LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

School of Business and Management

Master’s Programme in Strategic Finance and Business Analytics

Master’s Thesis

Profitability Analysis of Internet of Things Investments

Mikko Kaukonen

1st Examiner Professor Mikael Collan

2nd Examiner Post-Doctoral Researcher Azzurra Morreale

2018

TIIVISTELMÄ

Tekijä:	Mikko Kaukonen
Tutkielman nimi:	Esineiden internet -investoinnin kannattavuuslaskenta
Tiedekunta:	Kauppatieteellinen tiedekunta
Pääaine:	Strategic Finance and Business Analytics
Vuosi:	2018
Pro Gradu -tutkielma:	Lappeenrannan teknillinen yliopisto 80 sivua, 15 kuvaa ja 6 taulukkoa
Ohjaaja:	Professori Mikael Collan
Tarkastajat:	Professori Mikael Collan Tutkijatohtori Azzurra Morreale
Avainsanat:	Esineiden internet, kannattavuuslaskenta, reaalioptiot

Tutkimuksessa tarkastellaan esineiden internet -investoinnin kannattavuuslaskentaa. Ensimmäiseksi esineiden internet -investoinnin teknologisia tasoja analysoidaan. Toiseksi analysoidaan tärkeimmät liiketoiminnalliset ulottuvuudet liittyen esineiden internet -investointiin. Kolmantena tutkimuskohteena on esineiden internet -investoinnin kannattavuuslaskentaan käytettävät menetelmät, joita tutkitaan analysoimalla esineiden internet -investoinnin kannattavuutta sekä perinteisimmillä takaisinmaksuaika-menetelmällä, sisäisen korkokannan menetelmällä ja nettonykyarvo-menetelmällä että uudemmalla reaalioptiomenetelmällä. Kannattavuuslaskentamenetelmien vertaamisessa käytetään haastatteluilla kerättyä aineistoa, jossa uudenaikaisen esineiden internet -kyvykkyyksillä varustetun tehdaslaitteen elinkaarikustannuksia verrataan perinteisemmän ilman esineiden internet -kyvykkyyksillä varustetun laitteen elinkaarikustannuksiin. Elinkaarikustannusanalyysin perusteella esineiden internet -kyvykkyyksillä varustetun tehdaslaitteen investoinnille lasketaan kannattavuusanalyysi yhdeksän vuoden investointiajalle. Elinkaarikustannusanalyysin tulokset osoittavat, että esineiden internet -kyvykkyyksillä varustetun tehdaslaitetteen elinkaarikustannukset ovat alhaisemmat kuin verrokkilaitteella. Kannattavuusanalyysin tulokset osoittavat esineiden internet -kyvykkyyksillä varustetun tehdaslaitteen hankinnan olevan kannattava. Kannattavuuslaskentamenetelmien vertailu osoittaa, että reaalioptiomenetelmää on hyödyllistä käyttää esineiden internet -investoinnin kannattavuuden analysoimiseen perinteisten kannattavuuslaskentamenetelmien rinnalla esineiden internet -investointiin liittyvien epävarmuuksien ja estimoinnin vaikeuksien takia.

ABSTRACT

Author:	Mikko Kaukonen
Title:	Profitability Analysis of Internet of Things Investments
Faculty:	School of Business and Management
Master's Program:	Strategic Finance and Business Analytics
Year:	2018
Master's Thesis:	Lappeenranta University of Technology 80 pages, 15 figures and 6 tables
Supervisor:	Professor Mikael Collan
Examiners:	Professor Mikael Collan Post-Doctoral Researcher Azzurra Morreale
Keywords:	Internet of Things, profitability analysis, real options

This study explores the profitability analysis of an Internet of Things investment. First the general technological layers of an Internet of Things investment are analysed. Secondly, the most relevant business dimensions related to the Internet of Things investment are presented. Finally, the profitability analysis of an Internet of Things investment is analysed with a real-life case where Internet of Things -capable industrial machine is compared to an older version without the Internet of things capabilities in a total cost of ownership analysis. Based from the results of the total cost of ownership analysis an investment profitability analysis is calculated to determine the financial benefits of the Internet of Things -capable machine during a 9-year investment period. Traditional profitability analysis methods of internal rate of return method, payback method and net present value method are compared to real option valuation method to analyse whether Internet of Things investments would require more advanced profitability analysis methods such as real option valuation methods. Results of the total cost of ownership analysis show that the Internet of Things -capable machine has lower lifetime costs than the compared industrial machine. Results of the profitability analysis for the acquisition of the Internet of Things -capable machine demonstrate the investment to be financially profitable. Results for the comparison of the profitability analysis methods show that real option valuation method is better suited for Internet of Things investments due to the high uncertainty related to Internet of Things investments and estimates related in its profitability analysis. More advanced profitability analysis methods such as real option valuation methods are therefore advantageous alongside the traditional methods to analyse capital budgeting decisions related to Internet of Things investments.

TABLE OF CONTENTS

1 INTRODUCTION 6
1.1 Background 7
1.2 Purpose of the study 11
1.3 Limitations of the study 12
1.4 Structure of the thesis 12
2 INTERNET OF THINGS 13
2.1 IoT Technology layers 14
2.1.1 Sensing 16
2.1.2 Networking 19
2.1.3 Intelligence 24
2.2 IoT Business dimensions 31
2.2.1 IoT Ecosystem 32
2.2.2 Application areas 38
2.2.3 Business models 40
2.3 Profitability analysis 44
3 DATA AND METHODOLOGY 55
3.1 Data 55
3.2 Methodology 58
4 RESULTS 61
5 CONCLUSIONS 70
REFERENCES 75

List of Figures

Figure 1. IoT paradigm with different visions (Atzori et al., 2010) 9
Figure 2. Technological aspects and business dimensions of an IoT investment 14
Figure 3. Key functions of the sensing layer (Li, Xu and Zhao, 2015) 17
Figure 4. Key elements in the intelligence layer of the IoT investment 25
Figure 5. Five categories of DSS (Power, 2007) 28
Figure 6. Decision Support Systems framework (Chang and Song, 2010). 29
Figure 7. IoT ecosystem (Mazhelis et al., 2013) 33
Figure 8. Monetization models for IoT investments (CapGemini, 2014) 41
Figure 9. Similarities between financial options and real options (Leslie and Michaels, 1997) 52
Figure 10. Input section for estimates in the total cost of ownership analysis used in the Microsoft Excel-file 57
Figure 11. Example of a three cash-flow scenario where a triangular fuzzy number is constructed (Collan, 2012) 59
Figure 12. Yearly cashflows generated from the savings 62
Figure 13. Cumulative cashflows from the additional value scenarios 65
Figure 14. Discounted cumulative cashflows from the additional value scenarios 66
Figure 15. The fuzzy pay-off distribution. 66

List of Tables

Table 1. Categories of the total cost of ownership analysis. 56
Table 2. Results of the total cost of ownership analysis. 61
Table 3. Discounted cashflow analysis based on the savings generated by new IoT machine 63
Table 4. Scenario estimates and fuzzy values for real option valuation 64
Table 5. Results of the real option valuation 67
Table 6. Summary of the profitability analysis 68

1 INTRODUCTION

Internet of Things (IoT) is a concept where smart and uniquely identifiable machines are connected to the internet providing the potential to enhance current business processes and even create completely new ways to operate. Most research on the IoT has been focused on the technological aspects of IoT and during the last years more research has been made to analyse different aspects of IoT. Whitmore, Agarwal and Xu (2015) studied the literature on the IoT and found 127 relevant papers consisting from journal articles, conference papers and edited volumes and noted that due to the dynamic state of development of IoT majority of papers focused on the computer science and engineering domains of the IoT paradigm with less focus on the economical, managerial and social aspects of IoT. The aim of this thesis is to study the profitability analysis of an IoT investment. This is done by analysing both the technological elements as well as the business dimensions of an IoT investment. Technological elements and business dimensions of an IoT investment are analysed to determine if they create a solid reason for IoT investment's profitability analysis to utilise real option valuation method in addition with more traditional profitability analysis methods.

Palattella et al. (2016) state that in order for a large-scale implementation of IoT there has to be three elements in place. Firstly, the supply-side of the technology has to be developed. Secondly, there have to be functional business models to link the supply and the demand. Thirdly, market demand for the IoT technology should be strong. IoT investment is usually quite complex and multidimensional, and traditional profitability analysis methods might struggle analysing it thus causing carefulness for companies to really embrace it. This might then cause slowness in the demand of IoT solutions. Analysing the ex-ante investment profitability of IoT investments can be quite difficult because of the technological nature of the investments. The IoT investments consist from multiple technological layers and various business dimensions and valuation of an IoT investment can be quite challenging. Many aspects in these IoT investments require subjective valuations about the future technological and business developments which is difficult. Trigeorgis (2002) lists multiple reasons why real option analysis can be beneficial in investment analysis for example that real option valuation explicitly includes uncertainty and flexibility in the analysis, real option valuation allows including corporate growth options in the analysis and more accurate valuation of investments with managerial options.

Currently there are many challenges for IoT such as security, privacy, monetization and great amount of uncertainty about the future development of the IoT paradigm. A 2017 survey of over 1800 IT executives found that only 26 percent of companies had completed a successful IoT project and rest of the companies had had less successful IoT experiences so far (Cisco, 2017). Some experts even predict that the IoT might only result in niche or special purpose applications, without much effect on everyday life. There are many buzzwords and definitions related to the IoT such as Internet of Everything (IoE), Industrial Internet (II) and Ubiquitous computing. This is caused by the fact that the IoT paradigm is still in early development and there are many counterparties developing different aspects of the IoT such as Industrial Internet Consortium (IIC), Internet of Things Consortium, Internet Engineering Task Force (IETF) and International Organization for Standardization (ISO) just to name a few. This large variety of solutions and developing nature of the IoT paradigm possess challenges when analysing the IoT paradigm. (Atzori et al., 2010)

1.1 Background

Companies have to make strategic investments to sustain and increase their market positions against their competitors. Investment decisions regarding technological choices can be extremely important for companies and these decisions can be the reason for gaining or losing competitive advantage (Porter,1985). Recent technological development has opened huge potential in IoT and McKinsey (2015) estimates that the potential economic impact of IoT could be between $4 trillion to $11 trillion in 2025. IoT has the potential to be a very significant change in the world and companies have to take this change into consideration when making investments to adjust to changing market demands and competitor’s actions. This means companies have to be able to identify the correct investments to make so that they can maintain their competitiveness in the long run. Analysing the potential of IoT investments can be difficult and traditional profitability analysis methods such as net present value method, payback method and internal rate of return method might not be well suited to analyse these investments properly.

Investment decisions can be based on qualitative and quantitative criteria. These criteria can include for example the profitability, stakeholder expectations, strategic aspects, different risks involved and liquidity of the investment. The most important quantitative criteria in most cases is the profitability of the investment. Common investment profitability methods used to calculate the profitability of investments are net present value method, payback method and the internal rate of return method (Burns and Walker, 2009). Due to the uncertainty in the future of IoT technologies these methods on their own might not always be best solutions for IoT investments' profitability analysis. Lee and Lee (2015) argue that especially the high flexibility of the IoT investment with reversibility and scalability can be very difficult to include properly in the traditional profitability methods commonly applied in companies which can cause potential IoT investments to be undervalued. The undervaluing of potential IoT investments can increase when the complexity of the investments increases which can potentially mean that the most complex and revolutionary IoT investment opportunities might be the most undervalued investment options. Real option valuation method might be in certain cases an essential part to include to correctly analyse IoT investments.

Whitmore, Agarwal and Xu (2015) studied the IoT literature and found that from total of 127 papers 53 papers could be categorized as technology-focused, 32 papers as application-focused, 22 papers could be categorized with focusing on the challenges of IoT, 14 papers were overviews or surveys of the IoT paradigm, 4 papers were the focused on the business models of IoT and 2 papers were focused on the future directions of IoT. Li, Xu and Zhao (2015) studied the recent technological development of IoT for definitions, standards, architecture, enabling technologies, and applications. Their results show that IoT is still in early stages and there is significant uncertainty related to various aspects of IoT such as market demand, technological development, standardization, privacy and security.

Currently the IoT market is in an early phase meaning that there are fragmented solutions for specific domains and applications with multiple choices for platforms, protocols and interfaces (Mazhelis et al., 2013). One reason for difficulties in defining IoT concepts and possibilities comes from the fact that IoT can be approached from several different starting points. Atzori et al. (2010) separate three different visions how the IoT as a concept can be analysed. Figure 1 illustrates the IoT paradigm with three different visions. The visions are "Things" -oriented vision, "Internet" -oriented vision and the "Semantic" -oriented vision.

Based from these three visions can be determined three interconnected layers for the IoT investment: sensing layer, networking layer and intelligence layer. Sensing layer consists from sensors and actuators collecting the data and interacting in the environment. Network layer in this thesis is defined as networking technologies and computing paradigms. Intelligence layer includes various analytics solutions and different aspects considering decision-making based on the data collected in the sensing layer and which is transmitted in the network layer. Intelligence layer is arguable the most challenging and important aspect in the IoT technology stack. Atzori et al. (2010) state that the "fuzziness" in the term IoT is caused by the fact that there are multiple starting points to approaching the paradigm of IoT. When approaching the IoT concept it can be challenging to form a clear understanding of the situation if the sources applied in the situation approach the IoT paradigm from different visions. Atzori et al. (2010) define the three visions as:

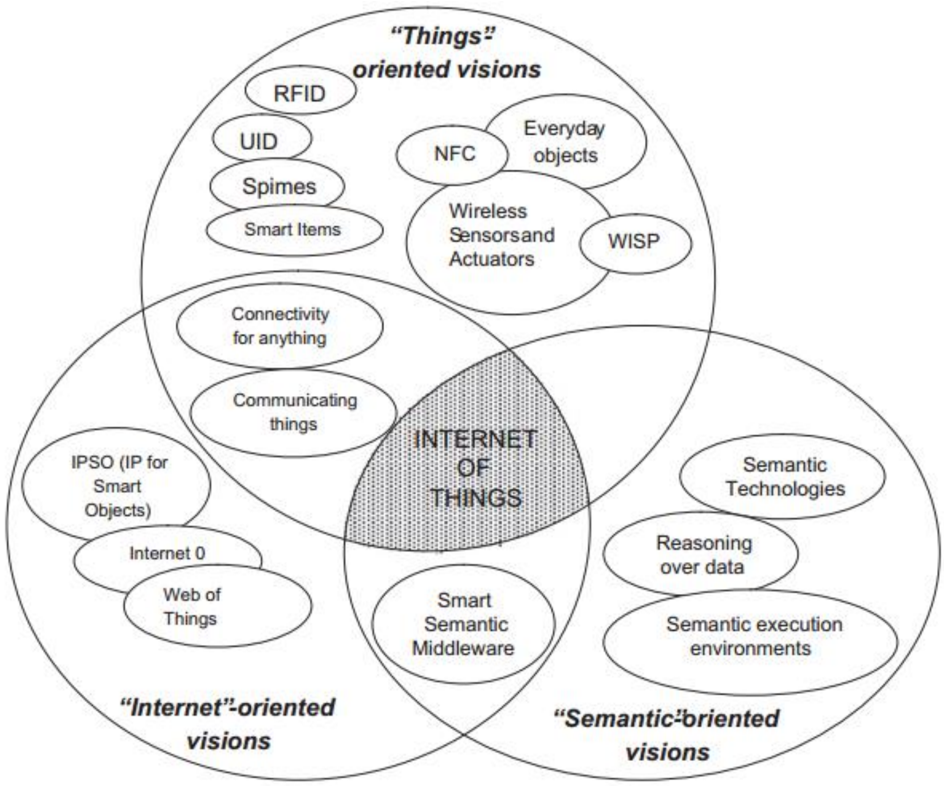

Figure 1. IoT paradigm with different visions (Atzori et al., 2010)

Things -oriented vision approaches IoT paradigm as connecting simple items to internet to allow tracking for location and status. This means that the hardware technologies for IoT such as radio-frequency identification (RFID) and near-field communications (NFC) are at the centre of attention when approaching IoT possibilities.

Internet -oriented vision on the other hand is starting from the ability to connect smart objects into the internet via networking technologies. Important aspect includes network connectivity, interoperability and automatic data transfer. The difference between things -oriented vision and internet -oriented vision therefore is that internet -oriented vision is more about connectivity solutions to allow easy and efficient network access to different items whereas things -oriented vision is more about how to make physical objects send information most effectively.

Semantic -oriented vision approaches IoT with the focus in the modelling of information which is the basis of this vision. Critical aspects in the Semantic -oriented vision are the representation and storing of data, interconnection between devices, searching and organization capabilities with regard to the huge amount of data generated by various IoT devices. Important challenges in the centre of vision include modelling solutions for IoT things descriptions, decision-making solutions for the IoT data, architectural and semantic execution environments.

Palattella et al. (2016) mention three major sources of profitability from IoT technologies. Firstly, the possibility for real-time instrumentation. Secondly and arguably the biggest source, the ability to generate insights from the amount of Big Data received from the IoT devices. Thirdly, the savings due to the wireless technologies. Susskind and Susskind (2015) argue that the future technological development happens largely by automation and innovation. IoT can affect in both ways and thus be a very important factor for companies trying to create competitive advantage by technological investments. IoT can help companies automating and improving their operations starting from the sensor level going up to the decision-making level. IoT can also be a significant source of new revenues for companies with new innovations.

Palattella and al. (2016) argue that the biggest source of profitability from IoT, the ability to create insights from the IoT Big Data, is not easily quantifiable. Lee and Lee (2015) argue that the widely used net present value method is not a well-suited method for IoT investments because of the high flexibility and future uncertainty of the IoT. Instead of the NPV method Lee and Lee (2015) suggest real option valuation method for the valuation of IoT investments. Real option valuation method is based on the logic of financial options and consists from valuation of real-life options in the capital budgeting process with the discounted cash flow analysis. Real option valuation is very useful in capital budgeting when there is a lot of uncertainty and need for managerial flexibility in projects is relevant.

