropriate strategy based on its own specifications and customers' expertise. However, the company should keep the cooperation in a way that is able to consult with customers during the development process and therefore, develop a system that fits with their needs and expectations.

Commercializing the innovative sensor-based solution is also an important factor that should be considered by the manufacturers. One of the important finding in this thesis is related to the selection of the first target market. Those early adopters can have a significant role in success or failure of the innovative solution. Working with those customers who have longer relationship with the company can increase the chance of acceptance and further success. Another important matter in launching innovative service is the difficulty of testing the service before the sales process. Therefore, companies need to implement parallel strategies to improve the launch process. In one hand, they have to involve the sales personnel in the design of sales process to be sure that they know the value and function of the service and so design the suitable incentives and learning programs. On the other hand, companies need to pay more attention to the after-sales process, so they can identify the customers' experience in utilizing the system and help them to implement it properly.

Utilization phase is the final place where companies can define their abilities to use a huge amount of collected data efficiently. The thesis suggests several possible uses of data for the engineering firms. Apparently collected data can be used to improve preventive maintenance. The received alarms from installed-bases as well as analyzing the trend of different attributes of the machine can help the companies to predict any probable breakdown and try to solve the problem in a timely manner. Collecting data from many installed-bases which are located in different sites turns to a valuable database for the manufacturer. By doing appropriate analysis on the collected data, the company can identify similar problems in its machineries and use it as an input in its product development plans. Organizing collected data in a proper way and selling it as reference data to the customers can be another possible use which allows the customers to compare their performance to their competitors. Using the collected data in sales and marketing to calculate benefits of new version of products and evaluating how customers use the machinery in order to correct their misuse or protect from any wrong claims are other identified opportunities in this field.

6.2. Academic contribution

The thesis gives a broader view of how engineering firms can develop and utilize sensor-based solutions. This research area has not been researched commonly. This study tries to focus on different aspects of the subject through multiple case studies. Most of the prior studies have been about the benefits of the customers from the sensor-based solutions. This study highlights the role of manufacturers and provides important information about how manufacturers can improve their business through the solution. Most of the prior studies have focused on preventive maintenance as the main application area of sensor-based solutions. However, this thesis provides other alternatives of utilizing collected data. Explaining the importance of launch plan for sensor-based solution was another topic that is highlighted in this thesis.

The thesis also studies sensor-based solution as a service enabler. It shows different goals of provided services to the customers and explains how sensor-based solution can help the firms to achieve their goals and overcome possible issues in implementing their services. The remote access to the installed base helps the companies to monitor their installed base and detect any upcoming issues in the production line and respond to them quickly. Thus, it enables service provider to do preventive maintenance efficiently. It also enables the company to identify needs for replacing parts or supplying consumable early enough and reduce the probability of machine breakdown. Analyzing the installed base via sensor-based solution can lead to more efficient inspection and the service provider can prepare to do the required actions in the customers' sites. The collected data via the system can also be helpful in enabling the manufacturers to provide suitable services. Analyzing the data properly can provide valuable information for the manufacturers and customers about possible needs to upgrade and modernize the machineries or the production line. It can also reveal any misuse of the machineries by the operators and help the company to provide required training program for these improvement areas in the customers' operations.

6.3. Limitations and validity

This study had some limitations. In the reviewed literature, other sensor-based solutions than remote monitoring system were not analyzed thoroughly due to the characteristics of case companies' solutions. Furthermore, each case company was in a different level of development phase. Thus some viewpoints are based on the experience of the interviewees in a specific subject and some of them are based on their predictions about future.

The methodology of the research was multiple case studies. The case study method can be highly subjective which may cause some misunderstanding and errors due to the researcher's interpretations. The interview, as a method for collecting information from case companies, is also subjective. In one hand, the interviewees may misunderstand the question or the general concept. On the other hand, the interviewer may misunderstand some interviewees' answers that can affect the results.

The number of interviewees in each company was limited and presented the views of small part of the people who are involving in service business and there is a possibility that this small percentage did not represent the viewpoints of their companies. Additionally, almost all interviewees were managers of some departments and business units. Thus, the viewpoints of employees who are involved in service delivery process and have direct contact with customers did not reflect in this study. The case studies were also done only with manufacturers and not with customers. Therefore, the knowledge about customers' expectations comes from the manufacturer's experience and perceptions.

