LUT School of Business and Management

Master's Thesis

Master's Programme in Supply Management

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UTILIZING RFID TO IMPROVE SPARE PARTS INVENTORY MANAGEMENT

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ABSTRACT

Lappeenranta-Lahti University of Technology LUT
School of Business and Management
Master’s Programme in Supply Management

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Utilizing RFID to improve spare parts inventory management

Master’s thesis
2021
89 pages, 15 figures, 4 tables
Examiner: Professor Katrina Lintukangas and Professor Veli Matti Virolainen

Key words: Spare parts inventory management, RFID, Maintenance environment, spare part classification

The aim of this thesis is to examine how RFID can be utilized to improve spare parts inventory management. To answer that question thesis also investigates which are the potential barriers for adopting RFID to spare parts inventory management and is there differences in the potential between inventory management and spare parts inventory management. Previous studies related to these topics are covered on the theoretical part of the study which has two main topics of inventory management and automatic identification. The qualitative research was performed by using a single case study method and theme interviews were used as a research material collection method. In total ten interviews were held and six of them were held to the case company and four them were external interviews.

The result of this study suggest that RFID technology has reached a maturity state, most of the technical issues have been solved, and tag prices have reduced to the achievable level. However, there are still issues in attracting suppliers to implement technology, especially in spare part inventory management. The study reveals that RFID has a significant benefit in reducing inventory inaccuracies and improving the inventory auditing process in spare part inventory management, but improvements in receiving processes are not that significant. This thesis suggests that hybrid solutions which utilize both RFID and QR-codes should be selected. Items that are equipped with RFID should be based on the characteristics of stocked items. One of the most important factors is the criticality of the spare parts and all critical parts should be equipped with RFID tag.

TIIVISTELMÄ

Lappeenrannan-Lahden teknillinen yliopisto LUT
School of Business and Management
Master’s Programme in Supply Management

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RFID teknologian hyödyntäminen varaosavarastoinnin tehostamisessa

Pro gradu -tutkielma
2021
89 sivua, 15 kuvaajaa, 4 taulukkoa
Tarkastaja: Professori Katrina Lintukangas and Professori Veli Matti Virolainen

Avainsanat: Varaosavarastointi, RFID, Kunnossapitoympäristö, varaosaluokittelu

Tämän pro gradu tutkielman tarkoitus on keskittyä tutkimaan RFID teknologian hyödyntämistä varaosavarastoinnin tehostamisessa. Vastatakseen tähän kysymykseen tutkielma keskittyy myös vastaamaan kysymyksiin mitkä ovat potenttiaaliset esteet RFID teknologian implementoinnille varaosavarastoinnissa ja onko varaosavarastoinnin ja normaalin varastoinnin välillä eroja saavutettavissa hyödyissä. Aihepiiriin liittyviä aikaisempia tutkimuksia käsitellään teoriaosuudessa, jolla on kaksi pääaihealuetta: varastonhallinta ja automaattiset tunnistusmenetelmät. Laadullinen tutkimus on suoritettu käyttämällä yhden tapauksen tutkimusta ja teemahaastattelu menetelmää on käytetty tutkimusmateriaalin keräämiseen. Yhteensä kymmenen haastettalua pidettiin, joista kuusi haastattelua oli case yrityksen sisäisiä ja neljä haastattelua pidettiin yrityksen ulkopuolisille osapuolille.

Tämä tutkimus osoittaa, että RFID teknologia on saavuttanut kypsyysasteen ja suurin osa teknologian haasteista on ratkaistu. Lisäksi tunnisteiden hintataso on saavuttanut hyväksyttävän tason. Kuitenkin edelleen on haasteena kuinka saada toimittajat ottamaan käyttöön RFID teknologia etenkin varaosavarastoinnissa, jossa yksittäisen toimittajan voluumi voi olla hyvin pieni. Tutkimus osoittaa, että RFID:n hyöty etenkin varaston epätarkkuuksien pienentämisessä ja inventointiprosessissa on merkittävä, mutta vastaanottoprosessissa teknologian merkitys ei ole niin suuri. Tutkimus ehdottaa, että hybridi malli joka hyödyntää sekä RFID tunnisteita, että QR-koodeja tulisi ottaa käyttöön. Valittava tunnistusmenetelmä perustuu varaosan omaisuuksiin ja tutkimuksen perusteella ehdottaan, että kaikki kriittiset varaosat tulisi varustaa RFID tunnisteella.

ACKNOWLEDGEMENTS

For me writing a thesis was a quite long process and I have to say that writing is not one of my best qualities, but here I am. These years that I have spent at LUT have given me amazing friends which I hope will last the rest of my life. I would like to thank all of my friends for the hours that we spent at the guild room by drinking coffee and hanging around and all the memories around that. I also would like to thank a few of my friends who have taken care of my grammar during the studies.

I would like to thank my previous manager for trusting my idea about the topic and for the opportunity to do this thesis. I also would like to thank all the interviewees for sharing their knowledge with me. I also would like to thank my supervisor Katrina Lintukangas for the advice and feedback during the writing process.

Lastly, I would like to thank my family especially my mother for the support during these years at the school. Without your support, during the first years at the school, I would not be writing this acknowledgement right now.

In Helsinki, March 23st 2021

Santeri Heiskanen

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1. Introduction

Radio Frequency IDentification also known as RFID is subset of the Automatic Identification and Data Capture (AICD) technologies (Parthiban, 2019). It has attracted attention in manufacturing, supply chain, and recently in the service sector. (Lim et al. 2013) RFID transmits data via radio waves between readers and RFID tags. RFID ecosystem requires RFID middleware for processing the collected data in a way that it can be utilized in business applications such as ERP system. Each tag has unique information about the product, for example, ID number, shipping date, etc. depending on the end-users needs. (Ustundag, 2013) RFID technology has multiple advantages compared to other AICD technologies such as barcodes to collect, transmit, and utilize the data (Baker, 2005). These advantages consist of improved inventory visibility, unique identification of each tag, traceability of tags within inventory management processes, improved inventory and receiving procedures etc. (Ngai et al., 2008; Baker, 2005).

More and more, RFID technology is considered to replace barcodes in the supply chain because it allows retailers and manufacturers to quantify their inventory without costly and time-consuming physical audits or use technology to reduce the amount of manual labour in the audit process. (Kok et al., 2007) Due to RFID's well-known capabilities and its popularity in the different industries, the interest towards RFID technology have been significant in the literature across different industries. RFID research in warehousing or inventory management has not been as much prominent as other application domains. (Lim et al., 2012) Curtin et al. (2007) argued that warehousing amongst dozens of fields in RFID research would be one of the main fields that considerably benefits from RFID implementation. However, according to Lim et al. (2013) comprehensive literature review, studies related the spare part inventory are lacking and the purpose of this thesis is to identify RFID's opportunities in the maintenance environment. Spare part inventory management has many common characteristics with standard inventory management, but it obliges an additional consideration of cost structures. High-performance spare part inventory management has a major role in cost-cutting and improving service level. (Purchasing and procurement centre, 2020) Spare parts inventories are required for maintenance tasks such as repairing industrial machines and equipment. Spare part inventory management has characteristics such as a large number of distinct parts and low turnover times. (Rego & Mesquita, 2011) Turnover times up to 5 years are not uncommon (Dekker & Bayindir, 2018) also, obsolescence risk is high due to specific functionalities of spare part (Dekker et al., 2013). Due to the spare part inventories' complex nature, efficient management requires a balance between inventory costs and expenses related to stockout situations (Trimp et al., 2003). Inventory accuracy is a crucial factor in spare part inventory, and a work order has to be made even for a small job. By following the work order procedure, managers know each work order and its history and what kind of inventory were used. If the procedure is not followed, inventory records are not accurate. Quick development on the utilisation of information technology and the use of enterprise resource planning (ERP) in the industry have offered companies the flexibility to differentiate the spare parts. However, in practice it is challenging and economically impossible to use different kind of control pattern to a singular spare parts in practice. (Sarmah & Moharana, 2015) Different kinds of spare part classification methods are utilized to group spare parts based on criticality and other factors such as lead time. (Teixeira et al., 2017)

1.1 Research questions

The use of RFID technology in inventory management has been studied in multiple fields, but studies related to spare part inventory management are currently lacking (Lim et al., 2013). This thesis aims to fill the gap related to the use of RFID in spare part inventory management. To build a more comprehensive view of the issue, it is important to focus on a few other themes. Firstly, the current state of spare part inventory management processes in the case company is studied to identify current challenges and possibilities to solve RFID implementation. Secondly, potential barriers to the implementation in a maintenance environment are studied. Lastly, the main differences in benefits between spare part inventory management and existing studies have been identified. Based on these objectives, the following research questions are composed.

Main research question is:

“How can RFID help in improving spare parts inventory management efficiency?”

Supporting research questions are:

“How spare parts inventory is currently managed at Case company?”

“What are the potential barriers for adopting RFID to spare parts inventory management?”

“What are the main differences of RFID potential between spare parts inventory management and regular inventory management?”

This thesis has the following structure. In the first part of the theory, the concept of inventory management is studied, sub-chapters are concentrating on spare part inventory management and spare part classification. The second chapter of the theory focuses on Automated Identification and Data Collection technologies, first barcode and RFID technology are compared. After that, RFID infrastructure is studied, and lastly, RFID application, benefits and critic in inventory management are identified. The empirical research of this thesis focused on the issue from the point of view of the practitioners. Empirical research is based on theme interviews conducted with external and internal interviewees to gain more comprehensive knowledge about the issue

1.2 Research methodology

The empirical part of this thesis is qualitative research that utilised theme interviews as a material collection method. More precisely, the case study research was the selected research method for this thesis. A case study is an investigative manner of explaining and investigating a phenomenon and understanding the issue more deeply and gaining knowledge about it (Hiusjärvi & Hurme, 2015). Still, some quantitative material such as ERP data is used to build a more comprehensive view of the case company’s processes. A qualitative approach was chosen for this thesis because of the nature of the research issue, since qualitative research is commonly used to examine the complex issue in real world context and gain knowledge about it (Eriksson & Kovalainen, 2008). As mentioned above, there is need for improving the knowledge related to how RFID can improve spare parts inventory management. Because qualitative research generally aims to answer “how” questions and provide insight into the less known issue, it was the most suitable research method for this thesis (Laine et al., 2011; Lapan et al., 2012). Primary data used in empirical research was collected from 10 different interviews, of which four interviews were external sources, and six was inside the case company. Interviews were used to collect information about the issues related to the current state of the spare part inventory management at the case company and the current challenges and maturity of RFID technology.

As this thesis is qualitative and only one case company is included, it can be said that this thesis covers only a limited perspective on the issue. These findings cannot be generalized outside of the case company, excluding RFID technology-related findings that can be generalized. However, this study's purpose was not to provide generalized results but rather gain in-depth insight into the case company about the current state of inventory management and the benefits and potential barriers to RFID implementation.

1.3 Conceptual framework

The conceptual framework aims to present the main concepts used in this thesis and the relations between them. As can be seen from research questions, this thesis aims to examine the relationships between spare part inventory management and RFID technology and how RFID can improve key processes' efficiency. Previous studies related to spare part inventory management revealed that spare part classification significantly impacts the efficiency of inventory management processes when critical items can be identified, and those can be monitored more accurately. (Huiskonen, 2001; Cavalieri et al., 2008; Sarmah & Moharana, 2015; Teixeira et al., 2017) Earlier research that concerned utilisation of RFID in inventory management identified two main benefits, inventory reductions (Kang & Gershwin, 2004; Heese, 2007; Lee & Özer, 2007; Sarac et al., 2009; Sarac et al., 2010; Hardgrave et al., 2013; Lim et al., 2013) and labour reductions which can be divided to the short-term labour reductions via reducing of manual tasks (Lee & Özer 2007; Soon & Gutierrez, 2008; Attaran, 2012; Chanchaichujit et al., 2020) and long-term labour reduction by reorganising processes (McFarlane et al., 2003; Banks et al., 2007; Curtin et al., (2007); Langer et al., 2007;). The key concepts and relations between them are represented in figure 2.

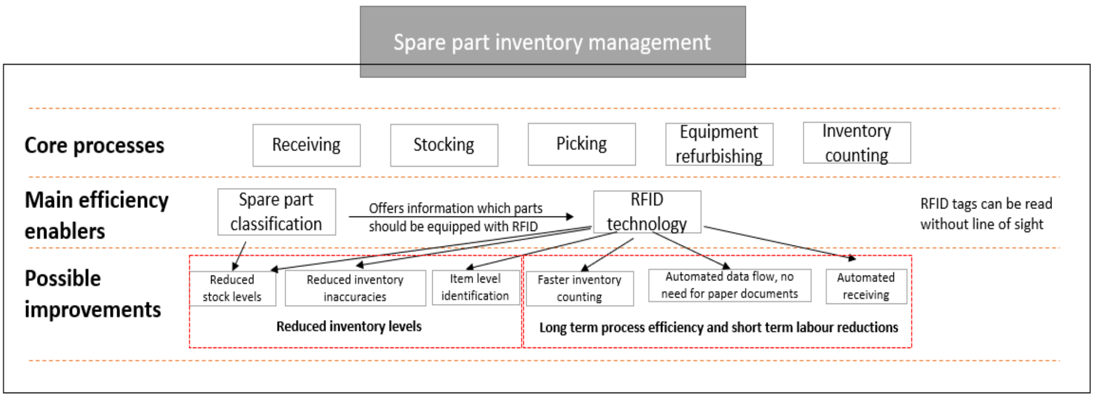

Figure 1 Conceptual framework

This thesis aims to identify the main benefits of RFID implementation in spare part inventory management, which have not been a popular research topic in previous studies. The lack of prior studies thesis also aims to address how these benefits differ from studies related to inventory management and the main barriers for the RFID implementation in the maintenance environment. Another goal is to provide a framework for the successful implementation of RFID. Reduced inventory levels and labour cost reductions were selected as main benefits also because those are quantitative benefits, and it is an essential factor for the Return On Investment (ROI) calculation. Attaran (2012) suggested that clearly defined measurable business benefits are one of the most important implementation factors.

1.4 Key concepts and their definitions

The key concepts used in this thesis are defined in this section. These concepts are described more precisely in the theoretical part of this thesis.

Spare part inventory = “Spare parts inventories are needed for maintenance and repair of final products, vehicles, industrial machines and equipment, frequently requiring high investments and significantly affecting customer satisfaction. Spare part inventory management is complex due to a large number of different items and low demands” (Rego & Mesquita, 2011, 656)

RFID = “Radio Frequency IDentification (RFID) is an enabling technology for remotely identifying, monitoring, and tracking various objects of interest using radio wave transmissions. The automatic identification of objects is possible by wireless communications between a tag (attached to an object) and its reader (interrogator) at a distant location.” (Nekoogar & Dowla, 2011,2)

UHF = Ultra High Frequency, the most suitable tag type in inventory management, due to the tag’s reading range. (Zannas et al., 2019)

Maintenance environment = Working environment where item consumption is based on maintenance work orders and the cost are allocated to the individual work order.

Spare part classification = “Spare part classification enabler managers to concentrate on the most important items and facilitates the decision-making process. However, important items from a maintenance perspective are rather different compared to important parts from an inventory management point of view”. (Syntetos et al., 2008, 293) There are multiple ways to do classification, such as VED, XYZ and ABC analysis.

AIDC = “Automatic Identification and Data Capture (AIDC) is an emerging technology that is used to identify objects, capture and store the data directly in the system without any human intervention. AIDC technology has a wide variety of different technologies, but RFID and barcodes are most widely adopted”. (Parthiban, 2019,191)

2. Inventory management

According to Wang et al. (2010), inventory management, including receiving and storage management and inventory management, are the most important part of warehousing operations. An inventory management system is trying to find a solution to the following questions: how much stock is needed for individual item and the suitable reordering point, and how parts should purchase. (Masound, 2019) These questions can fluctuate in different approaches of inventory management because each of the orientation has distinct factors. Especially cost factor has a significant influence on decision making. (Bakker et al. 2012) Huiskonen (2001) & Ruston et al. (2014) argued that the purpose of inventory management is to balance between a suitable service level and costs related to inventories.

In literature, inventory cost is typically grouped into three types: carrying costs, ordering costs, and shortage costs. (Shenoy & Rosas, 2018; Jacobs et al., 2011) According to Rushton et al. (2014), inventory cost can be determined as holding costs, reorder costs, set-up costs and shortage costs. Chopra & Meindl (2016) argue that inventory costs can be divided into ordering costs and holding costs. Inventory carrying cost, also known as inventory holding cost, is a cost associated with warehousing an item until it is used or sold to the customer. Regardless of different grouping, all of these definitions have similar content. Inventory carrying cost is a cost related to stocking item until it is used or sold. According to Shenoy & Rosas (2018) it has typically four different drivers: Cost of capital, -storage, -inventory risk and -servicing inventory. Cost of capital refers to opportunity cost related to tied money to inventory, cost of storage includes rent of physical space, cost of inventory risk refers cost associated with item spoilage and cost of servicing inventory means the cost of wages and equipment such as forklifts. Ordering cost is related to the procurement process and other processes associated with receiving items into an inventory system. It has four main components: Cost of administration, -transportation, -inspection and other costs. Cost of administration refers to the time and effort used to purchase. The cost associated with transportation includes unloading and uploading. The cost of the inspection is related to the goods of the receipt process. The last general cost category is shortage costs incurred when the organisation cannot satisfy internal or external customers’ demand. Together those costs cover a significant part of the company's costs, and it is vital to identify where those costs come from. (Shenoy & Rosas, 2018) According to Haverila et al. (2009, 444), inventory costs can be calculated as "a percentage of the value of inventory". They argued that costs could vary from 19,5% up to 36%. Trimp et al.'s (2004) research provided information where the cost ration varied between 17,5% and 25%. However, labour prices vary in different countries. Due to that, it is hard to give predict answer for the costs related to inventory. Subsets of each category and share of total inventory costs are described in the figure 2 below.