1.2 Purpose of the study

Purpose of the study is to analyse the profitability analysis of an IoT investment. This requires analysing the nature of the IoT investment’s technological elements and business dimensions. These elements are critical in the capital budgeting process required for the correct valuation of IoT investments. IoT investments might not be properly analysed with the more traditional profitability analysis methods such as net present value method, internal rate of return method and payback method causing companies to defer their IoT investments. Hypothesis of the thesis is that more advanced profitability analysis methods such as real option valuation method is sometimes needed for the profitability analysis of IoT investments due to the uncertainty and flexibility of the technological and business aspects in the IoT paradigm. Applying the correct profitability analysis methods for the IoT investments is very significant because IoT has the potential to create significant competitive advantage for companies in rapidly evolving markets.

Main research problem for the thesis is the determination of return on investment (ROI) for the IoT investment. Research questions of the thesis are:

1. What are the main technological elements of an IoT investment?
2. What are the most important business dimensions for the IoT investment?
3. Does IoT investment require more advanced profitability analysis methods due to the nature of these technological elements and business dimensions?

Forming an understanding of various technological elements in the IoT is important because there can be various interpretations of the concept of IoT as the three different visions of IoT articulated by Atzori et al. (2010) demonstrate. An IoT investment can include various kinds of technologies and approaches with different effects on the profitability analysis so understanding the technological elements in the investment is a natural starting point for the profitability analysis and a critical research question. The second research question analyses factors that can have a significant impact on the profitability of the IoT investments because the future development of technologies is affected from various non-technological factors.

Third research question is applying the findings from previous two research questions in the profitability analysis of IoT investments. Overall this thesis aims to study the IoT investment both from the technological and business point of views with the context of creating strategic advantage for the companies.

1.3 Limitations of the study

There are many limitations for the study. Technological aspects are not discussed on a deep level because the technological expertise required for understanding of various IoT technologies is significant and out of the reach of this thesis. Deeper analysis of the IoT security and privacy aspects are left outside of the thesis although they are vitally relevant technological and business aspects to consider in the IoT investment.

1.4 Structure of the thesis

The thesis is organized in the following way. Second section defines the IoT investment's key technological aspects and relevant business dimensions. In the second section the profitability analysis methods for the IoT investment are also presented. Third section presents the data and the methodology for empirical case for the thesis. Fourth section presents the results. Fifth section contains the conclusions of the thesis.

2 INTERNET OF THINGS

In this chapter IoT investment is defined both from the technological level as well as from the most relevant business domains. The profitability analysis of IoT investments is also presented. Technological elements of a general IoT investment are presented in three technological levels and three relevant business dimensions for the IoT investment are presented. The aim of this chapter is to analyse the technological nature of the IoT investment and the uncertainty in the future development of IoT. Technological uncertainty provides a reason to consider applying more advanced capital budgeting methods such as real option valuation method over the more traditional discounted cash flow methods. Different starting points to approaching IoT as a concept can cause confusion when talking about IoT investments so in this chapter the IoT investment is defined first from a technological view and then different business dimensions related to these technological layers are presented.

Combining Li, Xu and Zhao (2015), Atzori et al. (2010) and Whitmore, Agarwal and Xu (2015) the technological levels of an IoT investment are categorized in this thesis in the following three layers:

- Sensing
- Networking
- Intelligence

Based from Palattella et al. (2016), Mazhelis et al. (2013) and Atzori et al. (2010) important business aspects related to the IoT investment in this thesis are identified as:

- IoT ecosystem
- Business models
- Application areas

Figure 2 depicts the IoT investment consisting from these technological aspects and business dimensions.

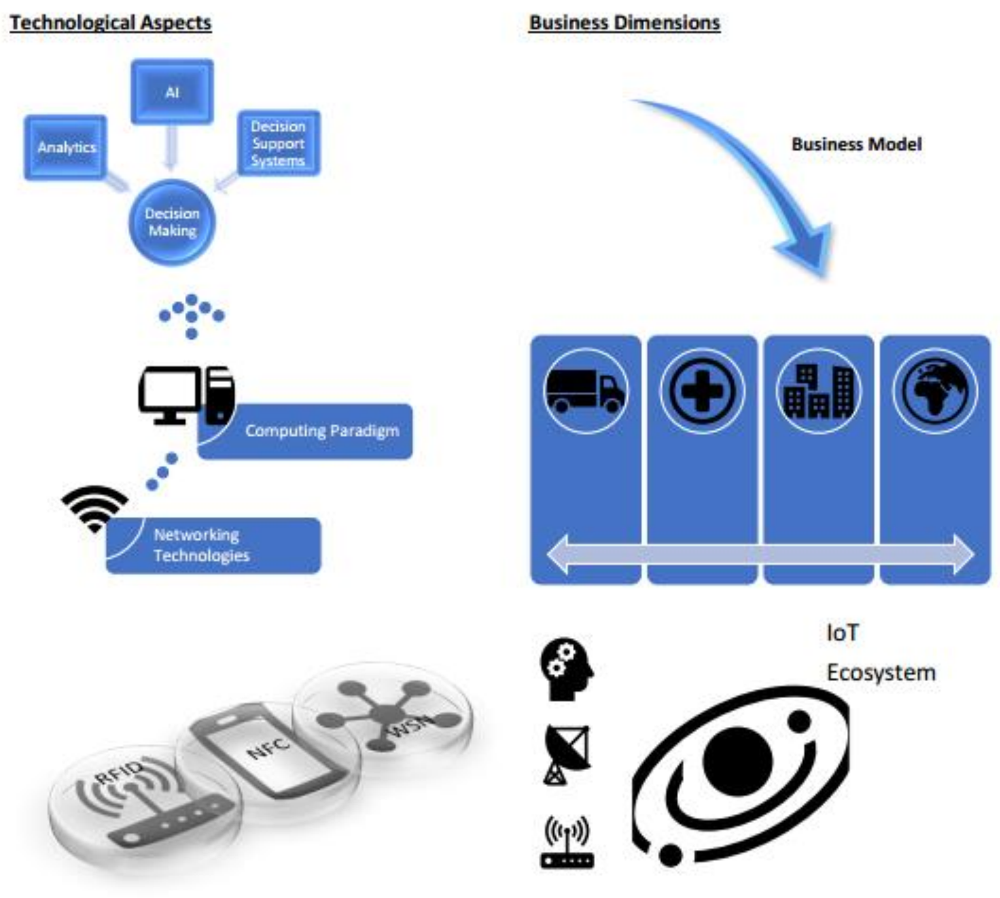

Figure 2. Technological aspects and business dimensions of an IoT investment

Figure 2 depicts the general IoT investment with the technological layers and business dimensions. Technological elements of the IoT investment are divided into three layers of sensing, networking and intelligence. Business dimensions consists from the IoT ecosystem, application area of the investment and the business model chosen for the investment.

2.1 IoT Technology layers

The technological layers in the IoT investment are sensing, networking and intelligence. These three layers can be thought as a basis for an IoT technology stack which is constructed for the IoT investment. Stated simply sensing layer collects the data, networking layer transmits the data, the intelligence layer sorts data for decision-making which can either include human decision-makers or can be partly or fully automated.

Sensing layer in the IoT investment consists from censors which collect the data that is analysed in the IoT investment and actuators which perform actions in the environment. Atzori et al. (2010) list three key technologies for the sensing layer which are radio frequency identification technology (RFID), near field communications technology (NFC) and wireless sensor networks (WSN).

Networking layer consists functionally from moving the data between the sensing layer and the intelligence layer. Important aspects in the networking layer are different networking technologies used in the transmission of data. Some relevant technologies for the IoT network layer are presented in the networking chapter. Choosing the computing paradigm for the network layer is also crucial and two different computer paradigms relevant for the IoT paradigm are presented: cloud computing and edge computing.

Intelligence layer in this thesis consists from two broad aspects: analytics and decision-making. It could be argued that the intelligence layer is the most important layer in the IoT investment. Having the ability to collect data and transfer it into computer isn’t worth much without the ability to understand it and make good decisions based on this data. The amount of potential data from all the censors in the sensing layer justifies using the term Big Data in the IoT context. This means that different analytics solutions have to be included in the IoT investment. Having the ability to understand the data from the censors leaves only one thing left to consider in the IoT investment: decision-making. Decision-making in the IoT Big Data context might be overwhelming for humans so decision support systems are presented. Having the ability to automate much of the decision-making in the IoT investment could also be a viable option with the aid of Artificial Intelligence (AI) so some key concepts for AI are also briefly presented.

Internet of Things is currently a very popular term and it holds huge potential but there is also a lot of hype around it. Defining exactly what IoT means and all the possibilities related to it can be quite difficult because there are multiple definitions related with IoT. Li, Xu and Zhao (2015) state that there is not a single definite definition for IoT but instead there are variety of terms with similar definitions to IoT or terms very much linked to the IoT such as:

- Internet of Everything
- Industrial Internet
- Ubiquitous computing

- Pervasive computing
- Web of Things

Internet of Things as a concept can be defined many ways and this can cause difficulties in understanding it and applying its potential for business. There is a large number of organizations working on multiple definitions, standards and protocols related to IoT such as Industrial Internet Consortium (IIC), Internet of Things Consortium, Internet Engineering Task Force (IETF), International Organization for Standardization (ISO), World Wide Web Consortium (W3C), 3rd Generation Partnership Project (3GPP) and Institute of Electrical and Electronics Engineers (IEEE) to name a few. Among the various counterparties involved in the IoT paradigm there are many ways of defining the IoT concept and different elements related to it.

2.1.1 Sensing

The sensing layer in the IoT investment consists from collecting data with censors and altering the environment through actuators. The sensing component in a IoT investment refers also to the “Things” in the Internet of Things term. The figure 3 describes key aspects in the sensing layer which are wireless communication, RFID systems and intelligent sensors (Li, Xu and Zhao, 2015). There are multiple technological aspects which affect the IoT investment and should be considered when making decision about the technological choices in the sensing layer. Mattern and Floerkemeir (2010) list some of these aspects such as communication, addressability, identification, sensing, actuation, embedded information processing, localization and user interfaces. Key technologies in the sensing layer mentioned by Li, Xu and Zhao (2015), Whitmore, Agarwal and Xu (2015) and Atzori et al. (2010) are:

- Radio frequency identification technologies (RFID)
- Near Field Communications technologies (NFC)
- Wireless sensor and actuator networks (WSAN)

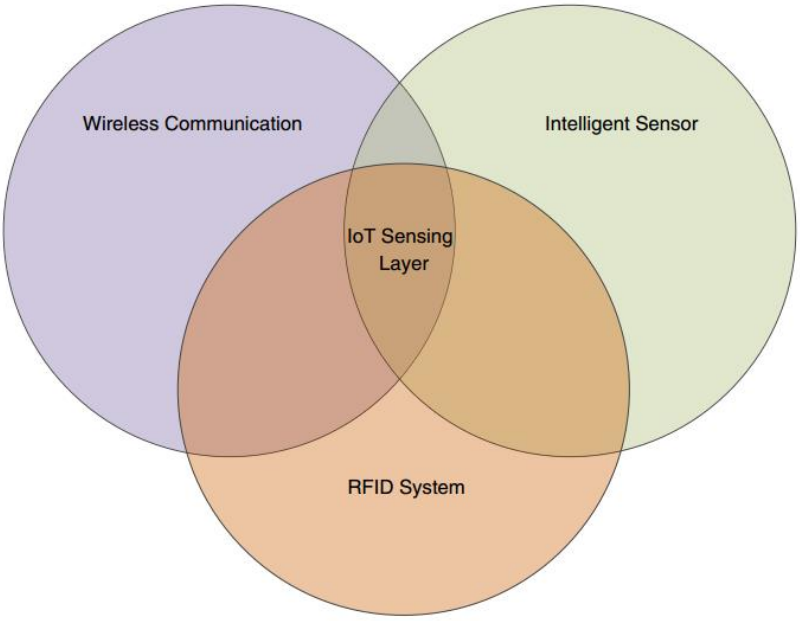

Figure 3. Key functions of the sensing layer (Li, Xu and Zhao, 2015)

Radio frequency identification technologies (RFID) are contactless identification systems. RFID system consists from two parts: the transponder and the reader. The transponder which is also referred as a tag, is embedded in the object which then can be uniquely identified. The reader is the data collecting unit which sometimes can also rewrite the data on the transponder. The reader normally consists from a radio frequency module, control unit, a coupling element and an interface to forward the data. RFID has multiple benefits when compared to more traditional automatical identification systems such as barcodes, optical character recognition, biometric recognition or smart cards. Technically RFID system compares well for example in data quantity, machine readability and operational costs. RFID technology can be seen as barcode system where the data can be read automatically without the need of a mechanical contact and the data can be reprogrammed if necessary. Aspects which the various RFID systems can be divided are for example operation type, data quantity, ability to program the system, operating principle, sequence, power supply, frequency range and response time. (Finkenzeller, 2010)

There are multiple differences between different RFID systems which have to be weighted with the intended nature of the IoT investment. For example, operating frequency, range requirements, security demands and memory capacity are few qualities that are relevant factors when choosing the hardware components of the sensing layer for the IoT investments. Functionality of the RFID systems can be classified into low-end and high end-systems. Starting from the lowest functionality class into to more sophisticated capabilities different functions of systems can include read-only capabilities, read-write capabilities, anti-collision capabilities meaning the ability to keep radio signals from different devices from mixing, authentication with encrypting capabilities, smartcard operating system capabilities and smartcard with cryptographic coprocessing capabilities. (Finkenzeller, 2010)

Near field communications technologies (NFC) are another key technology for the IoT investment in the sensing layer and are relevant when considering the application of RFID technologies (Atzori et al, 2010). NFC technology is a short-range wireless technology and the exchange of data between two NFC devices requires close distance between the devices. Many modern smartphones can be used as an NFC device as well as a compatible RFID tags. Communication between NFC devices happens with high-frequency alternating fields and requires two types of NFC interfaces: an NFC iniator and an NFC target. NFC device can act as either an NFC iniator or as an NFC target. NFC devices have two operational modes for communication which are the passive mode and the active mode. Rohde & Schwarz (2011) list as potential areas of use for example mobile payment, authentication, data transfer between NFC-units, unlocking other services, access of information and ticketing. Benefit of NFC technology compared to RFID technology is the ability of NFC devices to act both as iniator devices and target devices. With RFID technology, the tags are not able to act as transponders. This allows NFC devices to form peer-to-peer networks with various data exchange capabilities. Challenges for NFC technologies with regards to IoT investments can arise from the lack of standardization of NFC technologies. This can mean differences in censors and the operating systems in them. (Sundmaeker et al., 2010; Finkenzeller, 2010)

Wireless sensor and actuator networks (WSN) are the third key technology for the IoT sensing layer. Wireless sensor and actuator networks, which sometimes are called just wireless sensor networks, are networks consisting from nodes with sensing and actuating abilities. WSNs consist from nodes connected to base station which transfers the data forward. Nodes are formed from sensors which can collect different types of data such as speed, distance, direction, chemical changes, strain and load pressure. Wireless sensors usually have along with the sensing abilities some processing and communication abilities. Sensors can have their own processors which allows them to code and decode communication as well. WSN can be used with RFID technology to increase the amount of data produced in the IoT investment. Usually WSN sensors are embedded in other devices which provides the energy for the sensors and actuators. WSNs can also be operated with batteries which vary from duration, some requiring daily changing while some larger batteries can sustain energy for months. Critical aspect in the WSN is power supply because sensor nodes usually don't have large energy sources connected to them. This can mean that the lifetime of the single sensor node might be short. Usually this is dealt with lower overall performance level requirements in areas such as throughput and delay both with the application and as well network level to allow better power consumption. (Atzori et al.,2010; Akyildiz et al., 2002)

2.1.2 Networking

Networking layer in the IoT investment consists from the transference of data. The transfer of the data happens between the sensors in the sensing layer and the intelligence layer. The amount of data from the IoT sensing layer could be very significant which creates challenges for data transferring between the sensing layer and intelligence layer. Key elements in the networking layer are:

- Networking technologies
- Computing paradigms

Network technologies are responsible for the transfer of the data but there is also the question where to transfer and how to manage the huge amounts of data generated by the sensing layer. There are different ways to manage the data generated from the sensing layer. One is to process much of the data near the censor level known as edge computing. Another data management way is to transfer the data somewhere else for processing which is the cloud computing paradigm. Technological aspects that are relevant in the networking layer include such as deployment, mobility, cost, size, energy, heterogeneity, communication modality, infrastructure, network topology, coverage, connectivity, network size, lifetime and the quality of service of the technologies (Sundmaeker, 2010).

IoT is also one of the driving factors in the change from the current IPv4 internet protocol into the new IPv6 protocol. Fundamental change between these protocols is the amount of possible IP addresses for computers and with the change from IPv4 to IPv6 the number of potential addresses increases significantly, from the current around 4 billion addresses into undecillions. This is due to the fact that IPv4 addressing uses 32 bit addressing and IPv6 128 bits hence the larger selection of addresses. Atzori et al. (2010) point out that this change from IPv4 to IPv6 requires actions in IoT solutions since for example RFID tags use 64-94 bit addressing and some type of solutions are still needed to sort the addressing of things. (Mazhelis et al., 2013)

Networking technologies for IoT is very a broad domain and there are many competing solutions for transference of data. Differences between solutions come from different standards and communication protocols applied in the components which in many cases are not consistent with each other's. This can create difficulties when deciding the components for the IoT investment's networking because it is uncertain which technologies will become dominant versions for the IoT components. This would mean that choosing the wrong technology could prove to be challenging or costly to replace. (Mazhelis et al., 2013)

Networking technologies in general can be divided into wired and wireless technologies. In the context of IoT the wireless technologies are more interesting due to the versatility allowed by not having to connect items with wires in to the internet. Another classification factor for the wireless technologies is the coverage area which can be divided into short-range and long-range technologies. Short-range technologies include technologies with coverage areas smaller than a normal house where as long-range technologies cover much wider areas. In some IoT cases the short-range technologies can be more suitable due to their better energy efficiency and lower costs (Mazhelis et al., 2013). Palattella et al. (2016) list differences between short-range technologies and long-range-technologies being the longer coverage area, relatively lower deployment costs, high level of security and easier management for long-range technologies.