The validation of the study was improved by applying several means. First, the interviews were done based on structured-interview framework. This approach helped to have same focus on key themes in all companies. Second, the result of interviews was sent to the interviewees to review the result and validate its content. Third, a workshop was held for all companies to discuss the key results of the case studies and compare them with prior studies. The workshop was helpful to validate the interview data. Finally, the full manuscript of thesis was sent to the companies to review all results and analysis and send the final feedback on the study.

6.4. Future research

The topic of the thesis includes wide research areas. As mentioned in the limitation section, only one sensor-based solution (RMS) was studied thoroughly. Therefore, further studies are needed to cover other technologies such as RFID and Machine-to-Machine communication.

Roles of other players in the network than the customer must be studied as well. Suppliers, other companies who are not the competitors, third parties and so on can cooperate with the manufacturers to develop the system. The future researches should cover all cooperation possibilities and their characteristics and limitations. The role of customers also need to be investigated more to clarify what is the best cooperation strategy.

As mentioned in the limitation section, the thesis only reflects the viewpoints of the manufacturers. Customers' needs, expectations, benefits and limitations also have an important effect in the success of the offered solution. Thus, further studies should include some case studies in the customer's side to explore the innovative ideas and opportunities that can help the manufacturers to develop a better solution as well as their barriers and risks that should be overcome by the manufacturer.

Commercializing of new service technology is another topic that needs further research. The previous studies paid more attention to the normal demand-pull market. However, in the case of sensor-based solution, supply-push service market is needed to be studied considerably. The prerequisites of launch process, choosing the proper early adopters, designing incentives for customers and communicating the value of the solution with the customers and sales personnel are among the possible topics that need to be studied in the future researches.

Converting the collected data to the suitable formats, integrating multiple data and analyze them are critical areas that need to be studied carefully. Most of the case companies have this concern that they cannot utilize the huge amount of data efficiently. The collected data via the sensors does not have significant value if the manufacturer cannot create some information based on them. Therefore, further studies need to cover the required plans, software and analyzing method of database.

All case companies were accepted that they will need to change their business models but no suggestions were identified during the case studies. Hence, studying different alternatives, their benefits and challenges is encouraged. Other related topics like the effect of other players of the network on business model need to be studied too.

Data security was the most important risk of customers and barriers of the manufacturers to implement the remote monitoring system. Lack of the proper strategy to overcome this challenge will decrease the performance of the solution. Thus, different aspects of data security and possible approaches and plans to remove or mitigate this risk must be explored in future studies.

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APPENDIX (1 piece)

Questioning frame of interviews

1- Background information

a) Position in the company
b) Job description
c) How long and in which positions have you worked for the company?
d) How long have you worked in the industry/ or similar fields?

2- Information about the company and customers

a) What does the company and business unit do?
b) What is the core competency of the company?
c) How is the competition in your industry?
d) What are the key challenges in your industry?
e) Who are your customers? SMEs or big companies? Many or few key customers?
f) How many international customers do you have? In which geographical areas?
g) What do the customers expect from the company? needs, values, etc.
h) How do you aware of customer expectations?
i) How many branches, after-sell service offices, etc. do you have in other places?

3- Service business

a) What is the share of services in the company's turnover?
b) What is the importance of service business for your company now? And what it could be in the future?
c) What kind of services do you provide to your customers?

4- Service delivery

- Process of service delivery at the moment
- Any changes in the process during years
- Design of services
- Sell process of service offerings

5- Intelligent / ICT based service solutions

- Types of intelligent / ICT based service solutions

- Motivations of delivering these types of services for the company and the customers
- Development process of these solutions (internally/ partners)
- Future possibilities in this area
- Problems, risks and constraints

6- Sensor-based solutions

Do you apply sensor-based solutions in your service business?

If Yes:

i. What kind of sensor-based solutions do you offer to the customers?
ii. What were the initial motivations to develop these solutions?
iii. What were your expectations at the beginning? Have you achieved your goals?
iv. To whom these solutions are offered? To all customers or only certain customers?
v. What are the value drivers of sensor-based solutions for your company?
vi. In your opinion, what are the most important value drivers for your customers?
vii. How has this new form of service delivery changed your business model?
viii. How did you develop your solutions? Internally or with partners?
ix. Are you creating new sensor-based solutions now?
x. What are the future possibilities in this area?
xi. What are the problems, risks and constraints of these solutions?

If No:

i. Do you think that sensor-based solutions are applicable in your company?
ii. What are the perceived value drivers of sensor-based solutions for your company?
iii. In your opinion, what could be the most important value drivers for your customers?
iv. How can this new form of service delivery change your business model?
v. What would be the problems, risks and constraints of these solutions?

Do you have any suggestions or comments related to interview?