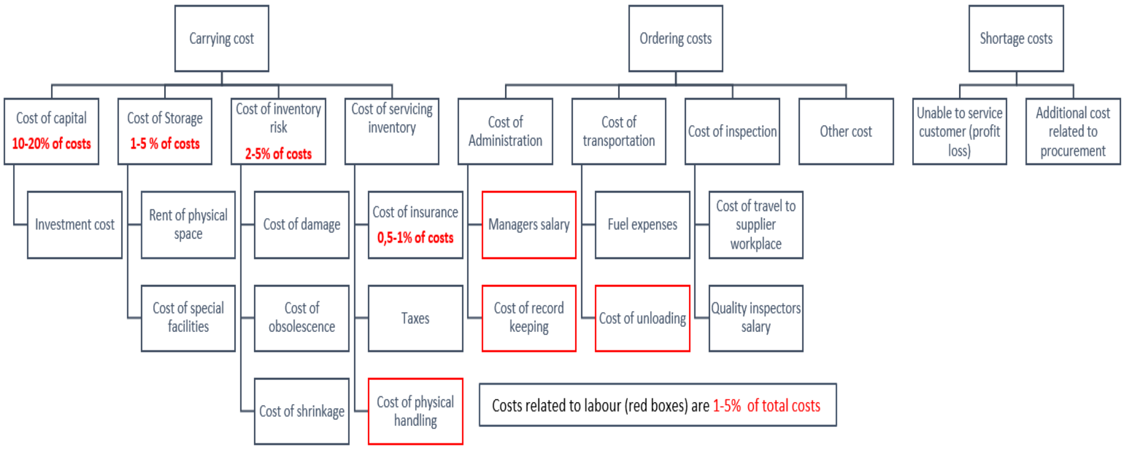

Figure 2 Summary of inventory management costs according Shenoy & Rosas (2018), 24-28 and Haveri et al. (2009, 444)

Organisations treat and categorise inventory differently depending on the field they are part of, for example, merchandisers or manufactures (Shenoy & Rosas, 2018). Manufacturer's inventory is often separated into three categories: raw materials, finished goods, and work-in-processes materials. However, merchandisers have only stocks for finished goods. Other classes, such as consumables and service, repair, replacement, and spare items (S&R items), should be included from a functional standpoint. (Muller, 2003) Items used to support production activities can also be referred to as maintenance, repair, and operation (MRO) supplies (Shenoy & Rosas, 2018). Consumables include everyday utilities which are used in many operations like cleaning materials, hand towels, lubricants. These are usually treated as raw materials. MRO item category contains after-market items that are used to maintain machines and devices on the production. MRO items should not be dealt with like other finished goods regarding determining your standard stock's quantity level. Equipment is characterised by failures, and stock levels of MRO items should be based on preventative maintenance schedules, annual shutdowns, failure rates and so on. (Muller, 2003; Shenoy & Rosas, 2018)

2.1 Spare parts inventory management

According to Cavalieri et al. (2008), MRO products have four different classes: consumables and accessory products, generic spare parts, specific spare parts, and strategic spare parts. Consumables and accessory products include items with constant demand, purchased from a wide supplier's base, such as wiping rags or oil filters. Generic spare parts are suitable for various equipment, and those are widely available on the market. Typically, these spare parts are retrievable on electronic catalogues, for example, mechanical components like bearings or valves. Specific spare parts are suitable for a specific equipment, or procurement is possible only from a particular supplier. For a strategic spare part it is a typical that wear-out time is hard to predict, lead time is long, part is expensive, and demand is sporadic.

Generally, companies own critical equipment in their production, which makes maintenance of that equipment crucial. Maintenance works can be divided into planned and unplanned maintenance works, especially unplanned maintenance works requiring good spare part inventory management that shutdowns can be avoided. For the spare part inventories, it is typical that some of the spare parts are refurbished because those are so expensive that it is economically worthwhile to repair them, and most of the spare parts are disposable. (Fortuin & Martin, 1999)

Spare parts inventories differs from inventories that are used in companies operating in fields such as retailing. (Rego & Mesquita, 2011) Spare parts inventory management has multiple common characteristics with "regular" inventory management, but it obliges an additional consideration of cost structures. Spare parts inventories are required for maintenance tasks such as repairing industrial machines and equipment. Spare part inventory management has characteristics such as a huge number of different part and low turnover time. (Rego & Mesquita, 2011) Turnover times up to 5 years are not uncommon (Dekker & Bayindir, 2018) also, obsolescence risk is high due to specific functionalities of spare part (Dekker et al., 2013). Maintenance and repair departments are internal to many organisation, and high-performance spare parts inventory management has a significant role in decreasing costs and improving service level simultaneously. (Purchasing and procurement centre, 2020) The majority of the companies hold thousands of spare parts in the inventories. Usually, spare parts are not appropriately categorised, and it affects inventory management (Sarmah & Moharana, 2015) because spare part inventories can rise significantly high if ineffective inventory systems are adopted. Management of spare part inventories requires a good balance between inventory costs and expenses associated with stockouts. (Trimp et al. ,2003) Spare part stocks are usually thought of as insurance. For spare part inventory management, it is crucial to secure critical equipment's high service levels. Otherwise, it might lead to the so-called squirrel stocks, for example, secret stocks, which are not to the inventory system by the maintainer of critical equipment. (Dekker et al., 1996) According to Huiskonen (2001), spare part inventories are generally managed by utilising general inventory management policies that do not pay enough attention to individual spare parts' control characteristics. Huiskonen (2001) also argued that control is often focused on local inventories rather than the supply chain as a whole. Dekker & Bayindir (2018) argued that even the number of studies related to spare parts inventory management is high, case studies are lacking.

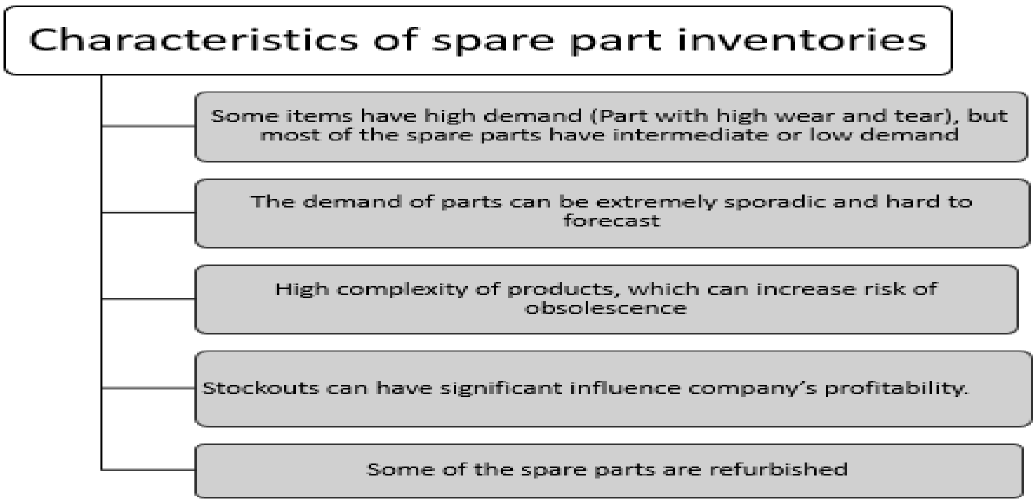

Figure 3 Characteristics of spare part inventories

The prerequisite for designing the logistics of spare parts diverge from other material groups in multiple ways. A stockout's consequences can be severe due to the downtime and lost profit of production, which cause high service level requirements (Huiskonen, 2001;Trimp et al., 2003). Nevertheless, the cost related to spare part stock out is challenging to quantify because of costs affiliate with low quality or losses on production (Kennedy et al. 2002). The demand for parts can be occasional and hard to predict (Huiskonen, 2001; Trimp et al.,2003), Trimp et al. (2003) and Dekker & Bayindir (2018) argued that turnover times up to five years for an individual part is not uncommon.

Lastly, individual parts' prices can be considerably high (Huiskonen, 2001; Trimp et al., 2003). Dekker et al. (2013) endorsed those ideas and highlighted the expensive nature of spare parts and added the concept of high obsolescence risk due to specific functionalities of the spare part. Stoll et al. (2015) highlighted the role of the individual spare part's criticality as a driver in the classification process. Furthermore, lead times and stock levels within supply chains are decreasing. Those traits set pressure for improving the inventory management of spare parts. (Huiskonen, 2001) Characteristics of the spare parts are presented at the figure 3.

2.2 Spare part classification

High-performance warehousing and inventory management of spare parts related to production equipment are crucial for organisations with maintenance services. Organisations need to plan optimal procurement strategies, stocking, and supply to achieve high-level serviceability for spare parts. (Stoll et al., 2015) Rapid development in utilising information technology and the use of enterprise resource planning has offered companies the ability to discriminate the spare parts. However, it is challenging and economically impossible to apply a distinct control pattern to each of the spare parts in practice. (Sarmah & Moharana, 2015) Also, Huiskonen (2001) endorsed this idea by arguing that efficient computers are able to make distinct modelling possible. However, managers still need to allocate resources, choose the control parameters, make procurement decisions and decide different materials’ policies. The author argued that item classification is as essential as ever. Other authors like Teixeira et al. (2017) agreed to this by saying that spare parts classification is vital to managing the inventory management processes in their entirety, and multiple benefits may be achieved via appropriate classification. Cavalieri et al. (2008) highlighted that it is crucial to execute the categorisation of spare parts that are used in an industrial plant because a plant has multiple different equipments that have different criticality. There is a wide range of technical materials which are used for maintenance or repair tasks. Also, equipment’s relevant economic and technological features such as criticality, specificity, type of supplier, value, and so on may be significantly different. Syntetos et al. (2008) pointed out in their research that focuses on spare parts management in Europe that via appropriate item classification and choosing proper policies to manage the inventories, the case company could reduce inventory levels and costs and increase the service level concurrently.

Classification methods can be categorised into quantitative methods and qualitative methods. Quantitative methods are often based on Pareto principles; they vary from single-dimensional methods to multi-dimensional methods where more factors are utilised. (Cavalier et al., 2008) Qualitative methods aim to evaluate the importance of stocking the spare parts in the warehouse based on information factors such as cost, downtime, and the equipment type of spare parts. One of the most widely adopted approaches for the items' classification is ABC analysis (Sarmah & Moharana, 2015). The critic towards ABC analysis has also led to the utilisation of other drivers than demand-based. According to the author, some of those criteria are lead time, reliability, criticality or obsolescence. (Mehdizadeh, 2020)

2.2.1 Quantitative methods

ABC analysis is single-dimensional, and categorisation is often based on annual usage value criteria (Syntetos & Keyes 2008). It is essential to use annual usage value instead of unit price because of different measure units, e.g., dollar per meter and dollar per kilogram (Guvenir & Erel, 1998). According to Huiskonen (2001), ABC analysis is undoubtedly easy to use. It fits well with the homogenous materials and that primarily diverge each other by demand volume and price. ABC analysis has gained criticism in spare part categorisation since it does not take into account essential dimensions of spare parts like criticality, lead-time, obsolescence, costs related to inventory, repairability, etc. (Sarmah & Moharana, 2015; Huiskonen, 2001; Guvenier & Erel 1998) According to Syntetos & Keyes (2008) ABC analysis can be modified to include more classes, by dividing the ranked stock keeping units (SKU's) into multiple product groups. Even though ABC analysis's successful adaptation requires that a spare part structure can be discriminated against based on one criterion. (Molenaers et al., 2011) Haverila et al. (2009) suggested that based on ABC analysis, items in A class should be purchases with great attention because the value of those items is high. For the Items in categories B and C, purchasing control could be coarser. A variety of methods has expanded traditional in relevant literature ABC analysis, and in the following paragraph, we will concentrate on those.

The XYZ analysis discriminates items based on their variations in consumption. Variations in consumption are the ratio of an item's standard deviation over a specific period and the average consumption. (Scholz-Reiter et al., 2011) Class X includes items with steady demand, class Y includes intermediate demand items, and last class Z holds items with sporadic demand (Reese & Geisel, 1997). Because of ABC analysis extensive implementation spectrum, analysis is generally used as a first approach and endorsed with the XYZ analysis. The combination provides three by three matrix for decision making (Reese & Geisel, 1997). One of these analyses' primary benefits is that spare parts can be categorised based on comparable characteristics and utilise the same material planning parameters for them. Because demand over time is an important factor, it is essential to perform item classification in periodic intervals. (Scholz-Reiter et al., 2011) Jin & Zhiguo (2013) created an inventory control strategy based on ABC-XYZ analysis, where they identified three different categories for an item. In the first category, including AX, BX, CX, and CY items, inventory control should be fully automated. The second category comprises AY, BY, and CZ and the author recommended half-automatic control for items. The last category includes AZ and BZ, and they recommended manual control of inventory. Other authors have also expanded the original ABC analysis by a wide range of methods. The following methods have not got publicity as much as the previously mentioned analysis, but according to the authors, theories have promising results. Chu et al. (2005) created an inventory control system called ABC-fuzzy classification, which can use both nominal or non-nominal attributes, authors argued that it is relatively easy to implement.

2.2.2 Qualitative methods / Multi-dimensional models

The VED classification method is a commonly known qualitative model where spare parts are classified as Vital, Essential, and Desirable. Different kinds of logic are used to categorise a spare part during VED analysis, e.g. if stock out of an item causes a run down and there is no backup equipment, then the spare part can be classified as Vital. Essential spare parts belong to equipment in which interruption of their function causes a significant loss of production, it does not lead to stopping the entire production process. If the part does not impact the safety or process, then it can be categorised as desired. (Cavalieri et al., 2008; Bosnjakovic, 2010) Compared to ABC or XYZ analysis, in VED model the spare part’s criticality is described by multiple criteria. VED analysis can include fewer categories than three, in Botter & Fortuin’s (2000) article, authors used just two categories, Essential or Desirable, to determinate the functional criticality of a part. Authors categorised parts based on does the breakdown of the part causes a shutdown of the whole system. Based on that, the authors categorised parts as cosmetic (D) and functional (V+E). The authors also argued that it is convenient to limit the number of classes for the spare part inventories that stock a large number of spare parts. This idea is approved by Dekker et al. (1997), which used to item criticality or non-criticality as criteria when classifying demand for spare parts. VED classification has been criticised since its conclusions might be affected by subjective consideration of the decision makers, but it is a rather simple analysis method. (Cavalieri et al., 2008) There can be parts used in machines or equipment with different criticality, which can cause problems to determine suitable service levels or stock levels. Dekker and Bayindir (2018) suggested that so-called protection levels should be defined for this kind of spare parts. In practice, this means that if the stock levels decrease under the re-order point, during the lead time, the stock is blocked from auxiliary equipment, and only demand from critical equipment would be achieved. Authors argued that simultaneously suitable service levels for the critical classes can be met and stock levels can be reduced.

Analytic, Hierarchic Process (AHP) use multiple criteria for decision making, and it was identified by Saaty between 1971-1975. The model's foundation is that decision-making is based on the idea that the problem has three levels. The first level is the target, and the second level characterises the target and different options for the decision are at the third level. (Saaty, 1987) AHP is one of the most used multi-criteria decision-making techniques in various fields, especially in operational management (Teixeira et al., 2017). The approach attracts researchers because input data is relatively easy to acquire. With AHP analysis, managers are able to break up the complex decision into a set of simple comparisons. It also makes it easier to understand results by showing the most suitable solution and the clear reasons for the decision via pairwise comparison. (Bevilacqua & Braglia, 2000) According to Bevilacqua & Braglia (2000), AHP is suitable for complicated problems that require both quantitative and qualitative criteria to be taken care of. Due to that, it is a flexible and powerful multi-criteria decision-making approach. According to Guvier & Erel (1998) approach has some difficulties, which might cause significant challenges in practice. The authors mentioned problems related to the subjectivity involved in pairwise comparisons, different members in decision-making might assess different comparison matrices due to a wide range of different reasons. The authors argued that it is also challenging to compare two different criteria and asses a quantitative value for it.

According to Gajpal et al. (1994), the VED classification method can be combined with the AHP to limit problems related to subjective judgments. The authors created a VED-AHP analysis that identifies three drivers: type of spare required, procurement lead time, and availability of the production facility, impacting the criticality of spare parts. The spare part's criticality is accomplished via a pair-wise comparison where a team of user utilize three factors in decision making. Stoll et al. (2015) argued that the most significant benefit of VED-AHP classification is that multiple qualitative and quantitative criteria could be used to identify the spare part's criticality. The authors also argued that the model could be modified by implementing different weightings and criteria' hierarchization. With those modifications, the AHP model might provide more realistic information for the decision-making process. In Moleranaers et al. (2012) case study VED-AHP based classification methods provided promising results in an industrial environment. The classification method assisted the case company to recognize the critical items stocked within a warehouse. The tool provided essential data for both maintenance and assets managers. According to Botter & Fortuin (2000), even VED-AHP analysis is the best solution for a logistic problem. It can be found too theoretical from the management point of view. Also, some crucial factors for an individual spare part can be part of multiple groups, e.g. response time, which makes classes management harder. In a case, study the authors decided to use the original VED model, with some modifications. According to Stol et al. (2015), VED-AHP analysis has problems in terms of sequential changes and other disadvantages because regresses during the development require a lot of modification effort, and those are often only partially possible. However, the authors emphasized that the utilization of AHP makes possible to automate the analysis process for each criterion, which is a considerable advantage because of the complicated structure of spare parts in the production environment.

Botter & Fortuin (2000) used a two-dimensional classification approach that combined VED analysis and FSN analysis, which evaluates inventory turnover based on categories “Fast-moving”, “Slow-moving”, and “No Moving” items. They used Parento principles to categorise items based on demand. According to Devarajan & Jayamohan (2015), FSN model is premised on the turnover ratio of the stock. Turnover ratio is specified as “the ratio of the annual consumption of a material divided by its average inventory”. According to the Botter & Fortuin, the frequency of demand plays a significant role in selecting the inventory model. Combining these two approaches and using three criteria: price, lead time, and usage Botter and Fortuin (2000) created a framework to identify eight different stocking strategies. With the framework the desired service level and significant inventory cost reductions were achieved. In 2010 Bosnjakovic created an inventory management approach based on ABC, FSN, and

VED analysis. Each spare part can be defined with three criteria: value usage, frequency of demand, and criticality. The model totally included 27 different classification and policies to manage spare parts. Also, Stoll et al. (2015) used in their research multi-criteria classification method to identify suitable spare parts for a central warehouse stocking in the car industry. The approach included separate parts, and firstly authors utilised two-dimensional analysis to determine the predictability and value of spare parts with ABC and XYZ analysis. In the second step, VED analysis was used to identify item criticality based on six feasible criteria to classify spare parts.