Short-range wireless technologies include both wireless personal area networking technologies (WPAN) and wireless local area networking technologies (WLAN). WPAN technologies connect devices together within small distances whereas WLAN technologies connect computers together from a larger area, usually around the size of a large building. Both WPAN and WLAN technologies usually need a router to connect into the internet. Short-range wireless technologies include many different technologies such as Bluetooth, ZigBee, Z-wave, Insteon, BACnet, Modbus, ANT, 6LowPan and Wi-Fi. Mazhelis et al

(2010) divide these technologies into four major application areas: user monitoring, home automation, building automation and cars. Some short-range wireless technologies can be applied in multiple areas such as Wifi and Zigbee while other technologies are more application area specific such as BACnet and Modbus which are used in building automation. Differences between technologies are created from to the fact that they operate in different layers on the short-range wireless technology stack. Short-range wireless technology stack layer consists from physical layer, link layer, network layer, transport layer and application layer. Technical differences also come from different operating ranges, frequencies and protocol inter-operability. (Bonaventure, 2011; Mazhelis et al., 2013)

Long-range wireless communication in the IoT context includes cellular technologies and wireless wide area networking (WAN) technologies. Cellular technology means many interconnected transmitters each responsible for a particular area or cell. Cellular technologies are normally categorized in the generations starting from the first generation of technologies (1G) to the current fourth generation of technologies (4G). The next generation forward is the fifth generation which is planned to be deployed from the year 2019 forwards. The fifth generation (5G) of cellular technologies is very relevant to the IoT because it enables much more efficient communication. The 5G technologies provide significant improvements in number of devices connected, data rate, coverage and quality of service measures compared to the previous fourth generation technologies. Fifth generation of cellular technologies also provide better security, mobility, quality of service support and global reach than current technologies. Key source of improvements for 5G technologies are the use of higher frequencies called millimeter waves. Another factor for 5G improvements are beamforming abilities and full duplex capabilities, which mean focusing transmission more intelligently and being able to send two-ways communications using the same frequencies more easily. (Palattella et al., 2016)

Wide area networking technologies are similar to PAN and LAN technologies but only with larger cover areas. Wide area networking technologies include for example Coronis, NWawe and On-Ramp wireless. Key features are wide coverage area, efficient energy consumption and use of low bandwidth. Wide area network technologies and cellular technologies are compatible technologies where WAN technologies are more suited for shorter range machine-to-machine, also called M2M communication and current cellular technologies more longer-range communication with previous mentioned benefits compared to WAN technologies. (Palattella et al., 2016)

The computing paradigm for the IoT investment is a very important aspect in the IoT investment, especially when the size of the generated data approaches Big Data levels. Lee and Lee (2015) argue that data management is one of the biggest challenges for IoT investments due to the huge amounts of data that IoT investment can potentially generate. Different computing paradigms include for example mainframe computing, pc computing, cloud computing and edge computing. For IoT investments the most interesting computing paradigms are cloud computing and edge computing.

Cloud computing is a computing paradigm where dynamically scalable resources are provided over the internet and much of the data is processed somewhere else than where it is created. Benefits for cloud computing include scalability, pricing and high availability. Cloud computing allows users to access very high amounts of resources such as processing power, storage, servers and applications on-demand and pay by the used amount without the need to invest in the IT infrastructure. Challenges for cloud computing based on Leavitt (2009) include security, privacy and certain level of uncustomizability of the cloud platforms. One challenging aspect is also difficulty in changing cloud computing providers due the location of the data. (Furth & Escalante, 2010)

Cloud computing can be categorized in three sections, private, public and hybrid. Private cloud computing is provided exclusively for one client which allows greater control on security, data control and more customization abilities. Private clouds can be provided by third-party providers or customers themselves. Public cloud computing is a computing service provided by a third party where multiple clients usually share the hardware, meaning servers, storage systems and networks. Hybrid computing is a mix of private cloud and public cloud. Main difference between these types of cloud computing is security. Private clouds can be much more secured than public clouds which in many cases can be in public use and can't be managed only based by particular client's needs. (Furth & Escalante, 2010)

Cloud computing is usually divided in three service-levels: Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). SaaS service model provides customers access to applications without the need to operate the IT infrastructure at all. This means that SaaS service model customers can purchase an access to the application via a license or a subscription. SaaS service model offers customers the complete IT stack, meaning application, middleware, database, operating system, virtualization and IT system infrastructure, as a service. There are two categories of SaaS solutions: horizontal and vertical. Horizontal SaaS solution provides application to specific function across different industries where as vertical SaaS solution consist from products tailored to specific industries. PaaS service model offers customers complete IT stack where they can run different applications but the applications themselves are not included in the service model. Therefore, customers get access to the middleware, database, operating system, virtualization and IT system infrastructure which are required to have an environment where to run applications. IaaS service model provides customers the IT system infrastructure and virtualization and the IaaS customer sets up the operating systems and the necessary applications themselves. (Bain, 2010; Furth & Escalante, 2010)

Edge computing, or fog computing as it can also be called, is a computing paradigm where big part of the data processing happens near the origin of the data at the edge of the network. Edge computing paradigm consists from putting a unit with processing, storing and analysing capabilities into the network. For example, routers or switchers with these abilities can be used as a fog node. Fog node, also called an IoT gateway device, communicates between other nodes in the network by using some wireless networking technologies presented previously. The IoT gateway node is also connected to the internet so it can send and receive data from the cloud platform. Edge computing can be well suited for example in industrial IoT cases where moving very large amount of data into the cloud for processing and back into the censors and actuators might not be efficient due time or other constraints. Edge computing can then be well suited regarding real-time analytics solutions because it allows faster reaction times. Actions would therefore happen based on given rules in the network itself and only certain data would be sent into the cloud platform for deeper analysis. (Cisco, 2015, Sap, 2017)

Benefits for edge computing appear when the IoT context requires fast responses for data meaning there is a low latency requirement for communication. Edge computing is useful in a situation where the network is very large geographically and there is significant number of units connected to the network. Application of edge computing can also provide some added privacy and security into the IoT investment because all the data doesn’t have to be sent into the cloud platform and back. This also decreases the required bandwith and transmission costs if the data can be processed and acted inside the network. Edge computing is not exclusive of cloud computing and there are interesting possibilities in integration of edge computing paradigm into the currently popular trend of embracing the cloud computing possibilities. (Cisco, 2015, Sap, 2017)

2.1.3 Intelligence

Intelligence layer in the IoT investment consists from the data analysis and decision-making after the data from the censors in the sensing layer has been collected and processed through the network layer. The common buzzword Big Data is very much linked to the IoT concept due to the huge amounts of data IoT censors can produce. An IoT investment can produce significant amounts of data which can be considered as Big Data. One common definition for Big Data is information with significant volume, variety and velocity or simply the three V's of data (Frizzo-Barker et al., 2016). The Big Data element in many IoT investment means that the intelligence layer is the most important aspect in the IoT investment. Key elements in the intelligence layer are:

- Analytic Solutions
- Decision Support Systems
- Artificial Intelligence

Figure 4 depicts the intelligence layer of the IoT investment. Understanding what the received information means and ability to make decisions based on these findings are crucial in the IoT context. Without these abilities, the hardware and networking solutions can't produce significant value.

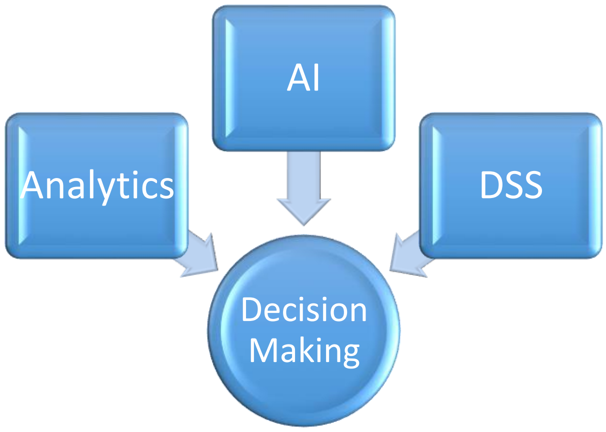

Figure 4. Key elements in the intelligence layer of the IoT investment

IoT investment is a way to collect very large amounts of data from various sources and using analytic solutions to turn that data into insights which then could be turned into profits. Refining the censor level data is done by using analytics solutions which are commonly called business intelligence or business analytics solutions. Another important part of the IoT investment is deciding how to manage the data and how to make informed-decisions based on this data. Decision-making in the IoT context might require some sort of decision support systems due to huge amounts of information produced. In case the amount of information rises over the human decisionmakers capabilities even with applying decision support systems artificial intelligence solutions might be required to extract all the potential value from the IoT investment.

Analytics means analysing data with the use of various methodologies, techniques, technologies, practices and applications to have a clear understanding of the situation. Goal of the analytic solution is to turn information into insights and allow action based on those insights. This is the reason why analytic solutions are highly critical aspect in the IoT investment. Analytics combines aspects from different fields such as information systems, computer science, statistics and business. Common terms used in the context of analytics are business intelligence (BI) and business analytics (BA). The meaning of BI and BA can sometimes overlap but generally BI can be seen as analysing the overall situation on a more general level where as BA provides more sophisticated statistical analysis why certain things are happening and what might happen in the future. According to Chen, Chiang and Storey (2012) some aspects to consider when analysing analytics solutions are data warehouse, data handling which are also known as ETL (extraction, transformation, loading) processes, database querying, online analytical processing and reporting and the different tools which to use in these processes. (Chen, Chiang and Storey,2012 ; Grossmann and Rinderle-Ma, 2015).

Analytics can be divided in to categories of descriptive analytics, predictive analytics and prescriptive analytics. Descriptive analytics provide overall clarity to situations by providing general level answers from historical data. Descriptive analytics consists from general summaries of data properties and statistics, pattern discovery and segmentation. Predictive analytics provides probabilistic answers to what might happen in the future based on the historical data. These can be done by some type of regression analysis or by classification. Predictive analytics is also known as forecasting or extrapolating from previous data. Prescriptive analytics includes both descriptive and predictive analytics and produces different options to act based on the situation. Prescriptive analytics calculates multiple different progressions based on future action by using tools from several disciplines. Descriptive analytics answers what happened in the past whereas predictive analytics provides predictions what might happen in the future. Prescriptive analytics takes both previous types of analytics into consideration and provides actionable answers to decision-making situations. (Grossmann and Rinderle-Ma, 2015; Waller and Fawcett, 2013)

The analytics solution in the IoT investment is responsible for refining the large raw data that comes from the censors and other sources into meaningful information. Other sources of data might include both structured and unstructured data, meaning data with good level of organization and data with low level of organization. Vermesan et al. (2014) list few functions the analytics solution has to be able to perform to provide value: allowing different users set their own filtering rules, providing application programming interfaces for accessing the collected data, allowing users to create their own workflows for processing incoming data, allowing a multitenant model for different types of users. Vermesan et al. (2014) mention multiprotocol abilities, de-centralisation, improved security and datamining as a future feature to be included in the analytics solutions. Multiprotocol abilities mean supporting different types of protocols and standards both in receiving data and forwarding it. This feature is highly important given the various standards and protocols in the IoT domain. De-centralisation means that sensors and data they generated is not tied to a single platform but that different types of systems can interact and cooperate. Improved security is obviously very important for all levels in the IoT investment, but analytics solutions are probably the most critical part in the security for the whole IoT solution. Improved datamining abilities are required to analyse past and current information more efficiently with huge amounts of data generated by the IoT devices and from other sources. (Vermesan et al., 2014)

The amount of data generated by the IoT solution might be so big that conventional analytics solutions might not be adequate and specific Big Data solutions have to be included in the intelligence layer of the IoT investment. Big Data solutions differ from typical analytics solutions by their ability to handle larger amounts of more complex data by utilising for example massively parallel processing databases, data-mining grids, distributed databases, cloud computing and scalable storage systems. Challenges with Big Data solutions are privacy, integrational issues between traditional relational databases and NoSQL database systems, requirement of more efficient solutions to speed up processing algorithms and optimization of data storage. (Vermesan et al., 2014)

Decision support system (DSS) is an interactive computer-based system designed to improve decision-making in complex situations where there is too much data for humans to process. Decision support systems can also be applied to make the decision-making more objective and systematic. The purpose of analytic solutions is to provide better understanding of the data which then creates the best opportunities for decision-making. To enhance decision-making, systems have been created which are commonly referred as decision support systems. Decision support systems can be used in many ways such as to make choices between various options, building different options for the process and even to identify opportunities to create decision-making situations. (Druzdzel and Flynn, 2002)

Decision models can be represented with three components. Firstly, the preference of objectives. Secondly the potential options available. Thirdly, the amount of uncertainty in the model regarding the effect of variables into the decision and the outcomes. General structure for a decision support system is three-parted application consisting from the database, backend-solution and frontend-solution. The database stores all the required data, the backend mainly runs the required operations and the frontend organizes the interaction between the user and the decision support system. (Druzdzel and Flynn, 2002)

DSS is a general term for any computer application designed to enhance the user’s ability to make decisions. There are five general categories of DSS: communications-driven DSS, data-driven DSS, document-driven DSS, knowledge-driven DSS and model-driven DSS.

Figure 5 depicts these categories of DSS. Communications-driven DSS emphasizes networking and communication technologies to facilitate communication and collaboration in the decision-making process. Data-driven DSS focuses on time-series data from internal and external sources. Document-driven DSS are related mostly in abilities to retrieve various documents and have the ability to analyse them. Knowledge-driven DSS focuses on problem-solving abilities and having the ability to suggest possible actions for particular situation. Model-driven DSS focuses on the access and ability to perform operations on various types of models such as financial or simulation models with limited set of parameters and data. (Power, 2007)

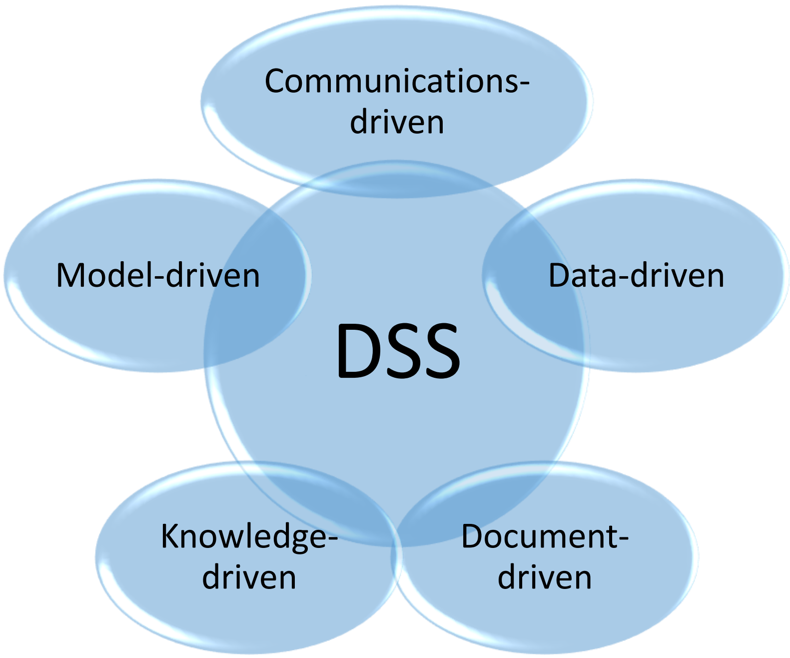

Figure 5. Five categories of DSS (Power, 2007)

Decision support systems and their performance can be analysed with a framework developed by Chang and Song (2010). Figure 6 depicts the framework of Chang and Song (2010). The framework consists from six parts:

- DSS characteristics
- Perception of DSS
- Motivation to use DSS
- DSS use

- Task motivation
- Decision performance

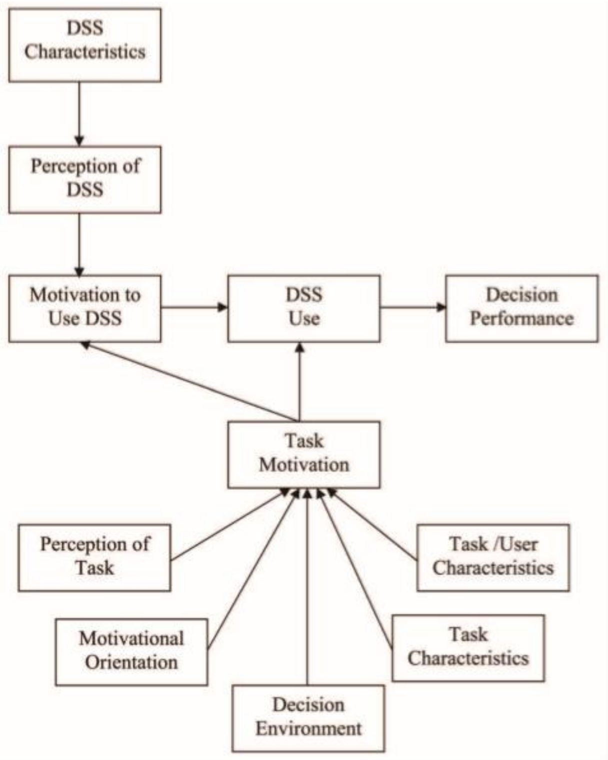

Figure 6. Decision Support Systems framework (Chang and Song, 2010).

In this framework DSS characteristics consist from aspects of usability, presentation format, restrictions of the system, decisional guiding, feedback and interactivity of the DSS. Perception of DSS analyses the user's perception of the DSS in three categories which are the effectiveness of the DSS, efficiency of the DSS output and effort required to operate the DSS. Motivation to use DSS can be analysed from example with the interest of the user to apply the DSS, importance of the task, utility and the cost of using the DSS. DSS use analyses elements such as the frequency and time of use of the DSS. Task motivation is related to the user's motivation for the particular task the DSS is applied. Task motivation can be divided into five categories: users' perception of the tasks value, user's motivation for the task, the actual decision environment with different elements such as rewards for the task, time constraints of the task and accountability for the decisions. Task characteristics include elements such as complexity, difficulty, structure, ambiguity and novelty of the task. User characteristics for the given task include elements such as proficiency, knowledge and experience. Decision performance consists from factors such as the ability to make better decisions with the DSS and the effort required making decisions with the DSS. (Chang and Song, 2010)

Artificial intelligence (AI) is a subsection of computer science which is focused on developing computers capabilities to match humans with regards to intelligence. Recently there has been a lot of interest in AI and specially towards machine learning and all the possible application areas AI could be used. AI applied in the IoT investment is very interesting due to the potentially huge amounts of data generated by the IoT censors. This amount of big data can easily be too much to involve humans in decision-making if the required actions have to be made close in real-time. The generated data can be so huge and complex that humans might not be able to identify all valuable elements in the data. Therefore, applying AI seems a logical element to consider in an IoT investment. IoT investment can also be thought as an investment to insert censors into a current system to create opportunities to apply AI capabilities.