3. Automatic identification

Automatic Identification and Data Capture (AIDC) is a growing technology that is utilised to identify objects, capture and store the data directly to the information systems. Some AIDC technologies, such as RFID, can do the whole process without any human intervention. (Parthiban, 2019) AIDC technology has a wide variety of different technologies, but RFID and barcodes are most widely adopted. RFID has multiple benefits compared to other AIDC technologies such as barcodes, especially when scrutinising collection, transmitting, and utilising data. RFID does not need a direct line of sight, and it can detect up to hundreds tags simultaneously. The most important feature is that it can track and identify individual items. (Liukkonen, 2015) Figure 4 presents a different fields which RFID technology can be implemented based on Liukkonen’s comprehensive literature review published in 2015.

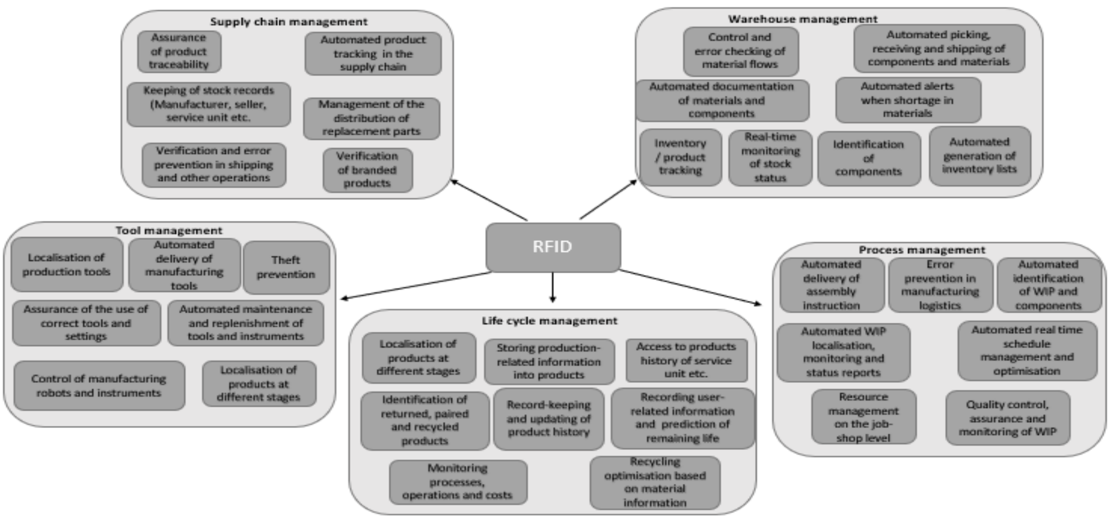

Figure 4 Where RFID can be applied based on Liukkonen (2015)

3.1 RFID or barcode?

Conceptually barcode and RFID systems are quite similar, and both are designed to provide fast and trustworthy technology in item identification and product tracking. However, these two technologies have some differences especially in reading and writing capabilities. (Sardroud, 2012) Nowadays, there are two main barcode technologies: one-dimensional barcode (1D) and two-dimensional barcode (2D). Quick Response (QR) code is the most well-known example of a two-dimensional barcode. According to Khandokar et al. (2010), there is also a 3D barcode, which adds the height dimension to the barcode and allows more storage capacity. In his research, radio waves were utilized to read barcode technology is not widely proved. One-dimensional barcodes consist pattern of parallel lines and spaces to form 10 digits. (Fan et al. 2019, 450) A two-dimensional barcode is able to store also alphabetical data by arranging dots and spaces to a matrix or array. The first group is called a stacked 2D barcode, e.g. Code 49 and PDF417, and another group is matrix 2D barcodes such as Data matrix and QR code. Compared to traditional barcode 2D barcode has a significantly larger capacity to store information. (Gao et al. 2007) Gao et al. also argued that QR code is superior compared to other 2D barcode technologies since it has a large capacity with high speed of scan in small print space. 2d barcode is generally used in industrial products such as components or raw materials, which require storing more data regarding the product. (Khandor et al., 2010)

In the RFID system, data is stored to tags and received with readers who are communicating with each other via radio frequency waves (Moselhl & Omari, 2002,). RFID technology has three main components, RFID tag, antenna, and receiver. The RFID tag has three sub-categories such as passive, semi-passive and active and suitable tag type is selected depending on the application and scenario. (Abrishambaf et al., 2014) However, without appropriate software to collect and analyse the data, RFID system will lose its potential. RFID infrastructure has been presented in following chapter. Both technologies, barcode and RFID, are used to identify items based on identification number and items are scanned with mobile reader, and data is transferred via middleware to the host computer for further processing. (Mirshahl & Akbari, 2015) As RFID becomes ever more popular in automatic identification, decision-makers might wonder how it measures up to a traditional barcode. Compared to a barcode, RFID is able to identify items as an individual, whereas a barcode can only recognise items on item level. (White et al., 2007) Lee et al. (2004) argued that by applying RFID tags on the item level, the case company improved inventory accuracy, especially from shrinkage and stock loss due to item identification on an individual level. The authors also founded that via RFID implementation, the visibility of the entire supply chain will improve, and it will benefit every party within the supply chain.

Compared to other traceability devices, another benefit of RFID is the ability to endure rough environmental conditions. RFID tags are robust, tags are not vulnerable to hot or cold weather, but radio waves cannot penetrate materials such as metals and liquids. (Attaran, 2012; Mirshahl & Akbari, 2015; Sardroud, 2012) Fu et al. (2012) argued that tags' endurance is a significant factor in selecting RFID tags over barcodes. Because most metals are good conductors, an incident wave will reflect almost completely from a surrounding metal, and it will recreate the antenna's radiation pattern. In cases when metal is near the tag's antenna, antenna resonance frequency and impedance and efficiency might change. (Raumonen et al., 2003) Ukkonen et al. (2005) also argued that electromagnetic waves emitted by the antenna are reflected from conductive materials and hence changes antenna's radiation directions and patterns. According to White et al. (2004) and Khandokar et al. (2010), barcodes dominate RFID in some industries because those are not affected by substrate materials. Conversely, in some cases, the RFID antennas' directivity can be boosted by using a metallic surface as a reflector (Zannas et al., 2019). According to Ukkonen et al. (2005), by using tag's antenna types that necessitate a ground plate on metal or the antenna design that utilize the metal surface as a reflector, earlier mentioned problems can be solved. This problem related to metal concern only passive and semi-passive UHF and UF RFID tags. It can be solved in various ways, and previously active tags and passive LF tags were a suitable solution. Nevertheless, a few researchers, e.g., Ukkonen et al. (2005); Ciudad et al. (2010); Zannas et al. (2019) have put a lot of effort to research opportunities to solve that problem and nowadays, there are available multiple UHF RFID tags that work well on a metal surface.

Barcodes are included in most of the product, past decades it has been the standard for identifying and tracking products. Companies are able to utilize those barcodes in inventory management with low expenses. (White et al., 2007) The cost of an individual barcode is relatively cheap, and it is one of the main reasons why it is adapted so widely. However, it still requires the same kind of infrastructure as RFID (Khandokar et al., 2010). The downside of barcode for both 1D or 2D is that once the barcode is printed, data cannot be changed, and even for 2D barcode, the data storing capacity is undoubtedly low. According to Sardroud (2012), RFID tag's read and write capability is a significant advantage in maintenance tracking. One of the main disadvantages of a barcode is that the reader requires line of sight, and it is time-consuming, requires a lot of labour, and exposes human errors. RFID receiver can read multiple tags simultaneously up to 10 meters away and allows real-time monitoring. (Mirshahl & Akbari, 2015) According to White et al. (2007), tolerance to user errors indicates that RFID might be a more straightforward technology to implement from an employee training point of view. The author argued that this might increase its attractiveness and cost-effectiveness if training costs are taken into account in implementation costs.

Table 1 RFID compared to barcode

Advantages of barcode	**Advantages of RFID**
Barcode is less expensive than RFID tags, but it still requires a similar infrastructure.	Information can be read from the tag up to 10 meters.
Works with the same accuracy on various material	Fast read rate and up to 40 tags can be read simultaneously.
Universal technology with well-known barcode standards	Tags have read and write ability, and they are reusable. RFID can also identify specific item versus barcode can only identify the item level.
Almost every item include barcode.	Tags have extensive data storing capacity, and wide range capabilities can be programmed to the tag.
Disadvantages of barcode	**RFID disadvantages**
Direct line of sight required.	RFID readers struggle to connect regular tag through metal or liquid.
Read range maximum of a half meter.	Lack of standards.
Read-only capability.	The cost of tags are higher than barcodes.
Not so durable as RFID, and if the barcode is ripped, barcode scanning is not possible	

Although RFID has a desirable technical capacity, as mentioned before, it has gained some critic related to issues on performance and price. (Kim & Huh, 2018) Some authors (Kim & Huh, 2018; White et al., 2007; Khandokar et al., 2010;) have proposed that a hybrid model for automatic identification that is based on both RFID and barcode would solve those problems. According to Herrojo et al. (2019), traditional RFID tags equipped with chips are too expensive for applications involving low-cost items. However, the hybrid model used to be proposed when tag prices were significantly higher, and problems related to tag on metal were not solved yet. According to Ngai et al. (2007b), the cost of tags is one of the highest cost of RDIF implementation. Therefore, ROI can be improved significantly if tags are reusable. Also, Sarac et al. (2010) argued that the cost of individual tag is not that important in a closed-loop system such as repairable spare parts since tag can be used many times. Also, the tag’s data storage capability could be used to improve maintenance processes, especially regarding storing information related to maintenance need or what has been done in maintenance. According to Piramuthu et al. (2013), the company cannot afford to deal with a scenario where only part of the inventory is item-level RFID tagged. The authors argued that maintaining two different infrastructure simultaneously causes synergy losses and decreases overall benefits due to incomplete item-level visibility and lack of inventory management automation. The authors also suggested that RFID tag is suitable solution also for the items that cost less than an RFID tag. Most of the research proposed a hybrid model concerning the retailing industry.

3.2 RFID infrastructure

Radio frequency identification (RFID) technology have three main components, RFID tags, RFID readers and middleware system which is communicating between reader and other information systems. RFID tag often composes two individual components, a chip that collects the data and the antenna, which is used to receive and transmit data in real-time via radiofrequency. (Zhu et al., 2012) RFID infrastructure is represented in figure 5. Environmental restrictions need to be concerned carefully when choosing RFID technology, to gain all the benefits of RFID technology has offer. By carefully analysing the environment and defining objects, strengths, opportunities, weaknesses, and constraints, the company can identify right type of readers, tags and etc and them implement the most efficient technology. (Sarac et al., 2010)The purpose of this paragraph is providing information related to that.

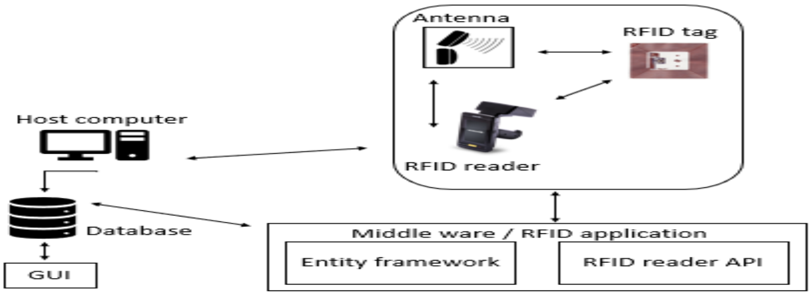

Figure 5 RFID infrastructure based on Alyahya et al. 2016

The used frequency of a RFID system directly impacts the system's reading range and, consequently, the target application. Four different frequency bands are used on RFID systems; low frequency (LF), high frequency (HF), Ultra-high frequency (UHF) and microwave frequency. The pros and cons of each frequency bands are represented at table 2. (Nekoogar & Dowla, 2011)

Table 2 RFID frequency characteristics based on Nekoogar & Dowla (2011)

RFID type	Frequency	Read distance	Advantages	Disadvantages	General applications
Low frequency	125-134 KHz, tag use inductive coupling (NFC) for communication with the reader	~ 0.5m	Works well around conductive materials. Less external interference (Lower frequency bands are not crowded)	Large tag size. Low data and read rate -> limited capability to read multiple tags simultaneously.	Security access and personal ID tracking
High frequency	13.56 MHz, tag use inductive coupling (NFC) for communication with the reader	~ 1m	Medium data rate, HF tags are relative cheap.	Short reading range	Short range item tracking such as library inventory control
Ultra-high frequency	868-928MHz, frequency varies by country. **USA** 902-928MHz, **Japan**, 950-956 MHz, **Australia** 918-926MHz and **Europa** 865-867. Use of back-scattering technique to tag-reader communication.	Passive tags have typically reading range of 3 meters to 10 meters and active tags can have reading range of hundreds of meters.	High diversity of tag sizes and shapes. Global manufacturing standard ISO 18000-6C. Can be used to read multiple tag simultaneously.	Actual frequency varies by country, might cause problem with international supply chains. Typically, tags does not operate well with items that contains water or metal. However suitable tag types are on the market	Supply chain, inventory management and asset management
Microwave frequency	2.4-5.8 GHz	+ 30 meters	Longest range	Highest costs typically used with active tags. Vulnerable to external signals.	Warehouse palette control

3.2.1 Tags

The purpose of this paragraph is providing information on which situations and applications each of these tags types should be applied, and the pros and cons of each tag. There can be various ways to classify RFID tags in related literature, which are not exclusive rather complementary to each other. Max Muller (2011) and Narayanan et al. (2005) argued that RFID tags have five basic classes based on the tag's write and read capabilities and communication type. Tag types in RFID networks can also be categorised based on a power source, and the three main groups are passive RFID, semi-passive RFID, which is a hybrid model and is the newest tag type on the market and active RFID tag. (Want, 2006; Zhu et al., 2012; Forouzandeh & Karmakar 2015). The first group is a near field, which utilises direct magnetic induction to transfer the Nekoogar & Dowlar (2011) argued that RFID tags are generally categorised based on the electromagnetic wave that is utilised to transfer the signal signal. First group is near-fied and the second group is a far-field, which uses captured energy release from electromagnetic wave. Both techniques have a similar communication protocol, and both of them utilises the radio frequency's electromagnetic field to transfer information between the tag and receiver. Near field, RFID applications are usually utilised to track tags in environments where metals or liquids surround the tag**.** In this research, we use power source-based classification, which seems to be the most used way also in other research (Ahuja & Potti, 2010).

Passive RFID tags generally contain two parts: an antenna and an integrated circuit called a chip containing a memory store and processor for decision-making. All tag types also include some encapsulation to protect the tag from the harsh environment. (Ahuja & Potti, 2010) These tags receive power via inductive coupling when the RFID reader reads them. Passive tags are read when needed, the lifespan of the tag is long, which makes it an optimal choice for items that are stored for a long time. Additionally, these tags are a cost-effective option compared to active tags. (Miller, 2019) Passive tags have three sub-categories based on the radio frequency range they use: low frequency (LF), high frequency (HF) or ultra-high frequency (UHF). UHF tag's range is often between 4.5 meters and 9 meters, and the speed of transmission is highest. HF tags are more suitable for metal items, but the range is around one meter. The LF tags can penetrate non-metal items better, but the reading range is around 30 centimetres. (Zhu et al., 2012) Nowadays, there are available multiple UHF RFID tags that work well on metal surfaces, and UHF tags are supplanting other frequency types on metal surfaces due to their long-read range (Ciudad et al., 2010; Zannas et al., 2019). Since the cost of a regular RFID tag is chiefly associated with the chip. The implementation of two-dimensional encoders that can replace the chip has been under intensive research in the last years. This solution is called chipless-RFID, which is a passive tag as well. However, the chipless-RFID tag is still in the development stage, and it is not widely implemented, but it fits exceptionally well to low-cost items where the price of the tag might be higher than the product itself. (Herrojo et al., 2019)

Semi-passive, also known as a battery-assisted passive tag, is suchlike to a passive tag. It also uses the backscattering technique to respond to the reader. (Che et al., 2010) However, it has a battery to power the chip, enabling the use of integrated electronic components like temperature sensors for environmental monitoring. (Miller, 2019) According to Che et al. (2019), a semi-passive tag can utilise a battery to improve uplink communication strength and is less reliant on receiving power strength, which improves read range and improves the tag’s reading rate with smaller costs than an active tag. Naraynan et al. (2005) argued that the reading range for a semi-passive tag is up to 100 meters but is limited usually because it still requires to use of the reader’s signal to communicate back to the reader. Semi-passive tags are commonly used in applications such as cold chain logistics and medicament quality control (Che et al., 2010). A semi-passive RFID tag can be used for indoor localisation of the products, such as within the warehouse instead of active tags combined with Wifi-technology, by combining passive tags’ known location, semi-passive tags can detect signals from other tags as well as reader. (Athalye et al., 2013)

The difference between Active and semi-passive RFID tag is that the active tag has an onboard transmitter whose purpose is to send energy directly to the reader rather than using backscattering technique to communication. (Narayanan et al., 2005) Due to the onboard transmitter, active tags have the widest range of operation. The increased size also enables more data storing capacity and more logic functions with integrated sensors. Consequently, the extra features cost of an individual tag is the highest, and it has a shorter lifespan. Businesses with high-value assets that requires real-time asset tracking and (or) environmental monitoring, an active tag is the best solution. (Miller, 2019; Want, 2006) The type of tag an organisation wants to use depends on how and why they are using RFID and environmental restrictions. In table 3 is represented a comparison of different tag types.

Table 3 RFID tag type comparison

Class	Programing cababilities	Tag type	Advantage	Disadvantages	Applications
0	Read-only tags	Passive	Low cost options for items, which does not require any additional information	Can store only ID number	Often used by manufacturers to identify items
1	Write once read multiple times	Passive	Users can add additional data to the tag. Can be printed for example within warehouse	Once data is written it cannot be change	Low-cost solution for inventory management for basic or low-cost items
2	Read write	Passive	Reprogramming enables reuse of tags, which lowers the costs and data can be updated	Surrounding material might affect use of general tag -> Products that works with metal and liquids are on the market. Highest cost of passive tags -> chipless RFID might solve this in the future	Inventory management, maintenance,
3	Read write with on-board sensor	Semi-passive	Battery can be used to improve the reading range of tag or log additional data like temperature. Cheaper solution than active	Limited life span	Cold chain logistics, medicament quality control and indoor localisation of products within warehouse
4	Read write with integrated transmitters	Active	Long reading range, which is not affected surrounding materials. High data storing capacity with logic functions.	Need of maintenance due to short lifespan, high cost of tag, physical size of tag	High value assets, with need of real time tracking and (or) environment monitoring.

3.2.2 RFID readers

An RFID reader is a major part of the RFID system, and it is used to read stored data at tag through the RFID antennas at a specific frequency as well as rewrite data to the tag. (Ahsan & Kingston, 2010) There two major classes of RFID readers fixed readers and mobile readers. Fixed readers generally have up to eight-port for additional antennas. Fixed readers are the RFID industry's backbone because they can offer high reading capacity and sensitivity to fixed applications like a port reader. The subset of fixed readers are integrated readers, which also include an integrated antenna within the reader. Mobile readers have the same functional capabilities than fixed readers, but it also has an integrated antenna. Mobile readers do not generally include additional ports, but they have a wide range of other features, e.g. onboard processing capabilities. (Smiley, 2014) It is also important to mention that mobile phones can be used as an RFID reader when it has NFC capability, and it is quite user-friendly for small jobs. Reader translates the tag's radio signal to the digital form that can be passed through middleware to the host computer. (Muller, 2010)

Readers have integrated anti-collision schemes to avoid problems related to reading multiple tags simultaneously. Reader to tag communication techniques have three main options: Listen-before-talk (LBT), frequency-hopping spread-spectrum (FHSS) or European telecommunications standards institute (ETSI)-302 208 standard and communication methods and used frequency spectrum are different for different regions (Parthiba, 2019) Additionally, each continent and some cases also countries have their own frequency allocation for RFID, for example, RFID UHF bands are 950-956 MHz in Japan and some other Asian countries, 866-869 MHz in Europe and 902-928 in South and North America. (Rao et al., 2005) Readers are electronic devices that can be used as a stand-alone solution or integrated with other devices. (Ahsan & Kingston, 2010)

Figure 6 Different types of RFID readers, from the left fixed reader, mobile reader and table reader.

3.2.3 Reader's antennas

The role of the reader's antenna is high-lighted in systems that work on UHF because LF and HF RFID systems use an inductor coil to create near-zone RF fields for transmission and reception, and UFH systems utilize antenna in back-scattering technique. Antenna's characteristics like bandwidth, polarization, voltage, standing wave ratio, gain, beamwidth, and front-to-back ratio, are crucial and directly affect the tag detection performance. (Parthiban, 2019) Antenna design and placement have been detected to be an important factor to increase basic tag identification probability. (Ukkonen et al., 2005)

Since RFID antennas radiate and receive radio frequency wave, polarization significantly affects the reading accuracy and reading range, and two main classifications are linear polarization and circular polarization. Linear polarization appears when electromagnetic waves broadcast either horizontal or vertical plane. With linear polarized antennas RFID tag orientation need to be known and tag must place on the same level as the antenna. Linear polarized antennas generally have longer reading range than circular polarized antennas with same gain and it is suitable solution for reading tags e.g. from conveyor. Circularly polarized antennas broadcast electromagnetic waves in a circular motion, either counterclockwise or clockwise. It is an appropriate antenna type where the tag's location and orientation cannot be predicted, such as inventory management. (Smiley, 2014)

During a practical UHF RFID system implementation project, usually, there is not paid enough attention to the reader antennas compared to other system components like tags, software, and readers. According to Rao et al. (2005), several tag's requirements greatly influence the criteria for selecting a RFID antenna, and those criteria are represented in figure 7. Reader's antenna selection criteria are much more application-specific than just picking an antenna based on tags capabilities because each application will have unique physical, electrical, environmental, and radio-frequency requirements. Parthiban's article provides a pervasive review of reader antenna design requirements. (Parthiban, 2019) Tag's read range needs to be critically observed during the antenna design process since its characteristics, such as size and used frequencies, affect maximum accessible gain and bandwidth. (Rao et al., 2005)

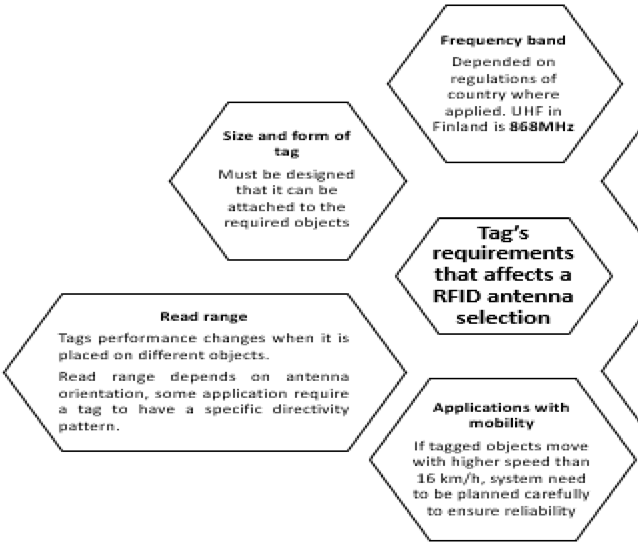

Figure 7 RFID tag's requirements that affect a selection of RFID antenna based on Rao et al. (2005)

A tuneable antenna design is better to provide tolerance for different kinds of tags and optimise antennas' performance on tags located on various materials in different frequencies. (Rao et al., 2005) For inventory management, it might be useful to start testing with an antenna that includes the following characteristics: High gain, circular polarization, mid-range directional beamwidth, high dust, water, and impact resistance (Parthiban, 2019).

3.3 RFID inventory management

According to Chao et al. (2007), RFID is defined as " a strategic tool redesigning business processes, cutting costs and improving the operational performance. Furthermore, an increasing variety of enterprises are employing RFID to strengthen their managers' ability to enhance organizational change and manage growth in an increasingly competitive environment". The benefits of RFID have been well comprehended in the field of retail, logistics, manufacturing, services, healthcare, pharmaceuticals, and the military (Ngai et al., 2008). Since each of industries might have diverted aims in the technological advantages (Lim et al., 2013), and because the return on investment (ROI) in the case of RFID implementation is not a straightforward calculation (Attaran, 2012). Investments related to RFID technology are significant, an optimal adoption decision must quantify achievable benefits and balance them against the cost (Heese, 2007). The purpose of this paragraph is to offer insight into how RFID adds value and improve the business processes, particularly in the context of inventory management which has been a rising research topic in the 2010s.

RFID implementations have various different benefits depending on the industry. The following benefits have been founded in various research (Lim et al., 2013; Ngai et al., 2008; Lee & Özer, 2007);

- Improved stock visibility and traceability within the supply chain.
- Each of the tagged items can be uniquely identified, and in some cases status of items can be monitored without any manual work.
- Increased accuracy of the data and possibilities achieved through utilization of data such as improved processes and data sharing within the supply chain.
- Improved warehousing processes such as automation of receiving, improved inventory counting and scanning, reduced shrinkage and stock-outs.

In Lim et al. (2013) literature review, which focused on the research between 1995 to 2010 related to RFID in the warehouse applications, authors provided a list of the top benefits for RFID implementation. Authors pointed out that in implementation focused articles, benefits were reduced labour (50%), data inaccuracy reduction (50%), lower total costs (58%) and resource management (50%), while on conceptual articles, benefits were product tracking (52%), resource management (40%), reduced labour (19%) and material handling (17%). The differences between research with implementation focus and conceptual research might be explained by costs associated with RFID infrastructure, which is required for real-time product tracking (Ustundag, 2011) and the fact that RFID implementation will provide cost savings immediately via reduced labour (Attaran, 2012). According to Lim et al. (2013), each item's unique identification has a significant role in achieving the benefits completely. Applying RFID in a case or pallet-level significant part of benefits may be diminished.

Lee & Özer (2007) have identified that among all the benefits that RFID has, three of them are quantifiable, inventory level reduction, cost savings from manual labour and shrinkage and stockout reduction. Ustundag (2011) endorsed the above idea and argued that four factors, efficiency, data accuracy and item visibility, need to be taken into account when measuring the benefits of an RFID investment. Since those are also the major cost drivers of inventory management, according to Shenoy & Rosas (2018) and Haveri et al. (2009), and stockouts might have a significant impact on spare part inventory management (Huiskonen, 2001; Trimp et al., 2003). And because according to Attaran (2012), well-specified business needs, or advantages, and measurable business benefits are some of the most critical implementation success factors. Those are the reasons why we will examine those topics mentioned above more closely in the following chapters.

3.3.1 Labour cost saving benefits

The labour cost reduction is generally mentioned to be one of the most important benefits of RFID implementation in studies related to warehouse or distribution centre. Manual labour reductions are possible because UHF RFID tags can be read autonomously without human labour or without much human intervention, which is impossible with other AIDC technology such as QR codes. (Soon & Gutierrez, 2008; Chanchaichujit et al., 2020) Lee & Özer (2007) endorsed this idea and argued that since a direct line of sight is not required, and up to a hundred tags can be read simultaneously, efficiency savings such as labour cost savings in receiving processes and inventory audits can be huge. According to Ustundag (2011) and Veronneau & Roy (2008), labour cost reductions are a consequence of increased process efficiency. Lee & Özer (2007) reported that labour cost savings potential with RFID from operations such as receiving, picking, and inventory audits in retailing could rise as high as 30 percent.

When the shipment from a supplier arrives in the warehouse, the content must be inspected visually or from a barcode to make sure that the pallet or individual item matches the prearranged purchase order. When the supplier labels items with a RFID tag, the shipment content can be verified instantly, and goods of receipt can be made automatically if fixed port readers are implemented. (Curtin et al., 2007) One primary founding in Veronneau & Roy's (2009) article that covered RFID deployment in a cruise corporation's global supply chain was that RFID implementation decrease amount of indirect labour, which is necessary to perform routine tasks such as system update entries and inventory control. According to Ustundag (2011), RFID technology assists in automating and reorganising the organisation's logistic processes, which leads to labour cost reductions. The five main warehouse logistic processes: receiving, put away, inventory counting, picking and shipping are affected by RFID technology. A number of manual operations can be decreased via implementing entry gates with RFID readers and antennas to implement a bulk reading ability, and product data might be automatically transferred to the company's information system. RFID can speed up and improve the reliability of operational processes like receiving, tracking, checkout, shipping and counting processes, which lead to cost reductions but also enhance the inventory accuracy and data flows related it (Chow et al., 2006). Soon & Gutierrez (2008) endorsed those ideas and argued that the warehouse operators only have to visually check the content of the delivery for any in-transit damage and transfer items to the assigned storage location.

RFID is known to provide visibility within the supply chain and have potential benefits to improve information accuracy (Sarac et al., 2009), Lee's and Özer's (2007) analytic model confirmed that improved visibility and information accuracy is required to reduce inventory inaccuracy, and it is proved that there is a connection between improved inventory accuracy and higher profitability (Lee & Özer, 2007; Heese, 2007; Hardgrave et al. 2013). Improved inventory accuracy is required to enhance replenishment policies (Sarac et al., 2010; Kang & Gershwin, 2004). In the following paragraphs, we go through how RFID can be used to reduce inventory.

3.3.2 Data accuracy and visibility

Supply chains are becoming furthermore data-driven, and therefore, higher reliability and data quality are essential to achieve and retain a competitive advantage. (Bagchi et al., 2008) Even though big organisation has automated their inventory management processes by utilising information systems such as ERP. However, inventory levels in information systems and physical inventory levels often are not equal. (Atali et al., 2004; Cannella et al., 2016) One of RFID technology's advanced property is a unique identification of items that, combined with automated data entry, enables accurate information especially related to inventory, that has not been easily accessible earlier (Sarac et al., 2010). According to Delen et al.'s (2007) case study, RFID can be used to enhance the performance of processes between a warehouse and production, also known as the micro supply chain level. RFID technology also enables items sub-categorisation based on non-critical differences, such as the age of the product, and better inventory management can be achieved (Zhou & Piramuthu, 2015). Ngai et al. (2007b) presented a case study of traceability systems that utilised RFID for supporting tracking and tracing repairable items, which aimed to enhance the maintenance operations and reduce the maintenance life cycle. A case study proposed that human errors in the handling of repairable items can be reduced. Pallet-level tagging improves visibility mainly at the receiving process, but it is unlikely to add any visibility to warehouse movements of goods or reduce inventory inaccuracy (Hardgrave et al., 2013). In Delen et al. (2007) article, the authors also argued that RFID could be used to eliminate the delay in information sharing between supply chain partners. It has to be mentioned that improved accuracy in storing and picking processes requires a bigger investment than implementing RFID in the receiving process. It requires investment in RFID equipped pallet and shelving positions and other infrastructure-related investments such as material handling equipment.

RFID technology can eliminate most of the errors but not all (Atali et al., 2006), especially in inventory management, the operating environments, product and packing materials, business processes and item orientation highly impacts the capabilities of RFID system (Ukkonen et al., 2005). Due to that, performance has been often mentioned as one of the obstacles to the widespread implementation of RFID technology. (Wu et al., 2006) It is also essential to convince top-level management and employees at the beginning of the implementation that it is difficult to achieve a 100 percent reading rate at the item level. (Ngai et al., 2007b) In a relative literature major part of research assume that the accuracy of data read from RFID tags is high, but read rate errors might happen due to various reasons. According to Jeffery et al. (2006), around 30 percent of RFID tag reads are inaccurate, Kapoor et al. (2009) argued that accuracy ranges of 60-99 percent are not uncommon. The reason for those read errors might arise from different sources: materials which radio waves cannot penetrate, for example, metal or fluids between the receiver and tag, antenna and chip defects, inconsistencies between different readers, reader, or tag collision and so on. According to Lim et al. (2013), RFID technology's reading inaccuracy affects inventory management operations such as receiving, picking and despatching, because items need to be identified with high confidence to avoid discrepancies. Ngai et al. (2007b) achieved a well-working RFID system in spare parts environment with correct tag type selection, repeatable testing of angle adjustments in operations and with developing of a workflow. In the past decade, numbers of problems related to RFID unreliability have been solved, such as tags that work on metal, world-wide standards and so on. Goebel & Gunther (2011) argued that recent item-level RFID pilots indicate that reading inaccuracy and other issues related to that does not represent a major problem anymore. Mostly because of the recent development in reader protocols and transponder design. However, RFID pilots are really important before full implementations.

According to Ngai et al. (2012), RFID technology has great potential in aircraft maintenance, especially in spare part inventory management, which has a large-scale requirement regarding quality, documentation and safety, and high cost for having unplanned maintenance. The authors argued that even technology solutions are considered essential tools in improving effectiveness and efficiency, there is still a number of challenges to solve. RFID technology has to be integrated with databases and legacy systems, and there has to be an interface for current and potential suppliers and business units within a company. Whitetaker et al. (2007) founded out that an suitable information technology structure is a precondition for successful RFID implementation. They argued that most of the benefits of RFID come from the utilisation of stored data. Rim & Park (2008) argued that one of the challenges related to RFID adoption is the challenges of integrating RFID middleware with other company's information systems such as ERP. This problem is also concerning with storing and efficiently handling the significant amount of data that the RFID system generates. Also, Kapoor et al. (2009) argued that RFID tags are well-known for constituting enormous amounts of data compared to one-dimensional bar codes. The main reason for enormous growth in the volume of data is that RFID tags merge item-level information with greater details, and tags are scanned more frequently than bar codes. The author argued that the RFID system could generate data quantity that is ten up to a hundred times bigger than the bar code system. Due to that, RFID processes might not scale up smoothly on existing back-end systems which might be operating at close to their limits. (Kapoor et al., 2009) Yang & Zou (2005) suggested that event-driven RFID reader management would be a suitable solution to prevent problems related to continuous streaming of data. Data would be sent to legacy systems on an event trigger basis, which means that the reader is only activated when stock movement is detected, and only meaningful data is sent to the legacy systems. The importance of integration was endorsed by Chanchaichujit et al. (2020), who argued that RFID's capability to collect and store a large volume of data within the supply chain and process the information in real-time to data analytics would be one of the major drivers for RFID implementation in the future. However, this is still quite a new topic it was first published by Zhong et al. (2016).

3.3.3 Inventory inaccuracy

That difference between stocked materials also know as physical inventory levels and system inventory record is called inventory inaccuracy, also known as inventory record inaccuracy (Cannella et al., 2016). Inventory inaccuracies might have a major impact on the organisations performance. (Kang & Yun, 2005) Dehoratius & Raman (2008) stated that around 65 percent of the inventory records in retail business were inaccurate, and Kang & Gershwin (2005) reported inaccuracy of 49 percent, and the best performing company had inaccuracy of 25 percentage. In additional, a ten-percentage profit loss is estimated due to inventory inaccuracy (Heese, 2007; Hardgrave et al., 2013). Companies have to carry safety stocks due to a gap between system inventory level and actual inventory level. By using RFID technology, an average inventory level is reduced, and inventory holding costs are decreased. (Ustundag, 2011) However, the cost of stock-outs and inventory inaccuracy cannot be observed directly, and that is the main reason why it is sometimes left out as input for ROI calculations (Goebel & Gunther, 2011). In Hardgrave et al. (2013), practical research results indicated that approximately a 26 percent decrease in inventory inaccuracy achieved due to RFID-enabled visibility and information accuracy. According to Attaran’s (2012) practical research, case company automated data entry with mobile RFID readers within its logistics and warehouse processes and was able to achieve close to 100 percent inventory accuracy and 75 percent reductions in handling times that also enable reductions in cycle times and inventory levels.