Artificial intelligence is a field where the aim is to improve computers abilities in domains where humans have been significantly better than machines such as learning, creativity, planning, reasoning and decision-making. The aim in artificial intelligence is to understand intelligence and then create intelligent computers. AI consists from many different areas linked to human intelligence such as natural language processing, knowledge representation, reasoning, computer vision, robotics and machine learning. The field of AI combines several disciplines such as computer science, mathematics, philosophy, psychology, linguistics, economics and biology. (Ertel, 2011;Russell and Norvig, 2010)

There are many subfields of AI such as robotics, speech processing, planning, expert systems, which are closely linked to decision support systems, artificial neural networks, evolutionary computation and machine learning. In the IoT context the most interesting subfield of AI could be machine learning. Machine learning is a subset of AI which studies how to make computers perform tasks without explicitly telling them and making computers make improvements on their own by using various algorithms. Domingos (2015) categorizes machine learning algorithms in five main groups: symbolism, connectionism, evolutionary, bayesian and analogism. Each one of these groups applies different types of algorithms as their main method in machine learning. In symbolism the algorithm applied is inverse deduction, in connectionism it is backpropagation, in evolutionary it is genetic programming, in Bayesian algorithm bayesian inference is used as the main method and in analogism it is support vector machine. Various types of these algorithms are used in areas such as supervised learning, unsupervised learning, neural networks and reinforced learning. All of these algorithms perform differently on different types of tasks they are assigned. (Ertel, 2011; Engelbrecht, 2007)

IoT investment where there are large number of censors and actuators installed into a company's systems provides a very interesting opportunity to apply artificial intelligence and especially machine learning. Artificial intelligence could be used in real-time decision making in a situation where it would be impossible by human operators to make decision as efficiently as machines. Exposing the IoT enhanced system to machine learning provides opportunities to identify potential ways to use the system profitably which might not be easily discovered by humans. Applying machine learning in a correct way into the IoT investment could thus able discovering interesting findings which could potentially then be applied either to increase sales or decrease operational costs.

2.2 IoT Business dimensions

There is significant uncertainty in the technological aspects of an IoT investment and this high level of uncertainty is very much linked to the business dimensions of the IoT paradigm. Three key business dimensions based on the research of Mazhelis et al. (2013), Palattella et al. (2016) and Atzori et al. (2010) for IoT investments are:

- IoT ecosystem
- Business models
- Application areas

In the design phase of the IoT investment choosing the correct technological components, deciding the correct business model and understanding the specific circumstances of the application area all have to be considered.

The IoT ecosystem is an important aspect in the IoT investment and a key driver in the technological development of IoT technologies. The IoT ecosystem is still developing and consists from a broad set of companies and counterparties. The IoT ecosystem is presented in the chapter with the key aspects of the ecosystem. Business model is another important factor in the IoT investment. IoT technologies can provide companies the ability to change their existing business models and allow integration of different types of business models to their operations. Choosing the correct business model allows the ability to monetize the IoT investment and currently there are many challenges in the monetization of IoT investments such as lack of technological standards, security and privacy concerns and need for large investments with uncertain returns (Gapgemini, 2014). Therefore, different business models should be considered when analysing potential IoT investments. The application areas where the IoT investment is operated might require different characteristics and possibilities for the IoT investment. Different application areas mean different market dynamics for companies and require potentially completely different types of business models or variations of business models.

2.2.1 IoT Ecosystem

IoT ecosystem involves the companies, officials and individuals interacting in the IoT environment. IoT domain is very large consisting from multiple different disciplines and understanding the ecosystem is especially important in the IoT domain because the development of the different technologies, standards and protocols is very dependent on the ecosystem. Mazhelis et al. (2013) define the IoT ecosystem as accordingly:

> *"a business ecosystem which comprises of the community of interacting companies and individuals along with their socio-economic environment, where the companies are competing and cooperating by utilizing commonly shared core assets related to the interconnection of the physical world of things and the virtual world of the Internet. The core assets may be in the form of hardware and software products, platforms or standards that focus on the connected devices, on their connectivity, on the application services built on top of this connectivity, or on the supporting services needed for the provisioning, assurance and billing of the application services. "*

There is currently uncertainty which technologies will become the dominant ones in the IoT domain and which technologies might turn out to be small niche technologies. This is very relevant for IoT investments because when technologies evolve to become more popular for example through standardization or general market adoption there is likely to be positive effects such as the speed of technological improvement and amount of support available for the use of these technologies. Figure 7 describes the IoT ecosystem by Mazhelis et al. (2013). The IoT ecosystem consists from three main segments: Device, Connectivity and Service. Device segment consists from chip manufacturers, module providers, device manufactures and SIM card providers. Main parties in the connectivity segment are the network operators and network equipment providers. Other counterparties in the connectivity segment are possible network subscription managers, machine-to-machine service providers and machine-to-machine platform providers. In the service segment the main component is the application service provider (ASP). Other roles related to the ASP include the service developers, service distributors, companies providing the provisioning, maintenance providers and companies providing billing abilities. Cloud providers are also important part in the service segment. Outside of the three main segments there are important counterparties in the ecosystem such as legislative and regulatory bodies as well as standard developing organizations. All roles may not be relevant in some IoT application domains. For example, roles related to advertising and content producing might be more relevant in the personal and social domain of IoT than in the healthcare domain of IoT.

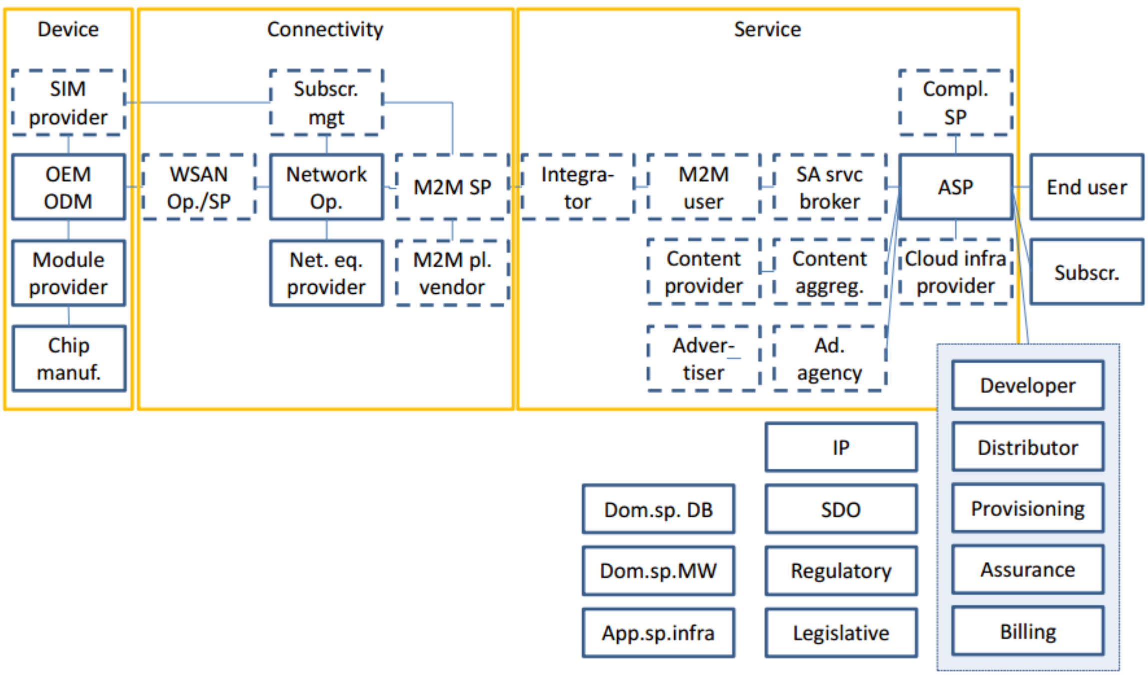

Figure 7. IoT ecosystem (Mazhelis et al., 2013)

Moore (1996) defines ecosystem as an economic community where organizations and individual interact to produce products and services to customers. The ecosystem can be divided into three parts: core ecosystem, extended enterprise and business ecosystem. The core ecosystem is all the companies providing the inputs for the products and services in the ecosystem. Extended enterprise part includes the core ecosystem as well as customers, suppliers of complimentary products and services, suppliers of core suppliers and standard bodies. The business ecosystem additionally includes also all the other stakeholders such as regulators, trade unions, trade associations and investors. (Moore, 1996).

Mazhelis et al. (2013) argue that the core functions shared by many participants in the IoT ecosystem in the future could consist from:

- Connected devices and gateways which includes both software and hardware platforms as well as the related standards;
- Connectivity solutions implemented with hardware platforms with standards and protocols and software platforms;
- Application services developed on top of the connectivity solutions using different software platforms and standards;
- Supporting services for providing for billing capabilities, assurance capabilities, provisioning capabilities, optimization of M2M network elements and related standards.

Key organizations in the IoT ecosystem can be categorized into segments of hardware manufacturers, network and software providers, service providers, regulators and officials. (Comptia, 2015, Mazhelis et al., 2013).

Hardware providers consists from companies manufacturing:

- Sensors
- Miniature devices
- Networking equipment

Hardware companies provide the physical components which IoT investments and solutions consist. These components include all the censors and actuators for the IoT investment’s hardware layers as well as the components for the network operators and cloud computing providers.

Software and connectivity providers are companies providing:

- IoT Platforms
- IoT networks
- Cloud computing
- IoT software

Software and connectivity providers include the IoT platform companies, network providing companies, cloud computing providers and software companies. For the IoT domain an especially interesting group is the IoT platform providers which could form potentially the biggest part in the whole IoT ecosystem. IoT platform is a group of technically standardized components which are used together to provide applications. Business ecosystems are in many cases developed around platform vendors with producers of complimentary services and end users. In the IoT ecosystem different platform providers can become critical players by providing interoperability between various technologies. (Toivanen, Mazhelis and Luoma, 2015)

Iot service providers include companies providing additional services to IoT solutions such as:

- Integration solutions
- IoT service management
- Analytics solutions
- Security
- Billing

Service providing companies provide additional services to IoT investments which can mean multiple additional services from different sources. The service providing segment includes companies offering integration of the IoT components, management of the IoT solution, companies providing additional features on top of the IoT solutions such as analytics, data security and billing capabilities.

Regulators and officials in the IoT ecosystem include:

- Organization responsible for standards and protocols
- Industry groups and consortiums
- Regulators and government officials

In the IoT ecosystem there is large number of different regulators, officials and organizations involved in the overall development and regulation of the IoT domain. Organizations can be generally categorized as technologically focused or vertically focused. Few organizations are also focused on general education of IoT domain. Technologically focused organizations can be divided into three subcategories which are hardware-focused, network and semantics -focused and multilayer -focused. (Postscapes, 2017)

- Hardware-focused organizations include organizations such as:
  - Institute of Electrical and Electronics Engineers (IEEE)
  - Bluetooth Special Interest Group
  - Wi-fi Alliance
  - RFID Consortium
  - NFC Forum
- Network and Semantics -focused organizations include such as:
  - Internet Engineering Task Force (IETF)
  - International Organization for Standardization (ISO)
  - World Wide Web Consortium (W3C)
  - 3rd Generation Partnership Project (3GPP)
- Multilayer -focused organizations include such as:
  - IPSO Alliance
  - Allseen Alliance
  - Open Interconnect Consortium
  - oneM2M

Vertically focused organizations in the IoT ecosystem approach the IoT more through the applications area rather than through technology. Based on Postscapes (2017) and Atzori et al. (2010) these organizations can be categorized in four areas:

- Industrial Internet
- Transportation
- Smart buildings
- Healthcare

Iansiti and Levien (2004) differentiate four strategies for companies in business ecosystems based on the level of asset-sharing in the ecosystem and the amount of innovation and maturity:

- Commodity
- Dominator
- Niche player
- Keystone

Commodity strategy means operating in a mature ecosystem with low level of innovation and using low levels of external assets, in other words operating in the environment very independently from other players. Larger use of external assets in a mature environment is considered as a dominator strategy. Niche player strategy occurs in a turbulent environment with high levels of innovation and when the opportunity to use external assets of the company is not large. Keystone strategy is when the company can use external assets to its benefit as a key player in the ecosystem. In the IoT ecosystem with its high level of innovation and lack of maturity, the keystone and niche player strategies are the most suitable strategies at the current development phases of the IoT field. Currently no keystone or dominator companies can be identified but a very large and various group of niche players exist. (Iansiti and Levien, 2004)

Iansiti and Levien (2004) argue that the state of the ecosystem can be analysed with the level of productivity of the ecosystem, robustness in the ecosystem and niche creation abilities. Ecosystem productivity can be measured simply as the return on the capital invested in the ecosystem’s companies. Robustness of the ecosystem means the ability of the ecosystems company to sustain change in the environment. Niche creation of the ecosystem consists from variety in the ecosystem. Niche creation in the ecosystem means new technologies and innovations entering into the ecosystem while old and updated technologies gradually cease to exist. Analysing the state of the IoT ecosystem reveals that it is in a dynamic beginning phase where there is a lot of niche players, and the robustness and productivity of the ecosystem have not been significantly tested yet. (Iansiti and Levien, 2004)

2.2.2 Application areas

There is huge general application potential for IoT technology and different application areas provide different types of opportunities and challenges to apply IoT capabilities. It is important to analyse the specific domain requirements with regards to the IoT investments technological capabilities to estimate the profitability of the investment. Interesting aspect in some of these examples is the business side of how these innovations could be provided in a profitable way and which type of business model would suit them best. Gubbi et al. (2013) mention network size, number of users, data management requirements and user involvement requirements as some differences between application areas. Different application areas also vary in required size of investments needed, maintenance costs and ease of maintenance. Energy consumption may also vary significantly between application areas as well as coverage and connectivity requirements. (OECD, 2012)

Number of potential applications for IoT technologies is significant and because the IoT paradigm is quite new, probably many of the technologically available applications are at the moment unimaginable. Whitmore et al. (2015) divide the IoT application spaces into four main categories of logistics, healthcare, smart environment and social applications. Atzori et al. (2010) divide application areas similarly in four main divisions:

- Transport and logistics
- Healthcare
- Smart environment
- Personal and social domain

Transport and logistics can have significant impact from IoT technologies. IoT capabilities can bring real-time surveillance resulting better supply chain management in logistics and IoT technologies could also allow monitoring the environment during the whole supply chain to prevent perishable goods from spoiling. Pang et al. (2012) mention potential benefits of IoT technology for food supply chains as increase in traceability, visibility and controllability during the whole food supply chain starting from food producing and processing all the way to storage and distribution. In transportation IoT solutions could be used for example to send information to the driver and passengers by sensors, actuators and processing power embedded in the roads or vehicles. Another benefit by IoT could allow different payment systems to be included in the mass transportation leading in to more usage-based pricing for example by placing censor in the mass transport vehicle which the passengers could read with a smartphone and make a ticket purchase. (Atzori et al., 2010)

Healthcare could be impacted by IoT with many improved abilities for example in tracking, identification, data collection and sensing. Tracking could be used both in handling patients in the medical systems as well to tracking flow movements inside the patient’s body. IoT technology has also potential to improve patient’s identification processes and allowing more efficient access to patient’s medical files. Sundmaeker (2010) provides an example of IoT a wireless device which would be implanted into the patient’s body with patient’s health records stored in it as one such example which could be a critical improvement in emergency situations. IoT could also be used to automate processes collecting patient data saving time and decreasing humanmade errors. Significant benefits could also come from increased ability to analyse the patients state with IoT censors. This increased sensing ability could then bring much more data available thus improving the accuracy of diagnosis. (Atzori et al., 2010)

Smart environment means increased intelligence both in homes and at work. Smart environment in industrial context refers to the term Industrial Internet. Bringing more intelligence to appliances both in home and at work can bring many benefits such as lower energy consumption and ease of use. Lower energy consumption could be achieved by optimizing use of appliances based on the actual requirements and increasing the usability with smarter applications and environments. Different applications in homes could include everything from adjustable room temperature and lighting to fridges being able to inform when certain food items are about to run out. In the case that certain perishable food’s containers would include an embedded tag with information fridges could even report when these foods would expire. This scenario could also be continued by fridges having the ability to optimize food recommendations to residents based on the expiration of certain foods to prevent food waste. Industrial Internet provides more intelligence in the manufacturing processes by allowing more information from the individual items and machines. Embedded IoT censors in items could send more data about themselves and improve logistics and overall efficiency in the factories. Industrial Internet applications can also provide information about the status of the machines which allows improvement in optimization and in maintenance timing. Including even more intelligence by IoT technologies would therefore allow the continuation of a trend of automation of factories. (Sundmaeker, 2010; Atzori et al., 2010)

Personal and social domains can also be highly impacted by IoT. The personal and social domain in IoT can also be called Social IoT. IoT technologies could for example provide opportunities in social networking to automate updating information such as location for social networking providers. Allowing users of IoT devices to analyse more broad set of historical data with their devices could also be a major benefit of IoT technology in the personal domain. Having a search engine for all things with IoT censors would benefit when trying to find items based on their location. This location feature would also be useful when applied to security due to the ability to follow items and receive alerts if they would be moved in an odd way from their pre-set location perimeters. Fundamentally IoT integrated with social media platforms allows opportunities to make every day human experiences much more personal. (Li et al., 2015; Atzori et al., 2010)

2.2.3 Business models

Business model is a conceptual model of the company's business and it describes how company creates, delivers and captures value. Choosing the correct business model is a fundamental aspect in creating a sustainable competitive advantage. IoT technologies can greatly impact which types of business models are competitive in future market conditions. The opportunity to transform business models from the product-based model, where companies insert their technology and intellectual property into a product with revenue coming mostly from selling the product, to a more service-based model with multiple types of revenue streams means that business model design can be a highly important ability in a IoT investment. Defining the right business model for the IoT context means making decisions when choosing technologies and estimating the future development of these technologies correctly. Important aspect in designing the correct business model for the IoT context is the difficulty of copying the chosen business model. (Teece, 2010)

Important aspect in the business model is the chosen model for monetization of the value. Four general monetization models for IoT are hardware premium model, service revenue model, data revenue model and ecosystem building model. Hardware premium is a model where the monetization of the value comes from selling a product with IoT capabilities with a premium. This monetization model is the most simplistic and requires a transactional relationship with customers. Service revenue is a model where non-material goods are provided to the customers instead that the client would acquire a product. Service revenue model is more complicated than the hardware premium model and it allows building deeper customer relationships. Data revenue model monetizes IoT capabilities by selling the data generated from IoT investment. There are many ways to monetize the IoT data and it could either be used internally to enhance customers own processes and business or it could be packaged and sold to external parties. Ecosystem building is a monetization model where a platform is provided for other parties to use and to connect demand and supply of a particular market segment. This type of model is more complex that previously mentioned and it requires more stronger relationship with customers. Figure 8 demonstrates the monetization models with the horizontal axis representing the simplicity of the model and the vertical axis representing the relationships needed with the customers. (CapGemini, 2014)

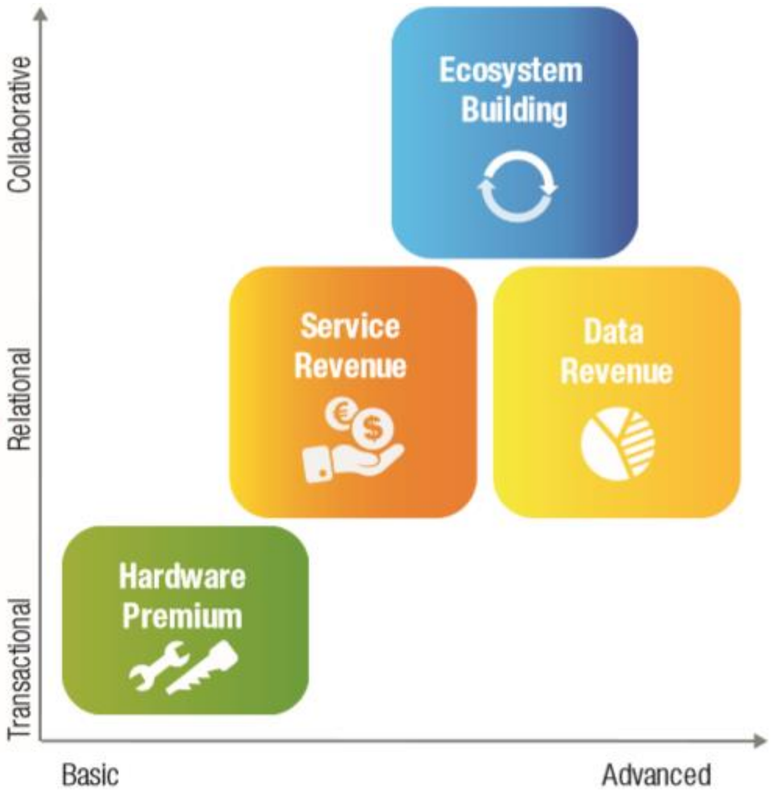

Figure 8. Monetization models for IoT investments (CapGemini, 2014)

One way to analyse different business models is business model canvas framework developed by Osterwalder & Pigneur (2010). The business model framework analyses companies' business models based on 9 different parts: value proposition, key activities, key partners, key resources, revenue streams, cost structure, customer segments, customer relationships and channels. Osterwalder & Pigneur (2010) define the categories in the following way:

Value proposition defines the way a company creates value for its customers. Different ways to create value are for example creating completely new services or products for a customer, improving performance or efficiency of existing products and services, ability to customize the product or service more, helping customers in their own processes, providing more status for customers or making the product or service more accessible and easier to consume. Value proposition can vary between various customer segments.

Key activities define the most important processes which create the value proposition. Some key activities could include for example problem solving, production or providing a platform or a network for the customer.

Key partners are the counterparties such as suppliers and partners who are essential for the functioning of the business model. Osterwalder & Pigneur (2010) categorize four types of partnerships: strategic alliances between non-competitors, coopetition (strategic partnerships between competitors), joint ventures and buyer-supplier relationships.

Key resources are the inputs which the company requires to create the value for the customer. Such inputs can be intellectual, financial, physical or human. Companies can either rent or buy these inputs.

Revenue streams can be either transactional or recurring. There are multiple ways to create revenues such as advertising, usage fees, subscription fees, asset sales, renting and licensing. The available monetization models for IoT investment can be categorized in the previously mentioned hardware model, service revenue model, data revenue model and the ecosystem building model.

Cost structure in the chosen business model have four components: fixed costs, variable costs, economies of scope and economies of scale. Cost structures can be divided into two categories: value-driven and cost-driven. Value-driven is the maximization of value whereas cost-driven is minimization of costs.

Customer segments identify and specify different needs and behavioral patterns of different types of customers. Defining customer segments is also important when deciding channels and customer relationship activities for each customer.

Customer relationships are the different types of interactions with clients which aim to increase sales, customer acquisition and customer retention. The chosen monetization model affects the customer relationship management significantly with some models allowing more significant relationships towards customers than other models.

Channels define how company performs the customer relationship activities and describes the routes how the value is transferred to customers.

All these nine segments could be affected by IoT technologies. Applying the IoT capabilities in companies' current business models could provide significant opportunities to enhance and reshape them. Teece (2010) argues that technological development often causes possibility to satisfy unmet customer needs. Bringing these technological innovations to market causes also need for innovations with regards to business models. Mazhelis et al. (2013) apply the business model canvas framework to develop a framework to identify and analyse business models available in the IoT domain based on different factors such as value proposition, financial structure and customer focus. The framework is two-dimensional with four different business model types. Dimensions in the framework are the role in the ecosystem with either co-operative model or independent model and types of customers with either focus on consumers or corporations. Four types of business model are:

- Co-operation in the ecosystem with business focus on consumers
- Co-operation in the ecosystem with business focus on corporations
- Independence in the ecosystem with the focus on the consumers
- Independence in the ecosystem with the focus on the corporations

Palattella et. al (2016) mention telecommunications industry as potentially affected by the changes in business models provided by the IoT technologies. The possibilities of IoT could change the market dynamics both for the network operators as well as the equipment vendors. Key differences between the operators and the vendors is the traditional focus on the consumers by the network operators whereas the vendors are traditionally much more focused on corporations. Therefore, depending on which types of customers emerge as the most important ones for IoT solutions, the business models required for IoT solutions could turn out to be different than previously required. (Palattella, 2016)

2.3 Profitability analysis

IoT investments can be very significant for companies. Each of the technologies available for IoT has its own advantages and disadvantages which have to be considered in the profitability analysis of IoT investments. Traditional profitability methods can be used to estimate the profitability of an IoT investment. However, the great potential in the IoT and the challenge of estimating future development can put challenges on using the more traditional discounted cash flow methods in estimating the IoT investments. Including all the uncertainty related to the IoT technological change into the profitability analysis methods can be quite challenging and unprecise. Real option valuation method can provide an improvement to the capital budgeting process when there is large uncertainty in the future development in the IoT investments. Real option valuation method can be more suited to include this optionality in the IoT investments and thus help managers to better analyse different investment opportunities when aiming to create a competitive advantage from these IoT investments. In the capital budgeting process, the different investments are analysed and evaluated to decide which investments are worth pursuing. Critical elements related to the capital budgeting process are risk and uncertainty related to the investments.

Risk and uncertainty both express unknown elements about the future with the difference that under risk the structure of the decision-making situation is known and the probabilities of future events are knowable whereas under different levels of uncertainty some or all these aspects are unknown. Uncertainty increases significantly with time and with more complexity and decreasing information. Collan, Haahtela and Kyläheiko (2016) differentiate three main types of uncertainty: parametric, structural and procedural. Parametric uncertainty consists of situations where the structure of the decision-making situation is clear but the probabilities or parameters of the situation are unknown. Structural uncertainty applies when there isn’t certainty about the structure of the decision-making situation and there are multiple choices or states of worlds that might be true. This means that all the possible actions or future states of worlds might not be known in the decision-making moment. Procedural uncertainty covers situations where the amount of information is such that the decision-maker’s capabilities can’t process it completely. (Collan, Haahtela and Kylaeheiko, 2016)

Burns and Walker (2009) divide the capital budgeting process into a framework of four parts:

1. Identification
2. Development
3. Selection
4. Control

The identification phase of the process consists from the creation of the investment opportunities. This includes aspects such as sources where the opportunities may rise, submission procedures of the investment opportunities and what sort of incentives and rewards are included to provide different suggestions for potential investments. The development phase consists from a general evaluation of the investment options and providing a more detailed view of the investments characteristics. In the selection phase the different investments are thoroughly analysed and evaluated against the investment criteria chosen. Based on the analysis the investment is either chosen to execute or rejected. The methods and techniques applied have significant impact on the outcome and have to be carefully considered because of their importance on the end result of the capital budgeting process. The fourth phase in the capital budgeting process is the control phase where the investment’s performance is monitored and where the investment is managed actively. (Burns and Walker, 2009)

Calculating the initial investment costs can sometimes be difficult but usually the challenging part is the estimation of the future cash flows and may require making large assumptions about the future. There are many ways to estimate future cashflows. Armstrong and Crohman (1972) categorize four different methods:

- Novice judgement
- Expert judgment
- Extrapolation
- Econometric

These four methods can be analysed in two dimensions. Firstly, the method of deriving estimates can either be subjective or objective. Subjective method requires making decisions during the process and some parts of the process may be implicit meaning not directly expressed whereas objective process is explicitly specified thoroughly. Secondly, the methods differ based on the number of variables used. The methods can either use only the dependant variable for forecasting hence they are called naïve methods or the methods can include independent variables in the process and these methods can be categorized as causal methods. Novice judgement is a combination of subjective naïve process whereas expert judgement is a combination of subjective causal process. Extrapolation methods consists from objective naïve processes and econometric models are objective and causal based methods. Other methods than previously mentioned include for example artificial neural networks methods which uses pattern recognition mimicking methods observed in biology. (Collan, 2004)

Burns and Walker (2009) list net present value method, payback method and the internal rate of return method as traditional methods to calculate the profitability of investments. Net present value method is the calculation of the discounted future estimated cash flows of the investment and the initial investment costs. Payback method values investments based on the amount of time it takes to receive back the original investment costs from the investment. Reasons for the use of the payback method are the easiness of the computation and its use of an additional tool to analyse the investments risk and liquidity. The overall profitability of the investment is not included in the method. Internal rate of return method gives the discount rate when the investment's net present value is zero. Internal rate of return can then be compared to the opportunity cost of capital. When the internal return of an investment is higher than the opportunity cost of capital or other benchmark value the investment is acceptable.

Real option valuation methods are based on the logic of financial options and consist of valuation of real-life options in the capital budgeting process. Real option valuation can be especially valuable when capital budgeting decisions require dealing with uncertainty and need for managerial flexibility in projects is relevant. Real option valuation is based on the valuation of financial options and real option is also a right without the obligation to make actions with the investments. Financial option is a derivative that gives the buyer of the option the right without the obligation to buy or sell the underlying financial asset at a specific price during a specified time whereas the seller of the option is required to execute the transaction with the agreed terms. Option to sell the asset is called a put option and the option to buy the asset is called a call option. Financial options can be categorized as either European style options or American style options. European style option can be exercised only at a specific date agreed in the contract where as American style option can be exercised any time during the lifetime of the option. Some real option valuation methods are suited to deal with parametric uncertainty but might not be adequate to deal with structural or procedural uncertainty, so the nature of the situation has to be considered when choosing the real option model applied in the profitability analysis of investments (Collan, Haahtela and Kylaeheiko, 2016). (Brealey and Meyers, 1996)

Trigeorgis (2002) mentions different real option types:

- The option to defer investment
- The option to stage investment
- The option to expand
- The option to contract
- The option to shut down and re-start
- The option to abandon
- The option to switch inputs
- Corporate growth options
- Multiple interacting options

The option to defer the investment allows the postponing of the investment which is beneficial in situations where there is high uncertainty regarding different inputs affecting the investment such as market prices or regulatory aspects. Management can therefore wait and see how the values of investment’s inputs and outputs develop. The option to defer can be compared to an American style call option on the present value of the project’s expected operating cashflows. (Trigeorgis, 2002)

The option to stage investment provides the opportunity to look and operate the investment in stages where all the costs of the investment don’t occur simultaneous but instead in stages. This allows the project to be abandoned during the lifetime of the project if new information arrives and the project is not worth pursuing any more. The option to stage investment can be seen in every stage as an option on the value of future stages which price is the cost of proceeding into the next phase of the investment. This means that the option of staged investment can be compared to compound options and is especially valuable in long term investments with lots of uncertainty in the characteristics of the investment and high capital requirements. (Trigeorgis, 2002)

The option to expand means the opportunity for management to react in changing situations by increasing the scale of the investment. This means that if situations turn out better than expected the management has the ability to accelerate or expand the scale of production. The option to expand the scale of the investment can be seen as a call option to obtain certain percentage of the base-level project for the price of costs related in the expansion. Therefore, some investments with low profitability based on just the traditional profitability analysis methods such as the net present value method may turn out to be worth pursuing when analysed with the option to expand. This means that certain investments with big upside from technological development may be worth taking due to the possibility to scale the investment up if market situations turn positive for the investment even if the technology with more flexibility might be more expensive than some cheaper technology with less upside potential and abilities to expansion. (Trigeorgis, 2002)

The option to contract is the ability to operate the investment below maximum capacity or decrease the scale of the investment when the investment performs below expectations. The option to contract is similar to a put option on some percentage of the base-level project where the exercise price is the potential cost savings of decreased operations. One way to acquire the option to contract could be achieved by choosing an investment with lower initial costs and larger maintenance costs which would allow to decrease expenditure in negative market conditions. This could be done by choosing technological and business elements in the investment that allow more flexibility in the cost structure of the investment. (Trigeorgis, 2002)

The option to shut down and re-start provides the opportunity to shut down the investment and save the costs related to operating the investment. The management can therefore stop the investment temporarily if necessary and restart it when the situation turns more positive and the investment is worth continuing. Decision to operate the investment can therefore be seen as using a call option with the price of the operating costs related to the investment. (Trigeorgis, 2002)

The option to abandon for salvage value allows exiting from the investment with selling the assets. The option to abandon for salvage value therefore saves the operating costs of the investment and returns some of the previously invested assets. The option can be seen as an American style put option on the project's current value where the option strike price is the investment's salvage value. (Trigeorgis, 2002)

The option to switch inputs or outputs provides the opportunity to react to changing situations by switching inputs and outputs for the investment when factors related to them, such as prices or market demand change. The ability to change the input mixes to produce same outputs provides process flexibility which can be a significant source of competitive edge compared to competitors with a more static process. Competitive advantage could also be achieved from the ability to switch outputs to create product flexibility. (Trigeorgis, 2002)

Corporate growth options provide the opportunity for new possibilities in the future from the initial investment. This means that an investment with a negative present value might be worth pursuing for the future options it provides. Unprofitable investment can provide valuable experience which can be applied in the future or provide an infrastructure or by-products which can be used in the future and can prove to be very valuable in rapidly changing environments. The initial investment with embedded corporate growth options can reveal aspects which can eventually provide strategic advantage which would not have been discovered without the initial unprofitable investment. Corporate growth options can be very valuable in the high technology environments and in the research and development cases where the initial project might provide some unexpected benefits that turn out to be beneficial in the future. Corporate growth options can be seen as options on options. (Trigeorgis, 2002)

Multiple interacting options are the combinations of different types of real options. These combinations can consist from both options increasing the upside benefits of the investments similar to call options and from options decreasing the downside risks of investments similar to put options. The interaction of these real options might provide additional benefits meaning that the value of these might be larger together than their sum separately. (Trigeorgis, 2002)

There are many ways to calculate the value of real options. Key factors in choosing the correct model for the real option valuation are the assumptions made about the nature of the future where key elements relate to risk and uncertainty. Collan, Haahtela and Kylaeheiko (2016) categorize six different model types for real option valuation:

- Differential equation -based models
- Lattice-based methods
- Marketed asset disclaimer models
- Real option decision tree analysis
- Simulation-based models
- Fuzzy numbers -based models

Differential equation -based models are common methods of valuation of financial options and can be applied to real options also. Widely used differential equation -based method is the Black-Scholes model where the theoretical price of a European-style option with no dividends included is derived by applying partial differential equation to create a replicating portfolio with similar characteristics as the option which then can be used to value the option under the assumption of perfect markets (Black and Scholes, 1973). The formula for the Black-Scholes model is:

$$C = SN(d_1) - Xe^{-rT}N(d_2) \tag{1}$$

$$d_1 = \frac{\ln\left(\frac{S}{X}\right)+\left(r+\frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \tag{2}$$

$$d_2 = d_1 - \sigma\sqrt{T} \tag{3}$$

In equation (1) S is the price of the underlying asset, X is the strike price of the option, r is the risk-free interest rate at time j, T is the expiration time of the option, N(x) is the cumulative distribution function of the standard normal distribution and σ *is the volatility of the underlying asset.*

The original Black-Scholes model uses five inputs but the original model has been modified to also include dividends. Improved option pricing models require six inputs in the valuation of the price of the option. These inputs are:

- Price of the underlying asset
- Exercise price of the option

- Time to the expiration of the option
- Volatility of the underlying asset
- Dividends of the underlying asset
- Risk-free interest rate

Real option valuation method based on the Black-Scholes model applies inputs modified from the financial options. The figure 9 demonstrates the inputs of a financial option and a real option. Inputs for real options are:

- Present value of projects expected cashflows
- Present value of fixed costs
- Time to the expiration of the actions available
- Volatility of the projects expected cashflows
- Value lost in the postponing of the project
- Risk-free interest rate

The six inputs for financial options are used to formulate the real option inputs. The stock price of the financial investment in the real option valuation is comparable to the present value of the expected cashflows of the investment. The exercise price of the financial option is the present value of fixed costs of the investment for the real option valuation. The expiration time of the financial options is the time window when actions can be taken with regards for the real investment. The volatility meaning the uncertainty of the real investment's expected cash flows is the counterpart for the volatility in the financial option valuation. The input of dividends in the financial option is replaced in the real option by the cash flows related to postponing the project. Risk-free interest rate is same with the two methods. Figure 9 demonstrates the similarities of the financial option valuation inputs and the real option valuation inputs. (Leslie and Michaels, 1997)