At the moment, most of the inventory management systems do not often consider inventory shrinkage, and as a response, costly inventory audits are used for corrective action. (Kok et al., 2007). Xu et al. (2012) compared different strategies to reduce inventory record inaccuracy and found out that technological strategy such as RFID is efficient compared to non-technological approach such as information sharing. To demonstrate RFID technology’s efficiency in reducing inventory record inaccuracy often three primary sources of inventory inaccuracy have considered: misplacement, shrinkage, and transaction errors. Articles indicated that inventory inaccuracy could be reduced efficiently, and discrepancies can be detected in timely manners with RFID. (Atali et al., 2009; Heese, 2007; Kok et al., 2008) Atali et al., (2009) differentiated those sources based on whether they cause permanent inventory shrinkages like damage and theft or does they lead to temporary inaccuracy, which will be corrected by physical inventory audit. They also take into account would error lead to inventory depletion or additional inventory via scanning errors. Dai and Tseng (2012) argued that reasons for inventory inaccuracy are physical loss such as shrinkage, supplier fraud and obsolescence and information loss due to infrequent inventory audits. Zhou & Piramuthu (2015) endorsed Atali et al.'s idea but also highlighted the role of identification shrinkage when an item is unrecognizable, but it still exists on the inventory.

RFID offers accurate information which can be used to align the actual inventory and the recorded inventory in an efficient way. Even if visibility could not reduce the errors, it provides information about the number of errors, and managers can make better decisions based on it. (Dai & Tseng, 2012) Kok et al. (2006) suggested that RFID have a great potential to detect shrinkage and prevent shrinkage, especially thefts. Biswal et al. (2018) argued that RFID could be used to especially reduce inventory shrinkage and misplacement even when the tag price is certainly high. Atali et al. (2006) also suggested that because RFID improves inventory audit process efficiency due to improved visibility and reduced manual labour, inventory audits could be done more frequently to minimize inventory accuracy related to misplacement and thefts. Also, Kök & Shang (2007) argued that inventory audit frequency should be higher for the item with a high value and larger error variance. According to Hardgrave et al. 2013, RFID fits well, especially with high theft rate products. They also argued that RFID technology in the retail sector has a great potential in reducing inventory records inaccuracy in an item that has big monetary sales, greater SKU variety, higher volumes, and greater inventory density. According to Kok et al. (2007), the break-even prices of RFID implementation varied based on two main features: the value of the item and the theft rate. According to Dai & Tseng (2012), via RFID implementation, manufacturers achieved up to 67 percent reduction on shrinkage and 47 percent reduction in a retailer industry. This could be a suitable solution, especially for critical spare parts, to reduce the so-called squirrel stocks and to avoid costly stock-out situations.

3.3.4 Replenishment policies

Replenishment policies have a significant impact on inventory management efficiency, especially when examining service level maximizing and low holding, ordering and stockout costs. Information systems such as ERP, replenishment policies are based on inventory levels. (Sarac et al., 2010, Bruccoleri et al., 2014) If the physical inventory and recorder inventory does not match, the system will fall short on orders or order unnecessary items. (Metzger et al., 2013) Even a small inventory inaccuracy can cause disruption to the replenishment process and cause major problems, especially in the spare parts environment (Kang & Gershwin, 2004). As we have stated before, companies suffer from inventory inaccuracies, and in this chapter, we focus on how RFID could be used to improve replenishment processes. Kök & Shang (2007) argued that an enhanced cycle-count policy that takes into account inaccuracy and has several inventory inspections per cycle is dominant compared to other replenishment policies because the base-stock level and consequently total costs are the smallest possible. The authors argued that approach is especially suitable for inventories that include products that have a high monetary value, high error variance, lower inspection cost or lower demand variability. They suggested that RFID systems might be suitable solutions to generate accurate information for the decision making of replenishment policies. Lee et al. (2004) had complementary results in theirs research and stated that with RFID's ability to take care of inventory continuously 24/7, the inventory inaccuracy problem can be solved entirely or can be managed effectively. Lee et al. (2004) also argued that technology offers the possibility to manage the replenishment processes more efficiently. Sarac et al.'s (2010) literature review disclosed that especially analytical models have left out the fixed cost of RFID implementation, and technology have considered a perfect solution that provides 100 percent accuracy. According to Ustundag (2011), there are two different options for utilizing RFID in the inventory auditing processes. Either the shelf is equipped with fixed RFID readers and antennas, or employees use handheld readers. Since the first option has a significant financial burden because of the large hardware requirements, and the second alternative is often used for inventory counting. In other words, it means that tracking inventory in real-time might not to be economically worthwhile. Authors, for example (Thiesse & Buckel, 2014), suggest that replenishment policies based on item-level RFID tag information have opportunity to increase replenishment process efficiency in terms of service levels and total costs. However, the system is highly dependent on data accuracy, and even a small share of inaccurate inventory reads might lead to a remarkable increase in cost. According to Fan et al. (2014), if a company is going to apply RFID to make optimal replenishment decisions and increase profits, it must take into account not only the cost of RFID implementation but also product properties which affects shrinkage recovery. According to Atali et al. (2006) that products with high inventory accuracy because of high misplacement or theft rate should be tagged fist. Among such products, items with high holding cost and high out-of-stock cost should benefit most from RFID implementation.

4. Methodology

To gain a deeper understanding of how RFID can benefit spare part inventory management and to answer the research questions, empirical research was carried out. The research methodology used in this thesis is presented, and both data collection and data are represented in detail in this chapter. Furthermore, the reliability and validity of the empirical study are assessed. The case company is shortly described at the last section. There is not precise information about the company, because they did not want that they are recognizable.

4.1 Research methodology

Qualitative research is generally used to examine the complex phenomenon in a real-world context to understand the issue more deeply and to gain knowledge about it. (Eriksson & Kovalainen, 2008) Qualitative research was selected because, as stated before, utilisation of RFID in spare parts inventory management is a fairly new topic and not a well-established study area yet. More precisely, the case study research was the selected research method for this thesis. A case study is an investigative manner of explaining and investigating a phenomenon and understanding the issue more deeply and gaining knowledge about it. Case study research includes different methods, and it is not actually a method itself. (Hiusjärvi & Hurme, 2015)

Conversely, there is hardly any limit what kind of empirical data can be used in a case study, and the methods of analysing materials can also vary significantly based on the purpose and aims of the research. That is why a case study has been compared to a research strategy rather than a research method. (Eriksson & Kovanen, 2008; Laine et al., 2011) Case study research is typically introduced as a research strategy when the aim of the study addresses complex managerial, organisational and other business-related issues, which are observed to be hard to measure with quantitative methods. (Ghauri & Gronhaung, 2010) In this thesis, the purpose is to evaluate one company more deeply. Hence, it is opposite to more quantitative approaches such as survey research methods which aim to gain a wide range of surface-level knowledge about the research topic. (Laine et al., 2011; Lapan et al., 2012) Both the human interactions and activities were examined in this thesis, which is a typical approach for a case study. According to Lapan et al. (2012), case study research methods can be categorised based on the amount of the incidence study contains. In this thesis, there was just one incident involved therefore this is a single case study. However, there were multiple stakeholders interviewed, but only one particular process in the supply chain was under examination. Also, some other external stakeholders have been interviewed to gain more thoughtful knowledge about the phenomenon and especially about the technology and its restrictions and challenges. Also, some other materials, such as process flow charts and quantitative data from ERP, have been utilised. Generally, in a case study the design of the study and the research questions have been designed a way that are meaningful to the stakeholders. (Lapan et al., 2012) The convenience of case study research approach can be measured based on the selected research questions. When there are many "why" and "how" questions included in the research questions more suitable case study is as a manner of approach. (Laine et al. 2011; Lapan et al. 2012)

4.2 Data collection and analysis

Primary data is collected directly by the researcher from original sources, especially for the research project. The aim of collecting primary data is to create new knowledge about the issue and answer to research questions with that fresh data. (Farquhar, 2012) A case study research generally utilises the primary data that is often qualitative and comprehensive data about the multiple perspective of the case (Laine et al., 2015). As mentioned earlier, data collection methods for a case study can be versatile compared to other qualitative research methods. Methodological versatility is crucial, and some kind of control to make sure the quality of the results is required during the data collection phase. Yin (2009) suggested that there are six different possibilities to collect primary data for the case study: "documentation, archival records, interviews, direct observation, participant-observation and physical artefacts". Case study researchers generally identify interviewees by using purposeful sampling, which offers better information in the case study since participants, data sources or cases are selected by how much the interviewer can learn from them. (Lapan et al., 2012) In this thesis, the research sample included nine interviewees, who were chosen based on their knowledge regarding the subject and their current position within the case company. Two of the interviewees were external to the organisation. They were chosen because they brought valuable information regarding RFID technology and the implementation.

A major part of the case studies includes human relations and behavioural events, and it might be challenging for a researcher how to capture those relations in precisely. Interviews are generally used methods of collecting data for a case study, mostly because it is an approach that allows to include opinions and attitudes of interviewees that makes it easier also to understand the behaviour aspect. (Yin, 2009) A semi-structured interview is used to gather data that is generally analysed qualitatively, for example, as part of a case study. Yin (2009) suggest that a focused interview, in-depth interview, and surveys are optional interviewing methods for a case study. A focused interview is a subset of a semi-structured interview where the interviewer has a list of predefined themes and generally a few key themes are covered, although the content of interview and order of questions might vary from interview to interview because of the flow of conversation between the interviewer and interviewee. Furthermore, additional or complementary questions might arise during the interview. (Sauders et al., 2016)

In this thesis, a semi-structured interview based on pre-defined themes is used as an interview method, and themes are not the same for the all the respondents because some of the themes required specific knowledge, for example, from the IT systems. The method can be described as theme interview, which has been proposed by Hirsjärvi & Hurme (2015). It was crucial that interviewees were able to bring their own ideas about the themes, and it is possible to discuss about those topics during the interview. Therefore, the theme interview was appropriate interview method for collecting the data from the case company and other interviewees. Interview themes are represented in the figure 8.

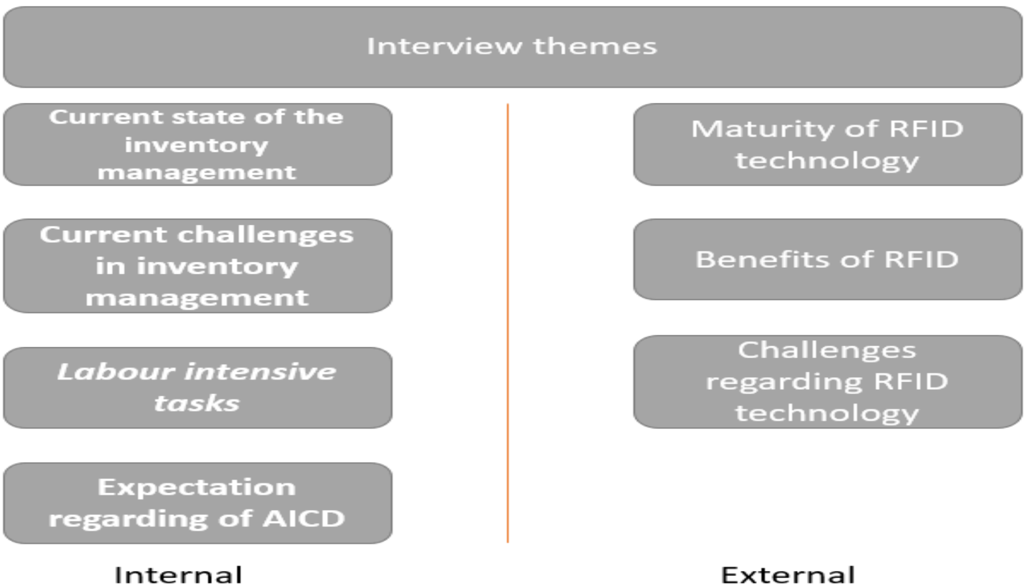

Figure 8 Interview themes

Table 4 List of interviewees

Reference	Job function	Internal / external interviewee	Interview method and length
A	RFID technology director	External	Teams, 64min
B	Executive Director	External	Teams, 71min
C	Warehouse employee	Case company	Teams, 23min
D	Warehouse employee	Case company	Teams, 48min
E	ERP superuser	Case company	Teams, 75min
F	Warehouse manager	Case company	Teams, 57min
G	Maintenance development manager	Case company	Teams, 46min
H	Senior IT manager	external	Email
I	Procurement manager	Case company	Teams, 62 min
J	Procurement manager	External	Email

Interviewee methods and length of the interview are presented in the table 4. Interviews were made during the January 2021 and were held on either on Teams or via email. All the interviewees had a general knowledge about the themes which would be covered during the interview, but they did not know the predefined questions before the interview. Most of the interviews were held in Finnish to avoid possible language barriers, but two of them were hold in English. Interviewees are separated from each other with reference letter A to J, because names of the interviewees are not public information and that is why those are not used in this thesis. Interviewees were recorder to ensure quality of transcription and transcripts were the starting point of data analysis. Based on transcripts each of the interview were studied carefully and information was grouped to the bigger themes. Those answers were compared to the other interviews and similarities and anomalies were identified. With that research questions were answered and problems regarding to existing process were identified.

4.3 Reliability and validity

According to Mills et al. (2010), reliability indicates to “consistency and stability of research results and is one of two foundational elements (the other being validity in conducting rigorous research”. It means that the same result and conclusions would be achieved if research were repeated using the same research procedures. (Saunders et al., 2016) The aim of reliability is to minimize error and bias in data collection and analysis. Stability and consistency are two characteristics of reliability. Stability indicates to “the degree to which the results can be replicated independently at the later point in time”. Consistency refers to “ the degree to which the results can be independently re-created within an acceptable margin of error and is a form of measurement error”. (Mill et al., 2010) There are multiple ways that researcher can use to enhance the reliability of the research, such as team of researchers, inter-observed reliability techniques and triangulation. Stability can be enhanced by documenting the research process in a way that it can be re-examined reliably. (Mill et al., 2010) Yin (2009) argued that the disadvantage of using interviews as a data collection approach is reflexivity, which means that interview might answer in a way that the researcher wants to hear or does not want to give his or her real opinion.

Validity refers to “the appropriateness of the measured used, the accuracy of the analysis of the results and generalisability of the findings” (Sauder et al., 2016). According to (Yin, 2009), three types of validity have to take account when measuring the validity of research: construct, internal and external. Construct validity indicates how well the research investigates what it is supposed to investigate. Internal validity refers to the accuracy of the existence of causal relationships found in the study. External validity measures how well the findings of the study can be generalized beyond the studied case. (Farquhar, 2012) Since internal validity is often applied to the explanatory case studies where the object of the research is to explain how one event leads to a second event, it is not a very suitable measure of validity for this case study. Construct validity has been ensured by triangulation where multiple data sources such as both internal and external interviews and quantitative data like ERP data is used in the analysis. Construct validity is also ensured by offering a reader a precise picture how each of the research questions are answered and conclusions are based on that. However, this thesis is unlike to provide generalizable results because there is only one company included in the case study and processes within different companies can vary a lot. Because of that repeating, the same study for a different company, even with the same industry, might change the results. This is a quite common feature for case studies, and especially single case studies have gained a lot of critic due to the lack of generalizability (Yin, 2009). However, the purpose of this thesis was not to provide generalized results rather gain a deep understanding of the observed case company.

4.4 Case overview

The case company has two main sites that are located close to each other, X and Y, and both of the facility has its own main warehouse, where the products are delivered for the receiving. The X site's main warehouse has three sub-warehouse facilities, and some of the products are stocked in the yard. Y site's warehouse is much smaller it has three sub-warehouse, and some items are also stored in the yard. The case company has recently rented an external warehouse that both sites can use to stock items that are so big that they cannot be stored within existing warehouse facilities efficiently. The warehouses` purpose is storing the spare parts and MRO products for maintenance operations at the plants. At the moment, warehouse facilities are really full, and some parts have to be stored way that is harmful to the products. There is no planned investment for new warehouses. In future, the case company is trying to use existing facilities more efficiently and reduce the stock levels. Via that, all the items could be stocked in a way that is not harmful to the products.

The case company uses an ERP system to manage warehouse processes, and those processes are well described at the moment. However, since every production facility has its own maintenance department, some of the employees or departments might work slightly differently compared to each other. This is a problem mainly at the X site since employees at the Y site are working more co-operational way, and it can be said that those processes are working better there. The reason for that could also size of the warehouse since a smaller warehouse is easier to monitor. Stocked items are identified based on codified item numbers, and Material Resource Planning (MRP) is utilised at the procurement process. At the moment, any AIDC method is not used to identify products. Items with high turnover rates are stocked at Agilon warehouse robot located in the main warehouse and so-called vending machines within each of the X site facilities. Main MRO supplier has responsibility for monitoring and restocking those. Agilon is also a storage bin for some of the codified items if its dimensions and other characteristics are suitable for that. Currently, the case company is satisfied with the efficiency of vending machines and Agilon, and it is something that is wanted to use also in the future.

5 Findings

In this chapter, the most important findings from the interviews are discussed and introduced. Firstly, the maturity of the RFID technology is discussed based on founded critic from the theoretical part and the empirical findings from the interviews. Secondly, characteristics of the maintenance environment are introduced to build a better understanding of how the maintenance environment affects spare part inventory management. Lastly, the current state of the inventory management processes and the potential benefits of the AIDC methods are covered.

5.1 Maturity of the RFID technology

The concept of RFID is quite old, and it has been utilized in the retail industry from the early 21st century by some of the leading companies in the industry, such as Wal-Mart and TESCO, and after that, it has been implemented to the other industries as well. However, RFID technology has received various types of critics, and the purpose of this theme was to identify the current state of the technology and how it has been changed during the past five years. These themes were discussed with external interviewees. Another has more than five years' experience in implementing RFID solutions to different companies. The other interviewee is the technology director at the company that provides RFID solutions.