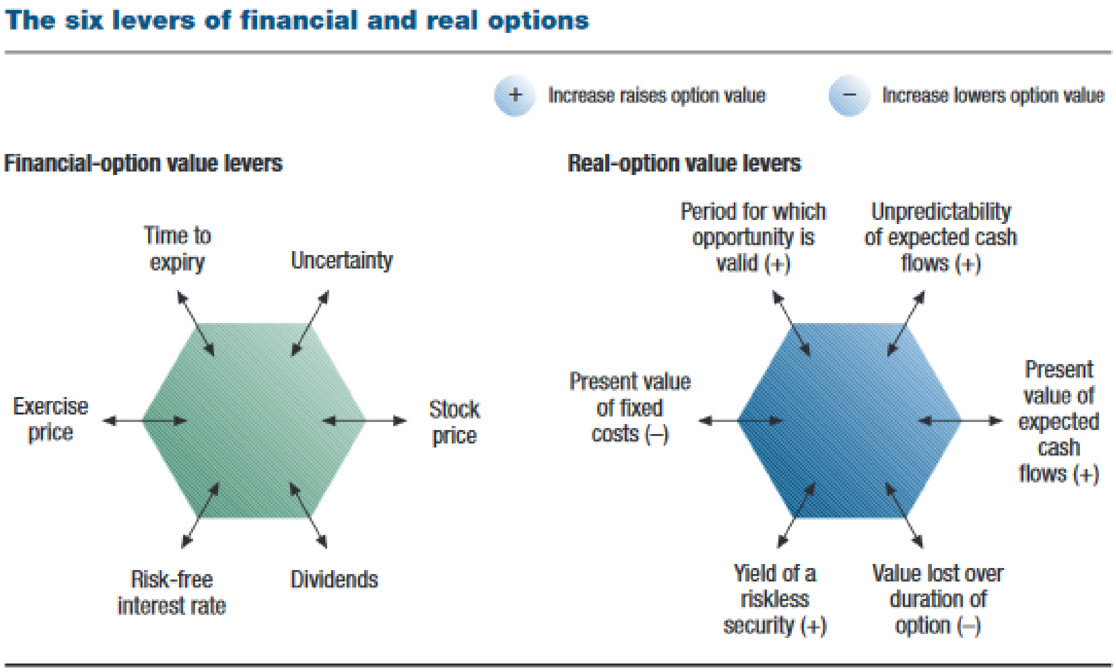

Figure 9. Similarities between financial options and real options (Leslie and Michaels, 1997)

The models based on the Black-Scholes model require assumptions of the world which have caused critique of the models. These assumptions include elements such as the perfect markets, exclusion of taxes and transaction costs, requirement that information is free and available for everyone, liquid markets and that assets are dividable into smaller fractions and that the underlying assets value, of which the option derives its value, follows a geometric Brownian motion. Some of the assumptions required in these differential-equation based models can be even more problematic when applying to real option valuation. This means that in order to valuate real options the models might have to be customized for the task. (Collan, Haahtela and Kylaeheiko, 2016)

Lattice-based methods are methods where a tree-like lattice consisting of nodes is constructed to determine the possible paths of the underlying asset's value through time. Valuation with lattice-based methods is done by determining the structure of the lattice when choosing the time between each layer of nodes and then calculating the options value at each node. After this, the path with the highest value is chosen. Common methods include binomial methods and trinomial methods. Lattice-based methods generally use the same inputs as the differential-equation based models. (Collan, Haahtela and Kylaeheiko, 2016)

Compared to differential equation-based models the lattice-based models allow easier calculation of certain types of options such as American style options with the early exercise abilities and compounding options as well as European style options. Lattice-based methods can be more suitable for real option valuation due to easier calculation and flexibility compared to the differential equation-based models. But like differential equation-based methods the lattice-based methods application requires that the level of uncertainty of the situation is contained into the parametric level. This means that the use of these two methods might not be best suited in the most complex and challenging real option valuation cases. (Collan, Haahtela and Kylaeheiko, 2016)

Marketed asset disclaimer (MAD) models are based on the argument that the net present value of the investment is a better estimate for the market value of the investment than any replication portfolio. The real option valuation with MAD models is done by using the investment itself as the underlying security. Therefore, the MAD models rely on subjective estimates as input values and only the cost of capital is derived objectively. Another factor which MAD models are based is that the value of the underlying asset follows a random walk which is modeled using geometric Brownian motion. The MAD models require first calculating the traditional net present value of the investment and then the real options included in the investment can be valued. (Collan, Haahtela and Kylaeheiko, 2016)

Real option decision tree analysis (RODTA) is a method where a decision tree is modeled which includes the values of real options of the investment. RODTA is done by mapping future events in the decision-making situation and calculating probabilities to them. In the calculations risk-neutral probabilities are used by using the correct discount rate instead of the risk-free discount rate. The values of outcomes of future events are calculated by using the risk-free discount rate. RODTA involves the same assumptions of the MAD models that the underlying asset is the net present value of the investment and that the cash flows of the investment follow a random walk. The value of the real options is calculated by comparing the decision tree with the real options to decision tree without the real options. Considering different levels of uncertainty, RODTA method can be better than the differential equation-based models and the lattice-based models due to the ability to include structural uncertainty in some respects. (Collan, Haahtela and Kylaeheiko, 2016)

Simulation-based models consist from a model based on the current situation which is used to perform different procedures to estimate different aspects of the situation such as the payoff functions. Monte Carlo simulation method is a commonly used method in real option valuation and can be applied well in the valuation of real options. Valuation of real options with the Monte Carlo simulation is performed by creating a large number of random paths for the underlying asset and the option payoff at the maturity is calculated for each path. A mean value is calculated from all these payoffs which is discounted with risk-free discount factor to determine the present value of the option. Simulation-based models can be modified to handle both parametric uncertainty and structural uncertainty to a certain degree. (Collan, Haahtela and Kylaeheiko, 2016)

Fuzzy pay-off distribution-based models are methods applying fuzzy logic. Fuzzy logic is a form of logic where different elements can have a varying membership function between either belonging to a class or not belonging to a class. This differs from classical set theory with crisp lines between categories and element's membership function being either 1 or 0 with regards to belonging in a certain class. In fuzzy logic, the element's membership function can be anything between values of 0 and 1. This lack of crisp categories makes fuzzy logic useful in dealing with uncertainties and inaccuracies. Many of the previously presented methods such as differential equation-based and lattice-based can be modified into fuzzy numbers -based models. A specific fuzzy pay-off method (FPOM) consists of using cashflow estimates from management when creating the project's pay-off distributions. The FPOM is usually presented triangular or trapezoidal fuzzy numbers which provides information on the net present value of the investment as well as the level of uncertainty by applying the three or four different cashflow estimates which are combined into the fuzzy number estimate. The level of uncertainty usually remains the same when fuzzy numbers are used in other methods but the FPOM can be modified to handle all three types of uncertainty, parametric, structural and procedural. (Collan, Haahtela and Kylaeheiko, 2016; Herrera-Viedma, 2015)

3 DATA AND METHODOLOGY

This section presents the data and methodology used in the empirical part of the thesis. Empirical part of the thesis concentrates on the analysis of an IoT investment's profitability analysis. This is done with a real-life case using an IoT-capable product and performing a total cost of ownership analysis between an older version of a large factory equipment and a newer version of the equipment with IoT-capabilities embedded. The case consists of calculating total cost of ownership of a traditional product and a newer version with IoT capabilities and calculating the profitability of acquiring the newer machine based on the savings generated by the new machine. Microsoft Excel-file was created for the case which includes a total cost of ownership analysis tool to be used with clients to demonstrate the profitability of an IoT-capable product. The data used in the thesis is collected from the case company via expert interviews.

Focus of the empirical part is on the financial benefits generated from the IoT investment so describing the IoT investment's technological elements and business dimensions are not included in the case. The Microsoft Excel -file will provide results for the traditional profitability analysis methods which are the payback method, internal rate of return method and the net present value method. The Microsoft Excel -file will also include analysis for the real options embedded in the new IoT capable product. The profitability analysis will include certain types of real options embedded in the investments to compare whether the profitability of the investments is affected by these real options.

3.1 Data

Data used in the empirical part of the thesis is collected from a case company which is a Finnish company manufacturing industrial equipment. The machine analysed in the case is a modern version of an industrial machine with IoT-capabilities which provides completely new ways to manage the industrial process where the machine is utilized. This new industrial machine with IoT capabilities is compared to a similar machine without the IoT capabilities. A total cost of ownership (TCO) analysis is used to compare the costs of a normal machine and a new machine with IoT capabilities. The TCO analysis is calculated with the Microsoft Excel -file created for the case. Data for the empirical part consists from estimates from a director of the case company. Table 1 demonstrates the cost categories and cost items identified relating to the lifecycle costs of the machines.

Table 1. Categories of the total cost of ownership analysis.

Cost Gategory	Cost items
Investment costs	
	Unit Price
	Installation / integration / engineering / calibration costs
	Testing / initial inspection costs
Operational costs	
	Annual licences
	Input 1
	Software licenses
	Software & hardware upgrades
Service and maintenance costs	
	Annual maintenance
	Preventative maintenance
	Spare parts
Anticipated downtime costs	
	Planned maintenance shutdowns - additional costs
	Unplanned shutdowns - additional costs
	Unplanned shutdowns - lost revenue

Table 1 lists cost categories and cost items used in the TCO analysis.

Cost categories of the machines can be divided into four sections: investment costs, regular yearly operational costs, regular yearly service and maintenance costs and anticipated yearly downtime costs. Investment costs include cost items of unit price, installation and inspection costs. Regular yearly operational costs include cost items from various inputs used in operating the machines. Regular yearly service and maintenance costs include cost items of annual maintenance, preventative maintenance and spare parts. Anticipated yearly downtime costs include cost items of planned maintenance shutdowns, additional costs due to unplanned shutdowns and lost revenue due to unplanned shutdowns. Figure 10 shows the input section in the Microsoft Excel-file which was developed to calculate the TCO analysis of the machines.

[Company Name]

TOTAL COST OF OWNERSHIP ANALYSIS

[DATE]

	Current Solution	New Industrial IoT Solution	Savings from the IoT Solution
Investment Costs	0	0	0
Unit Price			
Installation / integration / engineering / calibration costs			
Testing / initial inspection costs			
Regular operational costs (yearly)	0	0	0
Annual licences			
Input 1			
Software licenses			
Software & hardware upgrades			
Regular service and maintenance (yearly)	0	0	0
Annual maintenance - Service Contract			
Preventative maintenance - Service Contract			
Spare parts			
Anticipated downtime (yearly)	0	0	0
Planned maintenance shutdowns - additional costs			
Unplanned shutdowns - additional costs			
Unplanned shutdowns - lost revenue			

Summary Metrics:	Current Solution	New Industrial IoT Solution	Savings from the IoT Solutio
Investment Costs	0	0	0
Regular operational costs (yearly)	0	0	0
Regular service and maintenance (yearly)	0	0	0
Anticipated downtime (yearly)	0	0	0
Total	0	0	0

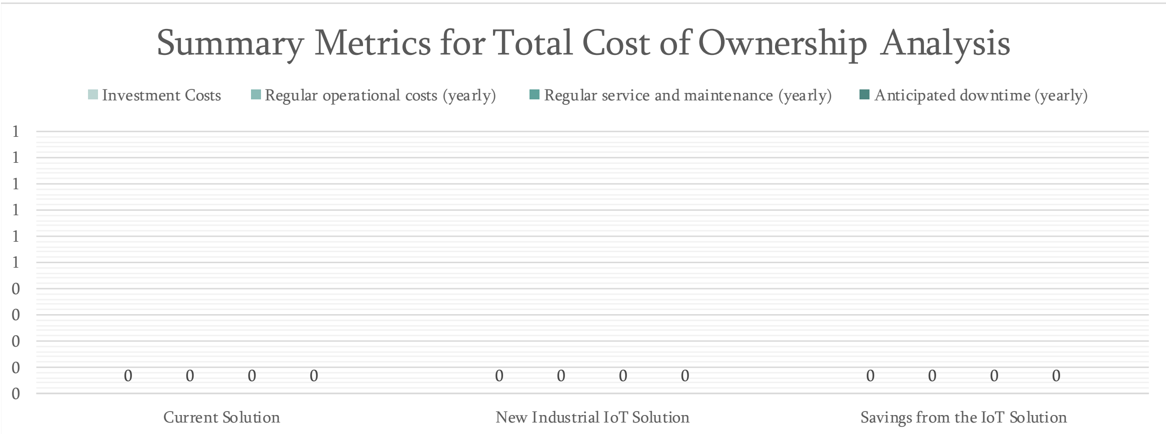

Figure 10. Input section for estimates in the total cost of ownership analysis used in the Microsoft Excel-file

The input section in the Microsoft Excel-file compares the TCO analysis of the normal machine without the IoT capabilities and the newer machine with the IoT capabilities. Based from these two TCO analysis the differences of cost categories are calculated. Yearly savings of the TCO analysis are used as the yearly cash flows of the IoT investment.

Data for the real option valuation consists from additional benefits achieved from the IoT-capabilities of the new machine. These benefits include capabilities such as improving production optimization based on the IoT-generated data and improving the maintenance capabilities of the processes where the machines are used. Additional capabilities could also include options to change methods to maintain and operate these machines based on the data generating abilities of the IoT-capable machine which could make possible for example remotely maintaining the machines. From these capabilities were formed three scenarios for the investment which are included in the analysis by applying the real option valuation.

3.2 Methodology

Profitability analysis is performed based on the results of the TCO analysis. The yearly savings generated from the new IoT capable machine are used as the IoT investment's cash flows during the investment period which is nine years. The discounted cash flow analysis is then performed on the estimated savings from the new IoT machine with IoT capabilities compared to the old version without the IoT capabilities. The discount rate used in the discounted cash flow analysis is set based by the perceived riskiness of the IoT investment. Profitability of the IoT investment is analysed with the traditional profitability analysis methods, net present value method, payback method and internal rate of return method. Additionally, real option valuation is used to analyse whether the IoT investments profitability would be significantly affected when including some aspects which are not as easily quantifiable.

Net present value (NPV) method is the calculation of the discounted future estimated cash flows of the investment and the initial investment costs. Formula for the net present value method:

$$NPV = -\sum_{t=0}^{n} \frac{IC_t}{\prod_{j=0}^{t}(1+r_{rj})} + \sum_{t=0}^{n} \frac{E\,(FCF)_t}{\prod_{j=0}^{t}(1+k_j)} \qquad (4)$$

In equation (4), IC_t is the initial investment cost at time t, r_{rj} is the risk-free interest rate at time j, $E\ (FCF)_t$ is the expected cash flow at time t, k_j is the discount rate at time j.

Payback (PB) method values investments based on the amount of time it takes to receive back the original investment costs from the investment. The overall profitability of the investment is not included in the method. Formula for the payback method is:

$$PB = \min_{k=1,\ldots,n} \left\{ k : \sum_{i=0}^{k} FCF_i \geq 0, \infty \right\} \tag{5}$$

Internal rate of return (IRR) method gives the discount rate when the investment's net present value is zero. Formula for the internal rate of return method is:

$$0 = -\sum_{t=0}^{n} \frac{IC_t}{\prod_{j=0}^{t}(1+IRR)} + \sum_{t=0}^{n} \frac{E\,(FCF)}{\prod_{j=0}^{t}(1+IRR\,)} \tag{6}$$

Fuzzy pay-off method (FPOM) is a profitability analysis method which is well suited for the analysis of real options due to its practicality, simplicity and intuitiveness. FPOM forms a pay-off value for real options from a pay-off distribution which can be constructed from cash-flow estimates. The pay-off distribution in FPOM is done by mapping the NPVs of the cash-flow estimates of the used scenarios into a fuzzy number. In the case of three scenarios a triangular fuzzy number will be constructed. These three cash-flow scenarios are inputted into the method for (a, a-α, and a+β). Figure 11 demonstrates the use of cash-flows in the FPOM. (Collan, 2012)

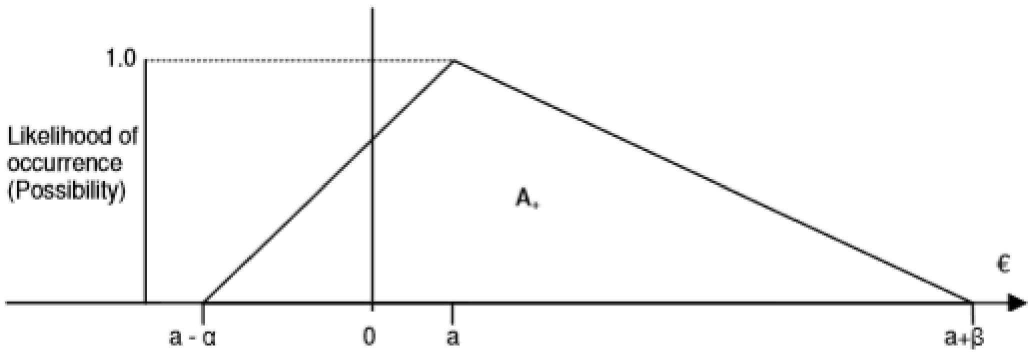

Figure 11. Example of a three cash-flow scenario where a triangular fuzzy number is constructed (Collan, 2012)

The real option value is calculated in the FPOM by area weighted mean formed of the distribution area of these three numbers (a, a-α, and a+β) while treating the distribution values below zero as zero and multiplying the mean by the ratio of area over the positive values over the whole area of the distribution. Formula for the FPOM is:

$$ROV = \frac{\int_0^\infty A(x)dx}{\int_{-\infty}^\infty A(x)dx} * E(A_+) \tag{7}$$

In equation (7), ROV is the value of the Real Option, A is the (fuzzy) NPV, $E(A_+)$ is the (fuzzy) mean value of the positive side of the NPV, $\int_{-\infty}^{\infty} A(x)dx$ is the area below the whole NPV distribution A, $\int_0^\infty A(x)dx$ is the area below the positive area of the NPV distribution A.