When discussing the maturity of the RFID technology, both interviewees (A&B) started to talk about the price levels of the RFID tags first. It is well lined with theory since through the times' price of tags has been the most significant barrier for the RFID implementation to the warehousing. They argued that the development of technology and the tags had been fast, and the prices have come down simultaneously. The reason for price reductions related to passive UHF tags is that there are available many suppliers for the tags and the competition between suppliers is hard. Interviewee B argued that high-quality tags cost around 10 to 15 cents, but she also mentioned the Asians markets where some companies are directly purchasing tags from there due to lower prices. The variation of the quality might change, and it can cause problems in production even if the tags are tested in the working environment. According to the RFID technology director (A), a passive UHF tag cost around 6 to 20 cents, depending on the features of the tag. There are also so-called hard tags that can be reused and can endure harsher circumstances and price ranges for those between 2 and 30 euros. Hard tags are usually utilised with assets such as trolleys, carriages, but according to interviews, it could also be a suitable solution for refurbished spare parts such as electric motors. Executive director (B) did not believe that tag's price reductions will continue anymore or as fast as in previous years, and the price level of passive UHF tags have been reached. She also told that the high-end mobile UHF readers' prices have been quite stable since those are still quite high-tech products, and there are not so many suppliers for those. However, standard RFID reader with reading and writing capabilities are not very expensive. Even some sources, e.g., Piramuthu et al. (2013), suggested that all the products should be equipped with RFID tag. Neither of the interviewees did recommend implementing RFID for all products, and even tags are cheaper in some cases, it is not technological or economical worthwhile. Interviewee (A) used the car industry as an example, and he stated that it is quite common there that for some spare parts such as bearings, RFID is used to identify batch, and individual bearing is still detected by barcode. RFID is used to improve the efficiency of the receiving process, but it is also a suitable solution to improve other processes like inventory and outbound when inventory records are high.

Challenges regarding implementing RFID middleware to other information systems such as ERP have a critical role in successful implementation. If that is not possible, the process should be stopped right away because most of the benefits cannot be utilised. According to interviewee B integration process is quite straight forward, and middleware is quite simple to implement via application programming interference (API). However, interviewee A did not approve of that entirely, He argued that currently, there are still old generation ERP systems used in big organisations, which usually have quite constricted API's related to information updating. He told that, especially if the company has an on-premises ERP system instead of a cloud-based solution, the integration process might be more time-consuming and expensive. Cloud-based solutions are also easier to scale up for the increased data quantity. ERP systems, such as SAP, have multiple versions. Even inside of those, there might be some customised solutions or different kind of modules, which means that it also requires a lot of internal knowledge to improve the existing processes. Interviewee (B) notified that one of the greatest challenges is how to read RFID tags to the ERP system in the first place to enable the automatic receiving process.

There are multiple ways to do that, but chosen solutions depend on the supplier relationship management level. Also, the order volumes have a big impact on which method should be selected. Interviewee (A) did not suggest this for small volume suppliers rather for long-term suppliers with decent volumes. Interviewee (B) suggested that the easiest way is that ID-numbers for the RFID tags are included in the purchasing order, and the supplier writes those ID-number to the tags during the shipment process. It does not require any other supplier's investment than the tags and RFID reader with write capability. It has to be said that increased administration of RFID tag will also have an impact on the total cost of purchased products, and it needs to be taken into account when counting ROI. I see that suppliers should not see that just an added cost because there is a wide range of benefits that they can utilise related to increased data.

Like mentioned before, RFID would offer an increased amount of accurate data related to inventory management and other processes that tags go through. Especially in spare part inventory management, inventory accuracy has a significant impact on overall efficiency since it is the starting point of the rest of the processes. In related literature, reading accuracy has been criticised. According to both interviewees, reading accuracy of 99-99.8 percent is achievable, but the 100-percent accurate is really hard or even possible to achieve. Reason for that is that in the physical environment, there are matters which can cause unexpected problems, and the tag cannot be read because of that. Interviewee (A) mentioned that if metal components are stacked one on the other, in some cases, tag’s antennas might affect each other, and some tag cannot answer to the reader. Or metal structures within the warehouse might reflect radio signals and cause blindsides. Interviewee (B) added that the tag’s orientation might some cases affect the reading capabilities of the reader. The development of tags that work on metal is also one factor that has highly affected RFID reading accuracy. It is a crucial factor in the spare part inventory management environment since a significant share of parts are made out of metal. They both highlighted the role of piloting at the beginning of the implementing process. “Environment has a significant effect, which theoretical should be really easy, you cannot be sure before testing” (B). Interviewee (A) said that if follows, RFID technology implementation’s golden rule of planning, testing, and developing reading accuracy of 99 percent should be achieved. Interviewee (B) added that piloting does not cost much because, in the beginning, there do not have to be integration between existing IT-systems and reader. At that point reader’s software can be used. She also told that most of the tag manufactures are willing to send samples that can be used in testing. Budget of 1000 euros is more than enough for good quality testing. But it has to be remembered that testing has to be done in every locating because even the building’s structures and existing WLAN broadways might affect the reading accuracy.

It is really rare that problems related to the working environment cannot be solved afterwards, but it might require extra purchases and time. (B) Proper testing does not remove the fact that technology users need to be aware of technology's restrictions and behave the way that it would not cause the problems. (A) "Expectations are usually really high regarding this kind of investment, and it can be a really big disappointment and have a negative impact to the employees if the reliability of reading accuracy is low and it needs a lot of fixing at the beginning". (B)

When building up any kind of well working IT environment, standards have a big influence. It also has a major role to avoid so-called technology risk where the buyer depends on one supplier's technology. Which can lead to higher prices, or even that whole technology will vanish. Particularly on the older studies related to the use of RFID, lack of standards was one issue that was pointed out. According to interviewees, during the past few years, standards related to the UHF environment have been quite standardised. One of the main ideas is that the protocols define communication between tags and devices. "It also means that data structures are standardised" (A). Few major parties work together to define and approve universal standards and protocols for RFID technology, International Standard Organisation (ISO), EPCglobal and GS1. ISO and GS1 generated global standard for RAIN RFID, allow the worldwide adaptation of RAIN RFID. "They all work so well together that you know that you can take almost any tag or reader and they can communicate with each other" (B). "ISO standards are related to air interface protocol between tag and reader, which have been allowed to make products that can communicate between other manufacturers products. It has led to a situation where the environment stays viable, and due to competition, prices stay moderate." (A) Interviewee A also argued that pioneers of RFID have been farsighted and have had a major role in standardisation, the same problems which barcode technology had were avoided. From my perspective, standardisation and its benefits are the main enablers that RFID technology can also be utilised in different kinds of industries where volumes are not that great than in retailing, and the supplier base might be wider.

5.2 Characteristic of maintenance environment

Interviewee (E), who is a warehouse manager described that due to spare parts inventory management items have the following characteristics: "Items are so different, and dimensions of our items vary a lot, and some items are so heavy that those need to be on the floor, it affects warehouse staffs capability to transport and stockpile them efficiently”. “It is hard to find a proper place for big parts and fit all the parts to the warehouse, especially warehouses at Y site are quite full” (D). Due to that, massive spare parts have to be stored in multiple locations across the site, and it is the main reason why spare parts cannot be organized based on turnover rate or criticality. (E) He also mentioned that because all the warehouse facilities are not warm, it is also a criterion when selecting the storing location. “Because we have many warehouses, duration of picking process might vary a lot” (C). Interviewees (E &F) mentioned that the spare parts supplier base is wide because spare parts can be developed for the one special equipment. According to the interviewee (I), who is the procurement manager, the case company has standardized its spare parts, which used to be tailor-made, but it still has around 600 suppliers at the moment. Case company has some big spare parts supplier, but in the big picture, there is still a lot of smaller supplier as well. However, most of the MRO products are purchased from a few suppliers, which have huge volumes. Those are currently stored in multiple locations: warehouses, vending machines at the production, and Agilon. About 30 percentage of MRO products are delivered directly to the solutions mentioned above, and warehouse operators do not need to make goods of receipt for those. However, currently, there is still a big volume which needs to be handled manually. Because most of the spare parts are so specific, it has caused trouble for the warehouse employees to identify them correctly (D). That is why contractors and maintenance staff have been part of the collection of items from the warehouse. Interviewee (F) stated that because some of the spare parts are so unique and have a lot of details, they need to be inspected before goods of receipt by a maintenance specialist.

The site is running around the clock, and maintenance needs have to be also fulfilled outside of office hours. According to the interviewee (E), it is possible that at night, users are not able to get the items because it requires lifting with a forklift and in some cases, warehouse stuff have to be alarmed to the site. Both of the Interviewees (E & F) mentioned that inventory reduction to the ERP system might forget to do in some cases. Or if it was done, a paper picking document might have lost, or warehouse employees have not made the reductions. They both argued that it does not explain all the inventory inaccuracy. I see that RFID technology have a big potential to reduce inventory accuracy related to these night shift picking activities since it can be noticed if some part has been transported outside of the warehouse without a work number. Also, interviewee (A) mentioned that it is common in the manufacturing environment that the night shift does something that comes as a surprise for the next shift. Interviewee (B) mentioned those same things and argued those are the main reasons why big organisations have automated their' warehouses or part of it. She argued that it is essential to plan well how users move in and out to the automated warehouse that, for example, a port reader cannot be bypassed. Otherwise, it is a zero-sum game.

Due to the significantly high prices of some equipment such as electric motors, pumps, or transmissions, some of them are refurbished. At case company, paper document should be delivered with the refurbished equipment, but according to the interviews which made last summer this document was not delivered with the equipment every time, and it causes extra work for the warehouse and repair centre's employees. According to interviewees (C, G & E), some of the employees follow the process, but some employees do not, and they cause problems for process flow. For example, these extra tasks are identifying the equipment and its equipment interface, maintenance needs, or destination. "Almost a daily we receive a repaired equipment and even service order have been done we need to check the maintenance employee who has made the order and ask him to make goods receipt or service entry. If codified identification number or purchase order number is missing, we need to dig it from ERP" (D). She also stated that equipment that should be delivered to the contractor for the repair could cause trouble due to missing information, but she said it is currently working better on the Y site than X site. (D) Interviewee (C) agreed that and added that it is common that employee who has brought the equipment to the warehouse will check some additional information and it takes multiple days to finish the process, or we need to ask that from maintenance department later.

For spare parts inventory management, the maintenance shutdowns are a common feature, and many external contractors are on the site during that time. In fact, the number of people on sites might triple at that time. According to the interviewee (E), during the shutdown an addition (unplanned) maintenance needs might appear, and it has affected to the inventory management processes. He said that "during the shutdown, all parties are so busy that nobody can do these things correctly". During the shutdowns, warehouse employees also have additional tasks to do, such as lifting and internal transportation of parts, which cause that there are not every time employees at the warehouse. This is especially a problem in the evenings and at the weekends. He also stated that even the pickup lists are done correctly and documented during the shutdown, it might take months at all of them are registered to the ERP system. According to interviewee (D), a few weeks after shutdowns, maintenance workers begin to deliver picking lists that need to be reduced from ERP. Interviewee (C) said that at the X site, it is not common to get a picking list after shutdown. He stated that “generally maintenance operator does not inspect picking list afterwards”. They both (C&D) said that it is impossible to take into account what items have been picked, and sometimes they collect items that I do not even know about it.

Another feature that interviewees (C, D, E) mentioned is that the case company is responsible for taking care of some contractors that are directly delivered to the site for some project. At the moment, traceability of contractor’s items is a big challenge. Sometimes those items just vanished from the site because they are not registered to the ERP system, and items are temporarily stocked around warehouses. At least it takes time to find those items when needed, and he said that some items are delivered months before use. (C) According to interviewee (D), who is a warehouse operator, it can take a lot of time to correctly identify items that belong to the contractors, and it affects to the receiving process efficiency. All the missing referral information deliveries are not for the contractors because some deliveries that belong to the case company are missing referral information. Warehouse operators need to find the information from the ERP system based on sender or other information, and it is really time-consuming. There are also cases where contractor’s delivery should not come to the case company’s warehouse in the first place, it should be delivered directly to the worksite, and it causes unnecessary internal transports for warehouse operators. (E & D) Interviewee (C) stated at least half of receiving products belongs to contractors’. Currently, this process is not described at the process flow and there might be multiple stages where a process can be improved.

In the maintenance environment, the efficiency of inventory management is highly dependent on how well and how early maintenance works have been planned. “From a maintenance point of view, it would be easier if all the components needed in maintenance tasks would be identified spare parts, it does not matter how they are procured” (G). If work orders have not done in advance, it causes a rush on the warehouse and processes cannot be followed correctly. Interviewee (G), who is maintenance development manager, argued that processes related to maintenance works had been developed during the past three years and works are better planned than earlier. It has also reduced inventory levels because most parts, e.g., pipes and valves, are ordered in advance to the site, and maintenance employees do not expect that all required parts are stocked at the warehouse. However, interviewee (C) said that a common feature at the warehouse is rush, situations are quite hectic, and those require a quick response. He said that we have a lot of that kind of situations on our daily basics. He also said that it is currently hard to predict how much picking activities are each day or how many outbound activities we have, and those usually require some extra investigation. According to interviewee (G), stocked parts are generally used for unexpected maintenance tasks and for the work orders, parts are ordered in advance. With this development, case company has achieved high reliability and utilization rate. “We have roughly 13000 work orders each year which have registered to the ERP system, and about half of them include changing components” (G). He also stated that because currently, they cannot trust inventory levels, the maintenance department employees need to inspect the storage bins physically to be sure that spare parts exist at the warehouse if the work order is critical for production. Because of missing components, some of the work orders needed to be rescheduled, and it has also caused unplanned shutdowns, those are really rare, but costs can be high. “For us, it is really important that even the smallest spare part cost should be allocated to the individual work order. It has been the main challenge for us to develop our processes with electronic solutions” (G). Currently, at the case company, pre-collected spare parts kits are not utilized, and it might have significant potential when streamlining the picking process.

As previously mentioned in theory, spare part classification has a major role in the spare part inventory management’s efficiency. Currently, the case company is doing spare parts classification. Based on the interviews, it reminds the VED model, but they call it ABC analysis. Currently case company is only able to monitor spare parts based on demand, or like interviewee (I) said, “demand that not exist”. And based on that, ask from the department is this spare part unnecessary. “Currently we need to stock items which we do not know if we are ever going to use them. Spare part classification should be ready by the end of the year. We should determinate which parts we have to stock at the site and which we can buy directly from the supplier based on demand” (E). According to interviewee (F), based on the current status of classification process, a major share of spare parts is classified as a critical component. However, it is hard to determinate which are the differences between the actions between group A and B. Some researchers such as Botter & Fortuin (2000) and Dekker et al. (1998) argued about their studies’ same issue. Interviewee (E) added that inventory reduction via classification requires a lot from a logistic and it will change some of the warehouse employees tasks, e.g., they will do the whole process from picking to the transportation of items to the production, currently processes depend on the schedules. It is crucial that the case company has started spare part classification because it will offer valuable information on which parts should be equipped with RFID tag, and it will also improve replenishment policies and reduce the inventory levels. Interviewee (I) stated that after spare parts classification has been done, we can identify products that we can order directly from a supplier instead of warehousing it by ourselves and how we should stock items that are used in both of the sites. She stated that “we also might identify some critical spare parts which we do not have supplier at all. This should improve our inventory management significantly”. (I) Interviewee (G) said that they had faced problems related to missing components that have not identified yet as critical, and it has also caused shutdowns.

5.3 Current state of inventory management processes and potential benefits of AIDC

Receiving process at the case company should be relatively straightforward. When the item arrives, either of the central warehouse staff inspects delivery one by one that is it matching with the referral. According to interviewee (D), she is facing daily deliveries that are missing referral information, or it has a wrong delivery address. She also stated that because some of the transporters do have an only electronic referral, the warehouse operator does not know any information about the delivery before is it unloaded, and the printed referral document can be inspected. Interviewees (C & D) said that deliveries that are missing referral information are the most time-consuming task on their workday. They also said that because referral information is missing or the delivery address is incorrect, freights can be unloaded to the wrong warehouse, and it causes internal transports. Interviewee (C) said that these deliveries encumber especially main warehouse at the X site, and he said that the current process is not matching with the company’s receiving process flow. It has many additional steps. Interviewee (E) agreed on this problem as well and stated that it concerns especially contractors’ deliveries, but interviewee (D) said that it is a problem also with the case company’s own suppliers. This is something that should be definitely solved immediately. Especially with the MRO products is quite common that quantity on the purchase order is not fulfilled in one delivery. It depends on how many pieces the main

MRO supplier has its local warehouse, and warehouse staff need to do multiple goods of receipt for one purchase order row. There are also some spare parts that need to be checked by a maintenance specialist before stocking. “For me, it is challenging to identify products that those match with the purchase order” (D). Interviewee (B) argued that RFID could be used on automatization of goods of receipt process by using port reader or handheld device to identify arrived products and middleware software can do the changes to the ERP system automatically. It is important to remember that automation of the receiving process requires administration from both buyer and supplier side, and interviewee (A) suggested that it might not be economical solutions for supplier with small volumes. Based on statistics related to the goods of receipt process, it can be said that case company does not receive a daily large amount of spare parts and there are only a few suppliers whose annual volume is big enough for economical RFID implementation. Based on that, it can be said that there is not big saving potential on manual work reductions on spare parts receiving process.

After goods of receipt process is done to the ERP-system, warehouse employees stock items based on characteristics of the received product, e.g. is it a codified item or MRO product which is stocked to one of the warehouses, staff transport item to correct warehouse and storage bin. If a product is a non-stock item, it will be transported directly to the correct unloading area, or it will stay at the warehouse for a while. This is very common, especially before maintenance shutdown when large volumes of MRO products are ordered for the maintenance works. Interviewee (C) said that currently, they do not have proper space for temporarily stocked items at the warehouse. Interviewee (E) argued that “even we have data from ERP systems receiving process, it is hard to say how much time it takes to complete the whole process because we receive many kinds of products and those will be stocked to the different warehouses, and we don’t have any data about the internal transports”. Interviewee (A) endorsed this idea of utilization of RFID on the receiving process and added that it could be used to track transportations between warehouses and departments and make process more transparent and offer valuable data about it. He also argued that if receiving process is congested and a lot of deliveries are waiting for unloading, it can reduce the need for internal communication e.g., via phone between warehouse and departments, if end user is willing to use that item right away and improve the overall receiving processes efficiency.

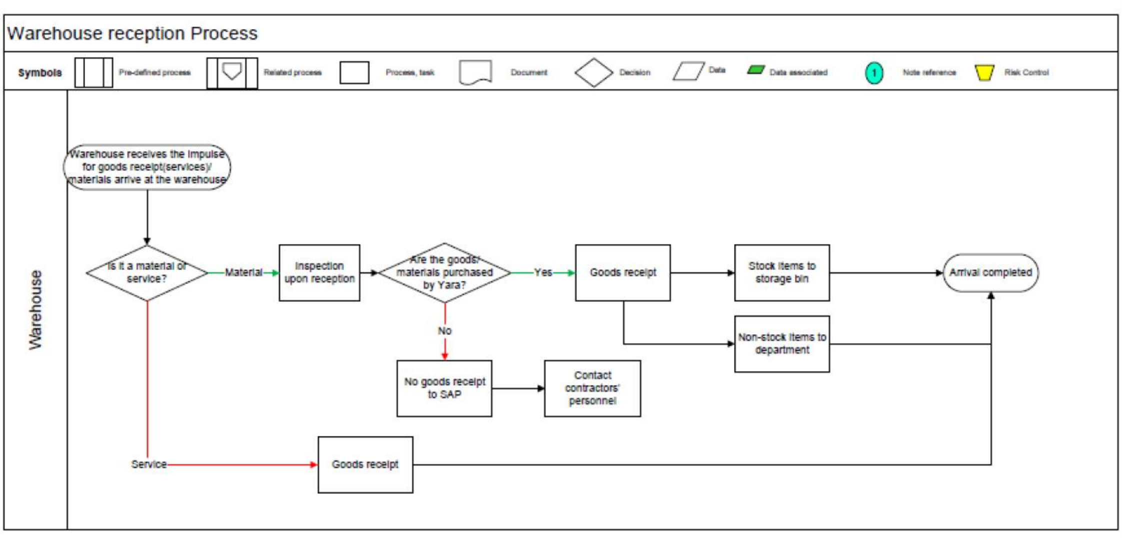

Figure 9 Case company's receiving process

The biggest challenge that arose from the interviews was inventory inaccuracy. The maintenance development manager (G) argued that case company has a problem related to inventory inaccuracy. It has led to a situation that some of the maintenance operators keep so-called squirrel stocks. He also argued that it is a common problem for the other companies that have a lot of maintenance works. According to interviewee (E), inventory inaccuracy was 11 percentage in 2020, it does not sound much compared to the results represented previously on the theory part. However, in the case company inventory inaccuracy is counted how many rows there are, it does not take into account how many pieces were surplus or were missing. Especially small items have a lot of inventory inaccuracy (D, E ,F). The biggest product groups founded from the inventory inaccuracies list are represented in figure (10). It is well lined with interviews. However, since there are no rules for the naming of codified materials, there might be some product groups that are missing due to the identification problem.

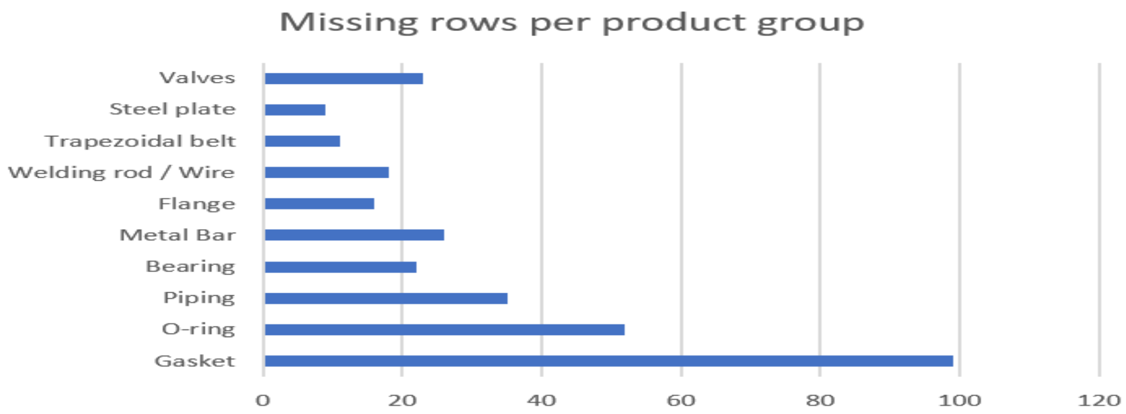

Figure 9 Number of missing products per product group

At the moment, inventory counting is done by printing a list of items within each of warehouse facilities and warehouse employees are counting and matching the inventory manually. Inventory count is done once a year in and it is a so-called cycle inventory count. “Inventory counting takes too much times at the moment. I can’t say precisely but many days anyway” (E). “It might take about three hours to make inventory counting for one shelf, it depends how I need to use a forklift.” (D). “It is hard to say how much it takes to finish inventory counting since we just started to do this cycle inventory count, but with a previous method it took one and half month to finish it” (C). Comprehensive analysis of the inventory inaccuracy list reveals that in 2020 inventory count was done on 94 different days, but there is no data about how many hours were used per day. Inventory inaccuracies cause extra work for procurement, warehouse employees and maintenance departments. (F) Two buyers, warehouse manager and maintenance departments, take part in process related to inventory inaccuracies. (I) “If something big and expensive is missing, we are looking that until we found who is used that, but we don’t care anything small like bolts and nuts” (D). The last unexpected shutdown could be avoided if inventory counting for critical components would have done more often. (G) Interviewee (E) stated that they might change the current inventory process in a way that pays more attention to the critical components. Currently, all the parts are handled with the same accuracy. “My previous workplace had all most the same quantity of spare parts, but warehouse was managed with barcodes, and it makes inventory counting much faster” (E). Interviewee (G) stated that “our current inventory counting system is from the stone age, nobody is not using this kind of inventory counting system anymore.” “With mobile RFID reader inventory counting can be done in 15 minutes which earlier used to take on the weekend. Inventory counting can be done more often, and it improves significantly inventory accuracy” (B). Interviewee (A) said that inventory counting could also be done during the normal picking process because a mobile reader is able to identify over 100 tags per second, and it can be used to identify potential differences between actual and system stock levels. Interviewee (E) suggested that if inventory counting process can be improved, it might also improve warehouse employees' knowledge about inventory inaccuracy reasons. Currently, managers are trying to solve those problems based on an annually provided list of inaccurate rows, but it is not very efficient currently. It has to be mentioned that inventory inaccuracies can have a significant impact on company's performance if the stock-out situation causes unplanned shutdown of the production. Those are important factors for RFID implementation, and it could be used as a saving measure when defining ROI. Interviewee (B) argued that improved inventory accuracy would lead to reduced inventory levels. In some research, live inventory level monitoring was suggested, but interviewee (A) said that it is theoretically possible, but nobody would not offer that kind of solutions because it would be really expensive because it requires hundreds of antennas and readers. Interviewees (E, F, G,I) stated that they believe that most of the inventory inaccuracies are caused by inefficiencies in picking process. Counting items manually and using paper as a documenting method might also cause inaccuracy on inventory counting process, because humane errors are quite common routine tasks such as this. Interviewee (D) said that with barcodes or RFID typing errors could be avoided.

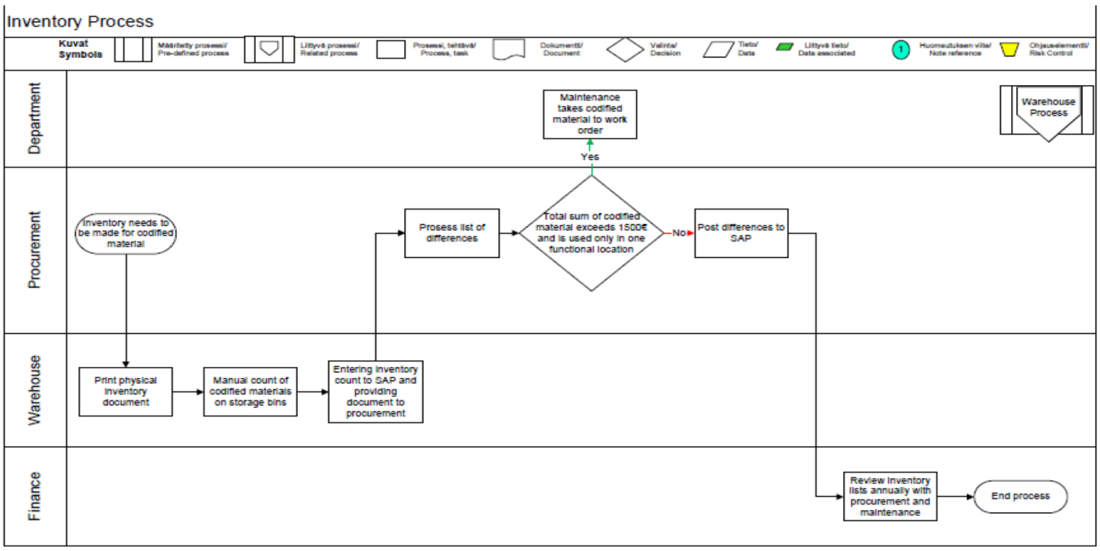

Figure 10 Case company's inventory auditing process

The item picking process is currently based on printed picking lists allocated to the individual working order that determine which parts should be collected and when and where those should be delivered at the site. However, according to interviews, this process is not currently followed precisely because some employees are not taking responsibility for their work (I, E, G). Last year 51 internal distribution points where launched if internal transport is a need, work order or purchase requisition should include a specified distribution point. Most of the time, those picking lists are delivered by paper, and in some cases, via email. In practice, warehouse staff, an employee from the maintenance department or, in some cases, contractors do the picking based on the picking list. According to the interviewee (I), it is hard to provide a good service level because our warehouses are located at many different locations. Interviewee (D) told that in most of the cases, maintenance employee collects items that he needs and delivers the picking list for her. After that, a warehouse employee will make the reductions to the ERP system at his or her personal computer based on the picking list. According to Interviewee (C), at the X site, warehouse operators do picking more often. He added that we also have some employees at the maintenance department who pick by themselves, especially with the hectic jobs picking list is not provided to the warehouse. During the picking process, maintenance specialists might discover additional consumption, especially with smaller parts. If it is not added to the picking list, it causes inventory inaccuracy. (E & F) It can also increase spoilage rate because the newest or best-looking part is selected, and FIFO does not actualise. Interviewees (E & F) were wondering is it possible that warehouse employees are not always checking that picking list and actually collected items are matching by quality and quantity, which causes inventory accuracies. Interviewee (E) stated that it is really expensive for the company because their salaries are really high when contractors do the picking. The objective for the picking process is that warehouse employee would be a charge of item picking and delivering items to the distribution point, and external parties would not be a part of it. “It would be really easy if we had employees at the warehouse 24/7 and we had enough employees for that”, said the warehouse manager. (E) Currently, the company is also facing problems related to the identification of the items, which is the main reason why external parties are involved in the picking process. “Maintenance team will complain if a collected product is wrong, but it is quite easy to find stocked items if the codified identification number is correctly placed during the stocking” (D). This year case company have been started to take photographs for products, and those are part of the item description of the ERP system. Nowadays, all the codified spare parts need to be created to the ERP system in advance, e.g., if investment includes some spare parts, those need to be created before delivery. It has been one of the main reason behind the identification problem. (E) “AIDC technology enables that task can be done directly there where it would be done naturally. It also enables digital information flow, and paper documents and picking list can be abandoned” (A). “it is not necessary that warehouse staff would be involved to the picking process if we would have mobile readers also maintenance operator could do the picking” (I). “It does not matter who does the picking, but the process needs to finish. Maintenance operators claim that they are so busy, but it does not take even a minute to leave a note that these items are collected. How employees work needed to be changed, any technology cannot resolve that”. (G) According to interviewee (E), processes should be so well defined that we could hire rental staff during the shutdowns to maintain service levels. Due to cost allocation is based on work orders, a well-working picking process requires that work orders have been done in advance and contain all the necessary parts when somebody arrives at the warehouse. That something that cannot be improved by any automatic identification method, it might be possible to add products to the picking list by the mobile reader during the picking process, but work orders need to be done in advance.

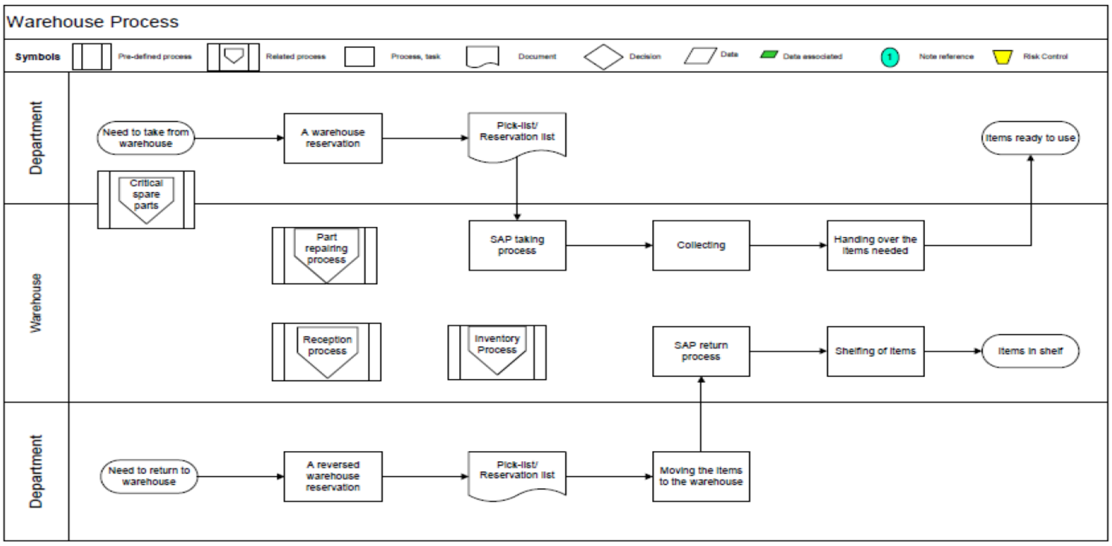

Figure 11 Case company's picking process

“I think that most important thing about RFID is data” (B). She suggested that when planning an RFID system, it is important to think about which processes are essential and what kind of data we need to monitor and improve the organisation’s efficiency. Often companies start the planning process reversely by examining tags and readers, but what kind of data we need should be the starting point and build requirements for infrastructure based on that. Interviewees (E & I) argued that reports related to warehousing are lacking, it is hard to get data from ERP, and it is not visualised for operative management. Middleware software can be used to improve the quality of reports related to warehousing. “So many things are depended on remembering at the moment, it is our biggest weakness related to current processes” (I). Interviewee (B) also stated that since the implementation of technology will change processes much, it is crucial that those processes are reviewed and make sure that users are working based on new processes. Interviewee (G) highlighted the same issue. He said that currently, employees see developments in processes as additional work, and they do not understand that changes should change the way they work and not increase the work load out. He also stated that currently, familiarisation to the employees’ task takes really long, company’s processes and guidance need to be improved. Interviewees (E & I) mentioned that currently, the staff at the warehousing processes are not very motived, and it causes problems for them. “Broadly one mistake that if have seen quite many to made is that at beginning huge amount of reading points are implemented which leads to large quantities of unnecessary data. Logical thinking can save a significant amount of money and readings point can be easily added afterwards if company notices that some specific data is needed”. (B)

6. Discussion and conclusions

The objective of this thesis was to understand how RFID can be used to improve spare parts inventory management and identify major barriers and benefits related to use of RFID in a maintenance environment. Previous studies related to utilization of RFID in inventory management have mainly focused on retailers or distributors, but there has been a lack of studies that would have focused on spare parts inventories or maintenance environment. Additionally, this thesis is trying to answer questions about how RFID’s benefits in spare parts inventory management diverge from inventory management in other fields. Previous studies have mentioned multiple critics of RFID technology, the current state of the technology was identified with interviews with external interviewees who have a long working history in the RFID industry. A comprehensive review of current literature related to the issue was conducted to gain knowledge of the issue and support the empirical study. To address gaps found in current literature, an empirical study was made where four external interviewees and six interviewees from the case company were interviewed, and some other quantitative and qualitative materials such as SAP statistics and process flow charts were used.

6.1 Discussion of the results

In this part, the empirical part's findings are summarized and compared to the theoretical part of the study. The research questions can be answered by combining the insight gained from the empirical part and overview from the theoretical part.

"*How can RFID help in improving spare parts inventory management efficiency?"*

This thesis aimed to identify how RFID can be used to improve the efficiency of spare parts inventory management. The biggest challenge that arose from the empirical research related to inventory management's current state was inventory inaccuracy. It was caused by inefficiencies in the picking process, such as item picking without picking list. Earlier studies, e.g. (Kang & Yun, 2005; Kang & Gershwin, 2005; Dehoratius & Raman, 2008, Hargrave et al., 2013) argued that it is a common problem related to inventory management. Huiskonen (2001) and Trimp et al. (2003) argued that the consequences of stock out could be severe in spare part inventory management. In the case company, inventory inaccuracies have caused maintenance work rescheduling, but there are also incidents that have led to unexpected shutdowns, and it has caused major costs. Inventory inaccuracies effects to maintenance department's process workflow. Currently, they cannot trust inventory levels, and employees need to check inventory levels of critical parts physically, and it is time-consuming. Additional to warehouse operators and maintenance department employees, inventory inaccuracies also affect other stakeholders, such as procurement which has the responsibility to identify where to allocate costs of used items. AIDC technology would not just reduce warehouse operators labour. It also affects other processes efficiency. With RFID, inventory inaccuracies can be reduced, and it will improve all the processes which require information about the inventory levels. It would reduce the rush, which has been the main problem why processes are not followed.