The mean value of FPOM is a possibilistic mean (Carlsson and Fullér, 2001) of the positive side of the fuzzy NPV as the expected value. Mean value of the FPOM is calculated differently based on the values of the cash-flow estimates. Formula for the FPOM:

$$E(A_+) = \begin{cases} a - \alpha > 0 \quad then\ E(A_+) = a + \frac{\beta - \alpha}{6} \\ a > 0 > a - \alpha \quad then\ E(A_+) = \frac{(\alpha - a)^2}{6\alpha^2} + \alpha + \frac{\beta - \alpha}{6} \\ 0 > a \quad then\ E(A_+) = \frac{(a+\beta)^2}{6\beta^2} \\ a + \beta < 0 \quad then\ E(A_+) = 0 \end{cases} \tag{8}$$

Real option valuation is utilized in the thesis by identifying an opportunity to enhance savings generated by the IoT-capabilities. Data generated by the IoT capabilities provides an interesting aspect for the investment, but this data can be quite challenging to include in the traditional profitability analysis due to the uncertainty related in monetizing it. Monetizing IoT-data from the investment can be related to anywhere from revenue increases from process optimizations to savings generated from predictive maintenance abilities of the new machine with IoT capabilities. Real option valuation is performed to quantify these opportunities.

4 RESULTS

This section presents the results of the TCO analysis and the profitability analysis. TCO analysis was performed based on the expert interviews with the one of the case company's director. In the TCO analysis the traditional industrial machine was compared to a new machine with IoT-capabilities to determine the differences of the machines during the 9-year investment period. Results of the TCO analysis are presented in the table 2. Based on the savings generated by the new machine the cashflows of the investment were determined. Profitability analysis was performed based on these cashflow estimates. Traditional profitability methods meaning the net present value method, internal rate of return method and payback method were utilized in the profitability analysis. Additional real option valuation was included to analyse how the adding of real options would affect the profitability analysis and how realistic would these valuations be. The IoT investment in the case consists from an IoT product so the technological elements and business dimensions are not included in the analysis.

Table 2. Results of the total cost of ownership analysis.

Machine	Investment cost	Operational costs	Service and maintenance costs	Anticipated downtime costs
New IoT machine	1010000	20000	70000	66000
Old non-IoT machine	0	0	150000	165000
Difference of current and new machine	-1010000	-20000	80000	99000

Table 2 presents the results of the total cost of ownership analysis on the two machines. The numbers are expert estimates on the costs associated to the machines. Investment cost is a one-off cost. Operational costs, service and maintenance costs and anticipated downtime costs are yearly costs.

Investment cost of the new machine was estimated to be 1 010 000 euros which is paid in the start of the investment. Old machine without the IoT capabilities is estimated to have zero operational costs of running the processes. The operational costs of the new IoT machine are estimated to be 20 000 euros annually. Service and maintenance costs of the old machine without the IoT capabilities are 150 000 euros annually whereas the service and maintenance costs of the new machine with the IoT capabilities are 70 000 euros per year. Anticipated downtime costs for the old machine without the IoT capabilities are estimated to be 165 000 euros annually whereas anticipated downtime costs for the new machine with the IoT capabilities are estimated to be 66 000 euros per year. Differences of the old machine without the IoT capabilities and the newer machine with the IoT are used to create the cash flows for the IoT investment. IoT investment's yearly cash flows are presented in the figure 12.

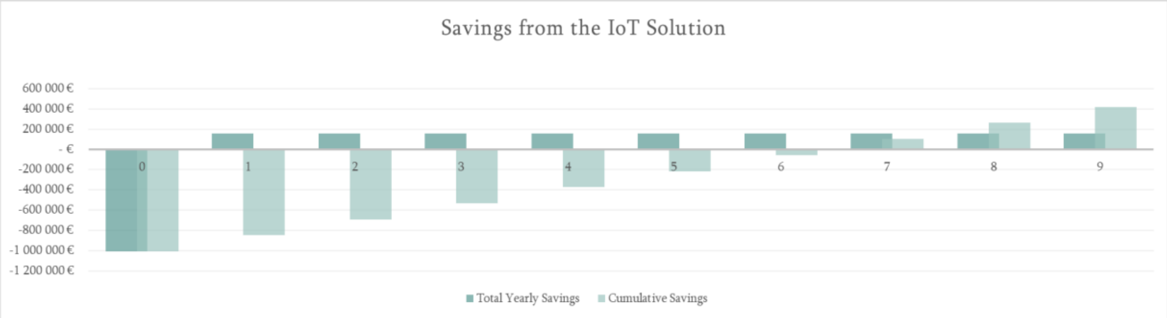

Figure 12. Yearly cashflows generated from the savings

Annual savings generated from the new machine with IoT capabilities amount to 159 000 euros annually. These annual savings of 159 000 euros form the annual cashflows for the profitability analysis performed and the cost 1 010 000 euros of the new machine with IoT capabilities forms the investment cost for the profitability analysis. Cashflows related to the investment are presented in the figure 12 where the yearly cashflows and cumulative cashflows are shown. Figure 12 shows that cumulative cashflows turn positive during year 7 of the investment.

Profitability analysis was performed based on these cashflows. Results of the discounted cashflow analysis are presented in table 3. The yearly savings form the cashflows of the investment and these cashflows are used in the discounted cashflow analysis. The discount rate used in the analysis was 7 per cent which was chosen based on the riskiness of these estimated cashflows. Results of the profitability analysis show the investment to be profitable. Net present value of the 9-year project is 525 430 euros. Internal rate of return of the project is 8 per cent and payback time for the investment is a little over 6 years. The results from the traditional profitability analysis can be considered a good reason on their own for taking the investment.

Table 3. Discounted cashflow analysis based on the savings generated by new IoT machine

Year	0	1	2	3	4	5	6	7	8	9
Investment costs	-1010000									
Savings operational costs		-20000	-20000	-20000	-20000	-20000	-20000	-20000	-20000	-20000
Savings service and maintenance costs		80000	80000	80000	80000	80000	80000	80000	80000	80000
Savings anticipated downtime costs		99000	99000	99000	99000	99000	99000	99000	99000	99000
Yearly savings	-1010000	159000	159000	159000	159000	159000	159000	159000	159000	159000
Cumulative savings	-1010000	-851000	-692000	-533000	-374000	-215000	-56000	103000	262000	421000
Net Present Value (NPV)	525 430									
IRR	8 %									
PB	6,35 years									

Table 3 presents the discounted cash analysis based on the savings generated by new IoT machine when compared to the old machine. Discount rate used was 7 per cent.

Analysing the investment with traditional profitability methods show that the investment would be profitable on its own. The traditional DCF analysis is not however able to include all the positive aspects of the new IoT-capable machine. All the data that would be received from the IoT machine is not easily quantifiable for the DCF analysis, but it is important to include it in the analysing process. Real option analysis was performed to include this data. Based on expert interviews with the case company director on the potential to apply the IoT generated data on the process different cashflow scenarios were formed. The estimates are presented in table 4 alongside the fuzzy values they present in the calculation of the real option value. The additional savings start from the second year of the investment so that one-year learning period is assumed for finding the sources of value where to apply the IoT data.

Table 4. Scenario estimates and fuzzy values for real option valuation

Scenario	Yearly Savings	Cumulative Savings	Discounted Cumulative Savings	Fuzzy Value
Best Guess	5000	40000	12300	a
Optimistic	45000	360000	110703	a+β
Pessimistic	0	0	0	a-α

Table 4 presents the expert estimates for the yearly cashflows in different scenarios when monetizing the IoT data in the processes. Discount rate used was 14 per cent. The additional savings are assumed to begin during year 2 of the 9-year investment.

Three scenarios were used in the valuation of the possibility to apply the IoT data in the case: best guess estimate, optimistic estimation and pessimistic estimate. Best guess estimate represents the most likely additional value gained from the IoT capabilities of the new machine. The best guess estimate for the additional value of the IoT data was 5000 euros annually. This value consists from additional benefits received in the process from IoT data applied for example in optimization of the processes and increased savings in maintenance. Optimistic estimate for the additional value received from the IoT capabilities was 45 000 euros annually. Pessimistic estimate for the additional value from the IoT capabilities was 0 euros where no additional value would be gained that is not already included in the DCF analysis. This would mean that the investment's profitability would be appropriately analysed with traditional profitability analysis methods of NPV method, IRR method and the payback method.

Based from the three scenarios of yearly additional saving generated from the IoT capabilities of the new machine the cumulative cashflows were calculated. The cumulative cashflows of the scenarios are depicted in the figure 13.

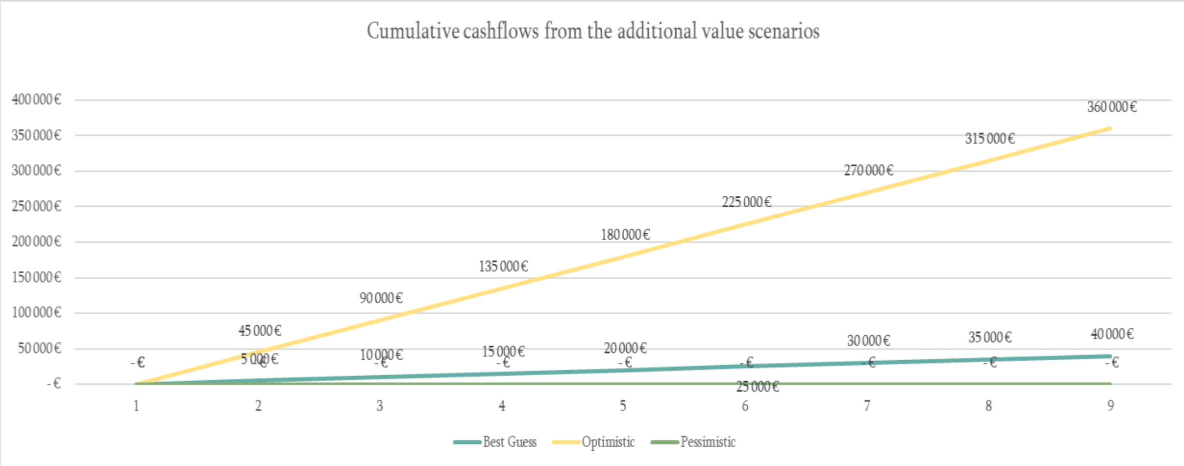

Figure 13. Cumulative cashflows from the additional value scenarios

The cumulative cashflows from the scenarios were 40 000 euros for the best guess estimate during the 8-year period. The cumulative cashflows from the optimistic scenario were 360 000 euros during the 8-year period for the savings. The cumulative cashflows from the pessimistic scenario were 0 euros. The cashflows from the yearly additional savings generated from the IoT capabilities of the new machine were discounted to include the time value of money and the riskiness related to these cashflow estimates. The discount rate for the cashflows from the yearly additional savings was 14 per cent which was more than the discount rate used for the DCF analysis due to the higher uncertainty related to them. The discounted cashflows from the yearly additional savings are depicted in figure 14.

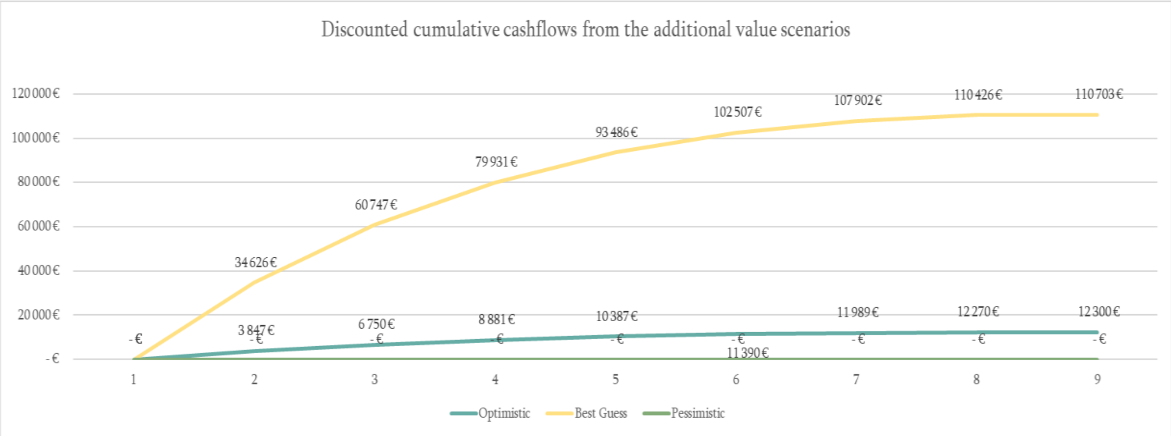

Figure 14. Discounted cumulative cashflows from the additional value scenarios

The discounted cumulative cashflows from the scenarios were 12 300 euros for the best guess estimate during the 8-year period. The discounted cumulative cashflows from the optimistic scenario were 110 703 euros during the 8-year period for the savings. The discounted cumulative cashflows from the pessimistic scenario were 0 euros for the 8-year period for the savings. Based from these scenarios for the 9-year investment period the fuzzy values can be formed. Best guess estimate for cumulative savings of 12 300 is assigned as the a, optimistic estimate for cumulative savings of 110703 is assigned as the a+β and pessimistic estimate for cumulative savings of 0 is assigned as the a-α. The fuzzy values are also depicted in the table 4. From these fuzzy values can be calculated the values for β and α which are 98 403 and 12 300 respectively. These values form the fuzzy pay-off method which is depicted in the figure 15.

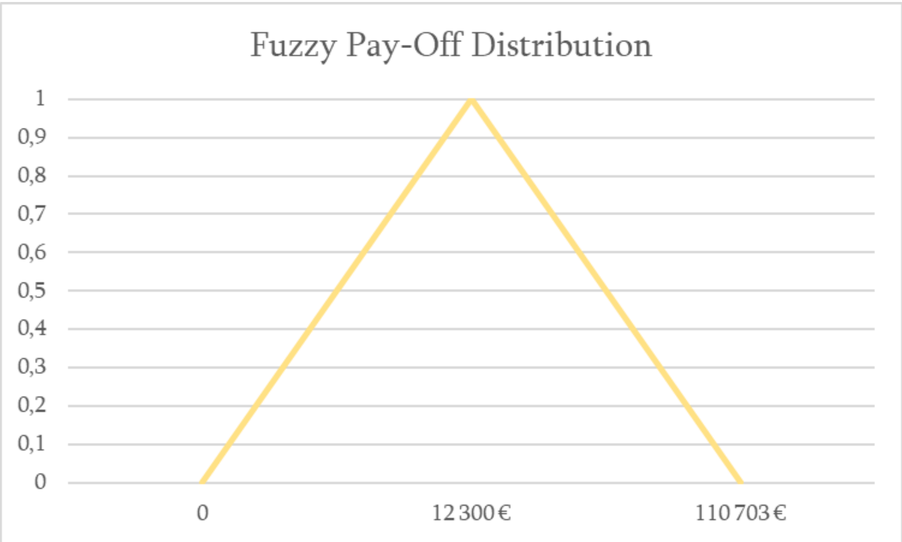

Figure 15. The fuzzy pay-off distribution.

Based from this fuzzy pay-off distribution the value for the real option for the additional savings generated from the IoT capabilities can be calculated. Results of the FPOM are depicted in the table 5. From the FPOM the value of the real option for the additional value for IoT data is 26 650 euros. This value can be considered quite conservative due to the discount rate of 14 per cent which was twice the rate which was used in the DCF analysis. The ROV value for the complete IoT investment is 552 080 euros. The ROV demonstrates that additional savings generated from the IoT capabilities are valuable and should be considered in the investment analysis. Although the true value of the FPOM comes through in the fuzzy pay-off distribution which easily communicates the characteristics of the real option. The fuzzy pay-off distribution shows that in cases where the optimistic estimate is more accurate than the best guess estimate the value of the real option would be significantly higher. Due to the uncertainty included in these estimates it is important to include it in the investment analysis which can be done with the FPOM.

Table 5. Results of the real option valuation

β		98 403
α		12 300
Area below the positive area of the NPV distribution A	$\int_{0}^{\infty} A(x)dx$	55351
Area below the whole NPV distribution A	$\int_{-\infty}^{\infty} A(x)dx$	55351
Mean value of the positive side of the NPV	$E(A_{+})$	26650
ROV (only additional value)		26650
ROV (Including the NPV value)		552080

Table 5 presents the results for the real option valuation with FPOM.

Results of the profitability analysis show that the most important aspect in the profitability analysis of an IoT investment is the TCO analysis. The ability to correctly analyse the costs related to the IoT investment as well as the non-IoT capable counterparts affects the profitability of the investment significantly. TCO analysis is significantly impacted on the accounting practices used and the ability to identify correct costs related to the processes. Table 6 summaries the results from the profitability analysis. Payback time for the investment is 6,35 years, internal rate of return for the investment is 8 per cent, net present value of the investment is 525 430 euros and the real option valuation for the investment is 552 080 euros.

Table 6. Summary of the profitability analysis

Payback time	6,35 years
Internal rate of return	8 %
Net present value	525430
Real option value	552080

Traditional profitability analysis methods are also highly dependent on the correct TCO analysis results. The traditional profitability methods in general are also not suited to optimally analyse the profitability of the IoT investment due to the uncertainty related to the investment. This uncertainty originates from different technological and business elements related to the IoT concept. Technological development related to the IoT as a paradigm is still uncertain and many different standards and technologies may turn out the be the dominant ones in the industry. This could mean that choosing the technological elements that develop into niche products might make it difficult to extract the maximum value from the IoT investments.

Real option valuation seems to be much more suited in analysing the IoT investments. The FPOM provides a good system for analysing the IoT investments profitability. FPOM allows constructing different versions of IoT investments from the technological components available and comparing them. FPOM allows comparisons where the level of uncertainty can be visually seen based on the fuzzy pay-off distribution. This method provides a good base for making strategic decisions where the different technological and business elements can be analysed. Complete profitability analysis of the IoT investment requires including the business ecosystem, the appropriate business model, characteristics of the application domain, so that correct design of the IoT investment is possible. The complete picture of the IoT investment is needed to be able to analyse the IoT investments ability to generate real competitive advantage for the company. Including factors from the ecosystem, business models and characters from the application area in the design phase of the IoT investments means creating possibilities to apply real option valuation thinking when analysing the profitability of the investment options. Applying real option thinking the IoT ecosystem, the business model chosen for the IoT investment and the application area of the IoT investment can be seen as sources to create real options for the IoT investment. These options then can be finetuned in the design phase of the investment and roughly quantified with real option valuation method. This process could help to quantify the potential profitability of the IoT investment.

5 CONCLUSIONS

Purpose of the study was to analyse the profitability analysis of a general IoT investment. Analysing the profitability of an IoT investment first required analysing the elements of the IoT investment. IoT investment's analysis consists generally from two parts: what information is essential from business point-of-view and how should this information be provided by the IoT technology. Based from the previous literature three technological layers and three business dimensions were identified. After identifying the relevant elements of the IoT investment different profitability methods were analysed to consider how the IoT investments profitability would be estimated optimally. Analysis of the different profitability methods was done with a real-life case with an IoT-capable industrial machine. Main research problem of the study was the determination of return on investments for the IoT investment and based from that three research questions were formed. First, what are the main technological elements of an IoT investment? Second, what are the most important business dimensions for the IoT investment? Third, does an IoT investment require more advanced profitability analysis methods due to the nature of these technological elements and business dimensions? The first and second research questions are studied in the second chapter of the thesis and the third research question is studied in the third and fourth chapters of the thesis.

First research question was what are the main technological elements of an IoT investment? Based from the literature the three technological elements of general IoT investment were identified as sensing layer, networking layer and intelligence layer. Sensing layer is the layer where gathering all the information generated by the data sources and acting on the data is done. Sensing layer consists from various censors and actuators. Key technologies are radio frequency identification technology (RFID), near field communications (NFC) technology and wireless sensor networks (WSN). Networking layer is the layer where the data is transferred from the sensing layer into intelligence layer for analysis and decision-making with different networking technologies. There are many networking technologies in the IoT paradigm such as Wi-Fi, Bluetooth and the fifth generation of cellular technologies. Another key component of the IoT investment is the computing paradigm. Cloud computing and edge computing offer interesting possibilities for IoT investments in areas such as scaling abilities and speed whereas more traditional mainframe computing provides more benefits in areas such as security. Intelligence layer consists from the elements related to analytics and decision-making and it can be considered the most important part of the IoT investment. Key technologies in the intelligence layer include analytics solutions for the IoT data, decision support systems for acting on that data and possibly some AI-solutions to take over some parts of the decision-making process when the amount of data reaches levels beyond human capabilities. IoT investments can be considered as a method to extract data from various data sources, understanding the meaning of that data and making decisions and actions based from that data. The amount and speed of the potential IoT data can reach easily Big Data amounts and thus humans might require assistance from decision support systems and even artificial intelligence, so these aspects are also important factors to consider in the IoT investment.

Second research question was what are the most important business dimensions for the IoT investment? Based from the literature three dimensions were identified: IoT ecosystem, the business model chosen for the investment and the application area of the investment. IoT ecosystem is the community of all the companies, officials and individuals interacting in the IoT environment. Analysis of the IoT ecosystem is very important for the IoT investment because the ecosystem is an important factor in the development of various technologies, standards and protocols. Not understanding the IoT ecosystem can create challenges if the chosen IoT technologies, standards and protocols are not supported in the future. Business model is the conceptual model of the company's business describing how company creates, delivers and captures value. For the IoT investment this is highly important because one major challenge in IoT investments is how to monetize the data received. The IoT technologies can however allow changes in the company's business models which can be the greatest source of the profitability of the IoT investment. Application area of the investment is very important dimension of the IoT investment because different areas have hugely different requirements. Atzori et al. (2010) separate the application areas into four main segments of transport and logistics, healthcare, smart environment and personal and social domain. Requirements for IoT investments in these application areas can differ for example with investment needs, maintenance costs, energy consumption, data management requirements and user involvement (Gubbi et al., 2013).

Third research question was does IoT investment require more advanced profitability analysis methods due to the nature of these technological elements and business dimensions?

Traditional profitability analysis methods such as net present value method, payback method and internal rate of return method are commonly applied methods but might not be best suited for the IoT investments due to the high uncertainty related to the IoT investments. Real option valuation methods however are more suited to include the uncertainty of investment into the profitability analysis. The analysis of the profitability analysis methods was done with a real-life case where total cost of ownership (TCO) analysis was performed on two industrial machines where one of the machines had IoT-capabilities and the other one did not. Based on the TCO analysis the investment case was calculated and profitability analysis was performed using the traditional profitability analysis methods and a real option valuation method of fuzzy pay-off method. The results of the comparison of the profitability analysis showed that including the uncertainty level in the profitability analysis is valuable for the IoT investments. Including the real options found in the case increased the net present value of the investment 5 per cent but the true value of the real option valuation is demonstrating the uncertainty related in the estimates. This uncertainty can be used more efficiently in the investment process because a great source of the IoT investments' values are generated in the most uncertain value sources which are hard to estimate with traditional profitability analysis methods. Results of the case indicate that real option valuation is a good method for analysing IoT investments because it can help identify the most valuable aspects of different investments which usually are the most uncertain components of the investments. Therefore, including the real option valuation in the profitability analysis of IoT investments is a good choice which can help companies identify the most potential value generating investments which can sometimes include a great deal of uncertainty.

Results of the thesis indicate that companies should consider IoT as a potential source of competitive advantage. IoT investments can provide companies many options either to automate their current operation or even innovate completely new products, services and ways of operating. Companies should also include real option valuation methods in their capital budgeting when analysing IoT investments. Otherwise companies might undervalue the most complex and possibly the most valuable investments due to the traditional profitability analysis methods' inability to include all the relevant aspects of the IoT investments in the profitability analysis.

Based from the results of the thesis it can be concluded that in the IoT investment's profitability analysis the real option valuation methods should be applied because traditional profitability analysis methods are not optimally suited to analyse all the relevant aspects of IoT investments on their own. From the results of the thesis it can be concluded that one aspect which might decrease the market demand for IoT investments might be the undervaluing of the IoT investments due to the inability to analyse the profitability of IoT investments correctly. This may be caused from to the high use of traditional profitability analysis methods which are unable to include all the relevant aspects of the IoT investment in the profitability analysis.

There are many limitations of the thesis. IoT is a very broad paradigm so analysing all the relevant areas is quite challenging and was not possible in the scope of this thesis. Also, previous literature of the IoT is heavily focused on engineering and computer science domains which causes challenges in understanding the true potential of the IoT for the laymans of those fields. Another limitation of the thesis is the exclusion of security and privacy aspects of the IoT which are crucial elements of the IoT investment but require deeper analysis than was possible in the thesis.

There are many interesting research areas regarding profitability analysis of IoT investments. Interesting further research topic would be comparison of different real option valuation methods to each other in profitability analysis of IoT investments. Another topic would be managerial flexibility for example in scaling the IoT investments or the aspects of reversibility in the IoT investments. The possibility to manage IoT investments and the opportunities to include real options in them would be an interesting area of research. The flexibility of changing technological solutions in the IoT investments is also an interesting future research topic. Additional research areas would be the business elements of the IoT ecosystem, different business models made possible by IoT technologies and changes created in the application areas by IoT technologies. Also, security and privacy aspects of the IoT investment provide interesting further topics for research.

This thesis studied the basic building blocks of the IoT investment both from the technological and business side and also an optimal profitability analysis method for the capital budgeting processes for the IoT investments. However, a very interesting future research topic would be to analyse the managerial flexibility of IoT investments, especially related to the intelligence layer and monetization of the data produced from the IoT sensors. In many ways the IoT investment can be considered as an instrumentation process of sensors to collect all the available data of the various processes of the companies and then extracting value from that sensor data. There are many possible ways to extract value from that data which provides the flexibility to change the IoT investment when situations change regarding the investment.

REFERENCES

Akyildiz, I.F., Su, W., Sankarasubramaniam, Y. & Cayirci, E. 2002. Wireless Sensor Networks: a Survey. Computer networks, 38, (4), pp.393-422.

Armstrong, J. S. & Grohman, M. C. 1972. A Comparative Study of Methods for Long-Range Market Forecasting. [online document]. [Accessed 9th August 2018]. Available at http://repository.upenn.edu/marketing_papers/82

Atzori, L., Iera, A. and Morabito, G. 2010. The Internet of Things: A Survey. Computer Networks, 54, (15), pp.2787-2805.

Bain. 2010. [online document]. [Accessed 12th August 2018]. Available at http://www.bain.de/Images/BainBrief_On-Demand_Game_in_Enterprise_Software_Industry.pdf

Black, F. & Scholes, M. 1973. The Pricing of Options and Corporate Liabilities. Journal of Political Economy, 81, (3), pp.637-654.

Bonaventure, O. 2011. Computer Networking: Principles, Protocols and Practice. [online document]. [Accessed 26th May 2018]. Available at https://www.saylor.org/site/wp-content/uploads/2012/02/Computer-Networking-Principles-Bonaventure-1-30-31-OTC1.pdf

Brealey, R. A. & Myers, S. C. 1988. Principles of Corporate Finance. 3rd edition. New York: McGraw-Hill.

Burns, R. & Walker, J. 2009. Capital Budgeting Surveys: The Future Is Now. Journal of Applied Finance, 19 (1/2), pp. 78-90.

CapGemini, 2014. Monetizing the Internet of Things: Extracting Value from the Connectivity Opportunity. [online document]. [Accessed 12th August 2018]. Available at https://www.capgemini-consulting.com/internet-of-things-monetization-models

Carlsson, C & Fullér, R. 2001. On Possibilistic Mean Value and Variance of Fuzzy Numbers. Fuzzy Sets and Systems, 122, pp. 315-326.

Chan, S.H & Song, Q. 2010. Motivational Framework: Insights into Decision Support System Use and Decision Performance, Decision Support Systems, Chiang S. Jao (Ed.), [online document]. [Accessed 2th June 2018]. Available at https://www.intechopen.com/books/decision-support-systems/motivational-framework-insights-into-decision-support-system-use-and-decision-performance

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

Cisco. 2017. Cisco Survey Reveals Close to Three-Fourths of IoT Projects Are Failing. [online document]. [Accessed 29th September 2017]. Available at https://newsroom.cisco.com/press-release-content?articleId=1847422

Cisco. 2015. Fog Computing and the Internet of Things. [online document]. [Accessed 8th September 2017]. Available at http://www.cisco.com/c/dam/en_us/solutions/trends/iot/docs/computing-overview.pdf

Collan, M. 2004. Giga-investments: Modelling the Valuation of Very Large Industrial Real Investments. PhD. Turku, Åbo Akademi University, Turku Center for Computer Science

Collan, M. 2012. The Pay-off Method: Re-inventing Investment Analysis: with Numerical Application Examples from Different Industries. USA: CreateSpace Independent Publishing Platform.

Collan, M., Haahtela, T. & Kylaeheiko, K. 2016. On the Usability of Real Option Valuation Model Types Under Different Types of Uncertainty. International Journal of Business Innovation and Research, 11 (1), 18-37.

Comptia, 2015. Sizing Up the Internet of Things. [online document]. [Accessed 2th August 2018]. Available at https://www.comptia.org/resources/sizing-up-the-internet-of-things

Domingos, P. 2015. The Master Algorithm: How the Quest for the Ultimate Learning Machine Will Remake Our World. New York: Basic Books.

Druzdzel, M. & Flynn, R. 2002. Decision Support Systems. In: Allen Kent (eds.). Encyclopedia of Library and Information Science, 2nd Edition, New York: Marcel Dekker, Inc.

Engelbrecht, A. 2007. Computational Intelligence: An Introduction. 2nd edition. Chichester: John Wiley & Sons.

Ertel, W. 2011. Introduction to artificial intelligence. New York, USA: Springer Science & Business Media.

Finkenzeller, K. 2010. RFID Handbook – Fundamentals and Applications in Contactless Smart Cards, Radio Frequency Identification and Near-Field Communication. 3rd edition. Wiltshire, UK: John Wiley & Sons.

Frizzo-Barker, J., Chow-White, P., Mozafari,M. & Ha, D. 2016. An Empirical Study of the Rise of Big Data in Business Scholarship. International Journal of Information Management, 36, pp. 403-413.

Furth, B. & Escalante, A. 2010. Handbook of Cloud Computing. New York, USA: Springer Science+Business Media

Grossmann, W. & Rinderle-Ma, S. 2015. Fundamentals of Business Intelligence. New York, USA: Springer.

Gubbi, J., Buyya, R. ,Marusic, S. & Palaniswami, M. 2013 Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions. Future generation computer systems, 29, (7) pp. 1645-1660.

Herrera-Viedma, E. 2015. Fuzzy Sets and Fuzzy Logic in Multi-Criteria Decision Making. The 50th Anniversary of Prof. Lotfi Zadeh's Theory: Introduction, Technological and Economic Development of Economy, 21, (5), pp. 677-683.

Iansiti, M. & Levien, R. 2004. Strategy as Ecology. Harvard Business Review, 82, (3), pp. 68-81.

Leavitt, N. 2009. Is Cloud Computing Really Ready for Prime Time? Computer, 42, (1), pp.15-20.

Lee, I. & Lee, K. 2015. The Internet of Things (IoT): Applications, Investments, and Challenges for Enterprises. Business Horizons, 58, (4), pp. 431-440.

Leslie, K. & Michaels, M. 1997. The Real Power of Real Options. The McKinsey Quarterly, 3, pp. 5-22

Li, S., Xu, L.D. & Zhao, S. 2015. The Internet of Things: a Survey. Information Systems Frontiers, 17, (2), pp. 243-259.

Mattern F. & Floerkemeier C. 2010. From the Internet of Computers to the Internet of Things. In: Sachs K., Petrov I., Guerrero P. (eds) From Active Data Management to Event-Based Systems and More. Lecture Notes in Computer Science, vol 6462. Berlin: Springer.

Mazhelis, O., Warma, H., Leminen, S., Ahokangas, P., Pussinen, P., Rajahonka, M., Siuruainen, R., Okkonen, H., Shveykovskiy, A. & Myllykoski, J., 2013. Internet-of-Things Market, Value Networks, and Business Models: State of the Art Report. University of Jyvaskyla, Department of Computer Science and Information systems, Technical Reports TR-39.

McKinsey. 2015. McKinsey Global Institute: The Internet of Things: Maping the Value Beyond the hype. [online document]. [Accessed 17th July 2018]. Available at http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/the-internet-of-things-the-value-of-digitizing-the-physical-world.

Moore, J.F. 1996.The Death of Competition: Leadership & Strategy in the Age of Business Ecosystems. New York: Harper Business.

OECD. 2012. Machine-to-Machine Communications: Connecting Billions of Devices. [online document]. [Accessed 19th July 2018]. Available at https://www.oecd-ilibrary.org/docserver/5k9gsh2gp043-en.pdf?expires=1534178709&id=id&accname=guest&checksum=D603A51D6E6C1C86E133D050C2B3D732

Osterwalder, A. & Pigneur, Y. 2010. Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers. New Jersey: John Wiley and Sons.

Palattella, M. R., Dohler, M., Grieco, A., Rizzo, G., Torsner, J., Engel, T., & Ladid, L. 2016. Internet of Things in the 5G Era: Enablers, Architecture, and Business Models. IEEE Journal on Selected Areas in Communications, 34, (3), pp. 510-527.

Pang, Z., Chen, Q., Han, W. & Zheng, L. 2012. Value-Centric Design of the Internet-of-Things Solution for Food Supply Chain: Value Creation, Sensor Portfolio and Information Fusion. Information Systems Frontiers 17, (2), pp. 289-319.

Porter, M. E. 1985. The Competitive Advantage: Creating and Sustaining Superior Performance. New York: Free Press.

Postscapes. 2017. IoT Alliance and Consortium. [online document]. [Accessed 4th August 2018]. Available at https://www.postscapes.com/internet-of-things-alliances-roundup/

Power, D.J. 2007. A Brief History of Decision Support Systems. [online document]. [Accessed 2th June 2018]. Available at http://DSSResources.COM/history/dsshistory.html

Rohde & Schwarz. 2011.Near Field Communication (NFC) Technology and Measurements. [online document]. [Accessed 4th June 2018]. Available at https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_application/application_notes/1ma182/1MA182_5E_NFC_WHITE_PAPER.pdf

Russell, S. & Norvig, P. 2010. Artificial Intelligence - a Modern Approach. New Jersey: Prentice Hall.

SAP. 2017. IoT edge computing. [online document]. [Accessed 13th July 2018]. Available at https://assets.cdn.sap.com/sapcom/docs/2017/03/068181cb-ae7c-0010-82c7-eda71af511fa.pdf

Sundmaeker, H., Guillemin, P., Friess, P. & Woelfflé, S. 2010. Vision and Challenges for Realizing the Internet of Things. Cluster of European Research Projects on the Internet of Things, European Commission.

Susskind, R. & Susskind, D. 2015 The Future of the Professions: How Technology Will Transform the Work of Human Experts. USA: Oxford University Press.

Teece, D. J. 2010. Business Models, Business Strategy and Innovation. Long Range Planning, 43, (2), pp. 172-194.

Toivanen T., Mazhelis O., Luoma E. 2015. Network Analysis of Platform Ecosystems: The Case of Internet of Things Ecosystem. In: Fernandes J., Machado R., Wnuk K. (eds) Software Business. Lecture Notes in Business Information Processing, vol 210.

Trigeorgis, L. 2002. Real Options and Investment Under Uncertainty: What Do We Know? National Bank of Belgium Working Paper Research, No. 22.

Vermesan, O., Friess, P., Guillemin, P., Sundmaeker, H., Eisenhauer, M., Moessner, K., Arndt, M., Spirito, M., Medagliani, P., Giaffreda, R., Gusmeroli, S., Ladid, L., Serrano, M., Hauswirth, M. & Baldini, G. 2014. Putting the Internet of Things Forward to the Next Level.

In: V. Ovidiu and P. Friess, (eds.) Internet of things - from research and innovation to market deployment. Aalborg: River Publishers.

Waller, M. & Fawcett, S. 2013. Data Science, Predictive Analytics, and Big Data: a Revolution That Will Transform Supply Chain Design and Management. Journal of Business Logistics, 34, (2), pp. 77-84.

Whitmore, A., Agarwal, A. & Da Xu, L. 2015. The Internet of Things—A Survey of Topics and Trends. Information Systems Frontiers, 17, (2), pp 261–274.