In previous studies such as Veronneau & Roy (2009) and Ustundag (2011), RFID has been used to improve the picking process efficiency. Improvements have been related to automatic data updating, which is possible due to mobile readers, which allows users to finish the whole process during the picking. This thesis identified the same kind of results, and AIDC technology has a huge potential to streamline the case company's picking process. Both technologies, barcode and RFID, enable that reductions to the ERP systems could be made simultaneously during the picking process, by using the mobile reader and digital information flow enables that paper documents are not required any more. Compared to the barcodes, RFID technology can track items that are not picked correctly if warehouse facilities are equipped with port readers. I see that this is an important feature because for some reasons, e.g. rush or disregard, some employees do not follow the processes, and it is something that is hard to avoid completely. Correcting actions can be done in timely manners, and high-level inventory accuracy can be achieved. However, case company has multiple warehouses on both of the sites, and it might require reorganising of stocked items and replanning for the passageways. Currently, both of the sites have one warehouse, which could be used as it is. Since case company have electrical locks, it could be easy to monitor warehouse users and identify who have collected items without picking lists.

The utilisation of RFID in receiving was mentioned as one of the main benefits of RFID implementation. With RFID technology time consuming manual labour in the receiving process could be avoided completely. (Curtin et al., 2007; Lee & Özer, 2007, Soon & Gutierrez, 2008; Chanchaichujit et al., 2020) However, in the case company, labour reductions related to receiving process would not be significant. Case company's supplier base is wide, it has around 600 suppliers, and most of them are small supplier measured by volumes. It means that RFID implementation would not be economical worthwhile if it is not already used by the supplier. It would mean that most of the spare parts deliveries would be delivered without RFID tags, and deliveries would be handled manually. Secondly, if inspecting deliveries by volumes, a spare part category is the smallest category. Currently, case company is receiving more MRO products and deliveries that belong to contractors' projects. However, because those products are not usually stocked at the warehouse, it would not be beneficial to used RFID just for the receiving process because warehouse employees are able to handle them manually. Focus on the previous studies generally have been on retailing where volumes are bigger, which would explain this difference. Currently, the case company is facing deliveries without proper referral information, and it is time-consuming for the warehouse operators to correctly identify those deliveries. Soon & Gutierrez (2008) argued that RFID would improve the transparency of information flow related to received products. However, this is something that is currently hard to solve with RFID technology because having RFID attached to the received items is a more complicated process. If the current process is not working, it is unlikely that RFID would solve the problem with the current state of supplier relationship management. However, RFID technology can streamline the receiving process in the future when supplier relationship management is better coordinated.

In the case company, RFID technology has a significant potential to reduce manual labour during the inventory audit process. This finding is well-linked with the previous studies such as Atali et al., (2009) and Heese (2007). Compared to barcodes, RFID allows the user to read multiple tags simultaneously without a line of sight. In practice, it means that warehouse operators do not need to inspect parts individually. According to the interviews, lifting items with a forklift was one of the most time-consuming inventory counting steps. Empirical research revealed that currently, it is unknown how long inventory counting takes, but according to quantitative material, inventory auditing was done for 94 days. With RFID tags and mobile reader, inventory counting could be done a fraction of time by walking between shelves at warehouses. If inaccuracies were found, warehouse operators would check them manually, just like now. Since the process would be much faster, the case company could do the inventory counting more often. It would improve inventory accuracy, and inventory accuracy problems could be avoided, as Atali et al. 2009, Heese 2007 and Kok et al. 2008 suggested. Based on empirical research, it would also be possible to do inventory counting during the picking process since the mobile reader is able to identify items without a line of sight, up to ten meters. Empirical research suggested that all the items are not appropriate for RFID. Generally, this same finding was endorsed at the theory, excluding a few sources such as Piramuthu et al. (2013) and Sarac et al. (2010).

Empirical research identified that the equipment refurbishment process has been causing a lot of inefficiencies to the inventory management processes, such as receiving and outbound. The main reason for that is that a paper document that identifies the equipment, maintenance need, and destination is not delivered with the equipment or is unreadable due to harsh environmental conditions. External interviews suggested that hard RFID tags are suitable solutions for this kind of equipment. Compared to the barcodes, those can endure harsh production environments such as chemicals and tags can be reprogrammed. Especially rewriting ability is important because maintenance need can be writing during the disassembly or based on the tag’s ID, state of equipment can be updated directly to the ERP system. With RFID paper document is not needed any more, and warehouse operators do not have to dig information about the equipment for ERP systems or do the internal investigation about it. Other theoretical research did not have finding regarding refurbished equipment. Based on empirical research, it would be suitable and efficient even if hard tags are significantly more expensive than normal UHF tags. Due to the price of equipment and because hard tags can be reused, increased price is not a significant issue.

As previously mentioned in the empirical research, accurate and quality data and is the most important factor in RFID implementation. Authors such as Bagchi et al. (2008), Sarac et al. (2010) and Cannella et al. (2016) endorsed that by arguing that advanced properties of RFID technology enable high-quality data with high reliability about the objects which have not been accessible earlier. Empirical research indicated that AIDC technology has a huge potential to improve the quality of reporting and improve daily operation management, which has been lacking due to the lack of existing reports on ERP systems. Custom made reports are time-consuming, and poor data quality affects report reliability. Compared to barcodes, RFID technology makes it possible to identify movements between warehouse facilities or identify movements by forklifts if machines are equipped with mobile readers. Empirical research indicated that it might be worthwhile to build RFID ecosystems in steps and add reading points rather than implement as many reading points as possible in the first place and collect a huge amount of unnecessary data. Yang & Zou (2005) and Kapoor et al. (2009) addressed issues related to increased data volume, and Yang & Zou suggested event-driven reader management but based on previous studies, building an ecosystem step by step was new information. It is pretty obvious, but it might be still possible that especially third-party service providers are trying to sell over-complicate the solution. Empirical research suggested that it might be an economical solution to start from core processes and scale up functionality later.

Supporting research questions are:

How spare parts inventory is currently managed at Case company ?

Inventory management processes are described at the case company with process flow charts, but at the moment, those are dependent on remembering, and processes are hard to monitor. The reason for that is that case company have multiple different warehouse locations on the sites, and those are not operated by warehouse operators all the time. It has led to situations where items are picked without that warehouse staff have any information about it. Problems occur, especially with small spare parts since bigger parts require use of a forklift and those are usually moved by warehouse employees. Empirical research also identified problems related to inventory management processes that are caused by the behaviour of employees. Based on empirical research, it can be said that since site Y is significantly smaller than site X, processes that are currently based on remembering are working better there. Another reason for that could be that all the maintenance operators are working in the same office, and internal communication is more effective there. Currently, the case company has encountered high turnover rates of employees. Combined with long training, employees might not be familiar with the correct way of working. There are also problems with some employees attitude which are not following processes even they know how they should work. Empirical research revealed that process development has been seen as extra work from an employee point of view rather than improving existing processes to reduce employees workload. This is something which cannot be solved with either of AIDC technologies studied in this thesis, but barcodes and RFID tags can be used to streamline inventory management processes and reduce manual work task such as updating inventory levels to the ERP system. Empirical research indicated that reduce of manual tasks is something that employees expected from the implementation of AICD technology, and it should have a high acceptance percentage. This is lined with White et al. (2007) findings which argued that RFID is easier technology to implement from an employee point of view because it has a higher tolerance to user errors. However, empirical research suggested that even RFID technology has a higher tolerance for user errors, users need to know the existing restrictions of technology. Compared to the other AIDC technologies, RFID can be used to improve monitoring of unmanned warehouses if all the spare parts are equipped with RFID tags and the facility has port readers at exists. Empirical research indicated that it is important to replan traffic within a warehouse that all the stored or picked items go through the port reader. Without that, it will not improve monitoring at all if port readers can be bypass.

Like proposed by Cavalieri et al. (2008), Syntetos et al. (2008) and Teixeira et al. (2017), spare part classification is crucial to perform in an industrial plant. The case company is currently performing spare parts classification, and it reminds earlier mentioned VED model. Since case company is having trouble to identify how to differentiate actions for V and E group, it might be a good way to use only two categories, functional (V+E) and cosmetic D like Dekker et al. (1997) and Botter & Fortuin (2000) suggested in their research which included a large number of spare part such as case company does. There are spare parts that are used in equipment with different criticality, which cause problems to case company determinate suitable stock levels. Case company could implement so-called protection levels, which means that if the stock level drops under re-order point, during the lead time, only critical equipment can use the part like Dekker & Bayindir (2018) suggested. Case company have also streamlined other processes related to the management of codified materials, which have already improved state of inventory management at case company. The objective is that case company can pay more attention to the critical spare parts and develop procurement processes and reduce inventory levels by moving non-critical items to the suppliers' warehouses. Based on the empirical founding and theory part, I would suggest that the case company could use three different dimensions of consumption, response time, and price to determine suitable stocking and procurement options for critical spare parts such as Botter & Fortuin (2000) stated. By using two classes on each dimension number of different segments remains eight, which efficient and manageable. The proposed framework is represented in figure 12. Additional, spare part classification offers valuable information about which items should be equipped with RFID tags, and it is a good starting point for RFID implementation.

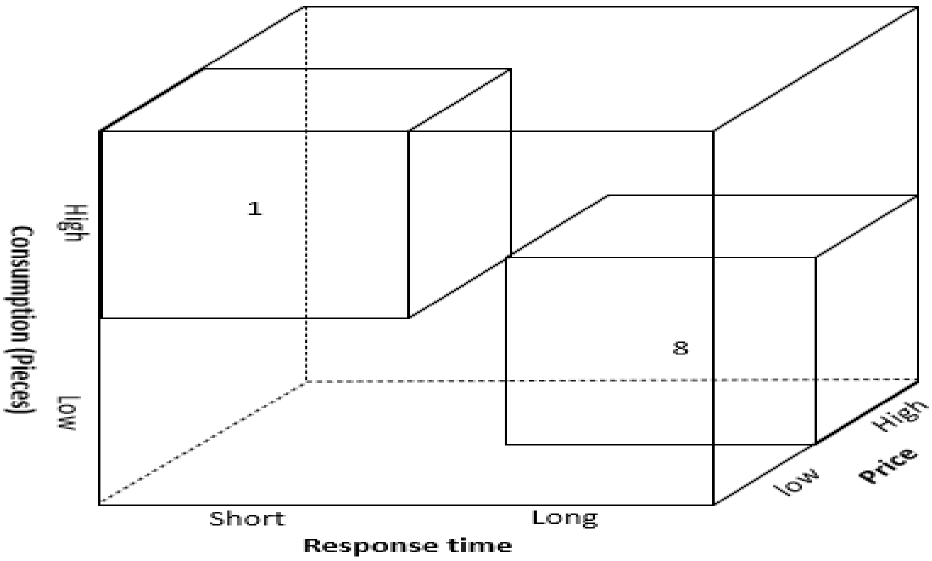

Figure 12 Item classification for critical item procurement based on Botter & Fortuin (2000)

From the empirical part arose a topic that is not currently managed very well. Around half of the deliveries received by case company belongs to the contractors. The reason for that is that a major part of the purchases is either investments or service orders that include parts that are directly delivered to the sites. A major share of the deliveries that belong to the contractors was missing referral information, and it causes inefficiencies to the inventory management processes such as receiving and picking. It was one of the most time-consuming tasks for warehouse operators. Additional to process inefficiency, it also caused a lot of internal transportation because deliveries were unloaded to the wrong destination, and it is costly and time-consuming. This is something that is currently hard to solve with any AICD technology because communication between case company and contractors is lacking. I suggest that case company would improve supplier relationship management with contractors and discuss during the quotation process why it is important that deliveries include proper information and why too early deliveries should be avoided. In practice, the first solution could be that the contractor's project team should forward all the purchases orders which are delivered to the case company to the warehouse. It would make the identification of delivered items easier, and costly internal transportations could be minimized. If this information is still missing, warehouse operators could ask for the information directly from a contractor, e.g. via email and avoid spending time on the internal investigation, but it will not fix the problem related to the internal transportations. Currently, the third party's process inefficiencies lead to time spent on extra task at the case company, and it needs to be solved as soon as possible.

"What are the potential barriers for adopting RFID to spare parts inventory management?"

In the previous research, RFID technology has received critic, and the purpose of the external interviews was to identify the current state of the technology. Researchers such as (Raumonen et al. 2003, Ukkonen et al. 2005, Khandokar et al. 2010) argued that RFID is not a suitable solution for metal items because metals reflect incident wave almost completely and it makes impossible to read tags or reading distance is significantly lower. Empirical research identified that problems related to tags on metal have been solved. There are a few main options to do that. Generally, a 1-3 mm thick insulation layer between the tag's antenna and a metal item is used to improve tag's reading capability. Interviewees also stated that tag's antennas could use the metallic surface as a reflector, as Zannas et al. 2019 suggested. This is a really important finding because, in a spare part environment, a significant share of items are made of metals. Otherwise, the RFID technology implementation would not be possible or economical worthwhile. Some authors' research (Kim & Huh, 2018; White et al., 2007; Khandokar et al. 2010) price issue related to the UHF tags was pointed out. Nowadays, these solutions are not as expensive as they used to be in the early or mid-2010s. Currently, tag prices have come down due to competition between tag manufacturers. At the moment, the basic RFID tag cost around 6 cents up to 15 cents, the price depends on the features of the tags and purchasing quantity. Based on the low inventory turnover rate and spare parts prices, we can say that the price of an individual tag is not that remarkable in a maintenance environment as in the retailing industry. Standardisation of UHF tags and technology related to that is the main enabler for tag price reductions. It does not matter which manufacturer’s product users take, it will work with the existing ecosystem. In the previous studies, for example, Connor et al. (2008) & Kapoor et al. (2009) have argued that RFID lacks in standardisation and Lim et al. (2013) stated that RFID standardisation is still in development state. Empirical research revealed that standards for the UFH RFID ecosystem have been finished during the past few years.

RFID performance measured by reading accuracy has been a hot topic in previous studies, Jeffery et al. (2006) and Kapoor et al. (2009) have criticized reading accuracy, but Ngai et al. 2007 and Goebel & Gunther (2011) have argued that reading accuracy is not a major problem with RFID. The empirical part reveals the same kind of result as, e.g. Ngai et al. and Goebel & Gunther, 99 percent accuracy is achievable. However, a full 100 percent accuracy is still hard or impossible to achieve. Empirical findings suggest that the pilot phase have a significant role in the success of RFID implementation. Colden rule of planning, testing, and developing should be made carefully, and it has to be done in every possible location since even building structures might affect the reading accuracy. Empirical results pointed out that piloting does not require big investments, a budget of 1000 euros is enough for comprehensive testing. One potential barrier which has not mentioned in the previous studies is that RFID technology requires that users, e.g. warehouse operators have to be knowledge about the restrictions of technology, such as if metal components are stacked on each other, it might affect tag’s antennas reading capability and orientation of tags. Another potential barrier at the case company is integration between the existing ERP system and RFID technology’s middleware. Case company’s ERP system is quite old, and it will require custom made solutions that will add the price. Also, the ERP system is an on-premises solution. RFID implementation will require more data storing capability, and it is more expensive with an on-premises solution than a cloud-based solution. Integration is definitely possible but might be more expensive compared to newer cloud-based ERP system. Empirical findings are supported with previous research such as Rim & Park (2008), Kapoor et al. (2009), Ngai et al. (2012) and Chanchaichujit et al. (2020). Another feature of spare part inventory management related to the integration of RFID technology is that the supplier base is quite wide. It can cause inefficiencies because it is not a suitable solution for the low volume suppliers due to increased administration for both parties. Based on the empirical result, we can say that RFID technology is quite mature, and most of the previously existed challenges have been solved already, but integration can still cause troubles for both buyer and suppliers side, and it can be time-consuming.

Another great challenge regarding spare part inventory management is that in a maintenance environment, inventory management processes depend on the efficiency of maintenance processes. The reason for that is that cost of codified materials have to be allocated to the individual work order. Empirical study reveals that poorly planned maintenance works caused rush at the inventory management processes. It leads to situations where normal inventory management processes cannot be followed, picking process was an example that arose from the interviews. In the case company, inventory inaccuracies are mainly caused by employees who do not follow the picking process. Usually, reductions to the ERP system are not made because warehouse operators are not aware that items are collected from a warehouse. Even if picking process at the case company would be changed, that only warehouse operators are allowed to do picking. As long as maintenance work orders are not done in advance, any AIDC technology cannot improve the picking process because costs cannot be allocated to the individual work order. This is something that was not mentioned in previous research, and drivers for cost allocation differences significantly, for example compared to retailing.

Based on empirical research, we can say that in spare part inventory management characteristics of stocked items vary a lot. Comprehensive analysis of ERP data related to inventory inaccuracies and interviews revealed that most of the items are quite small, and some parts have multiple duplicates. However, there are also part groups that are expensive, and stock levels are low. For the smaller parts such as sealings or O-rings, RFID tagging might be hard if they do not include any casing or packets. QR-codes and manual counting might be more suitable options for those like were identified in the empirical part. Most of the product groups identified were more like MRO-products such as piping, flange, welding rods etc. However, when spare part classification is ready, it will offer valuable information about which of them are critical and possible tagging decision should be based on that. Piramuthu et al. (2013) argued that companies do not afford to deal with a scenario where only part of inventory are item-level RFID tagged. Based on empirical founding, I would suggest that in spare part inventory management, it is not economically worthwhile or convenient to equip all spare parts with RFID tags, and so-called hybrid solution should be considered instead of full RFID or barcode solution.

What are the main differences of RFID potential between spare parts inventory management and regular inventory management?

A comprehensive literature review made by (Lim et al., 2013) revealed that in research between 1995 to 2010 related to RFID in the warehouse applications, the top benefits for RFID implementation in implementation focused articles benefits were reduced labour, data inaccuracy reduction, lower total cost, and resource management. Empirical research indicates that direct labour reductions on spare part inventory management are not that significant compared to the earlier studies. In a spare part environment, the supplier base is so wide that the benefits of RFID in the receiving process are hard to fully utilise due to the cost of administration, especially with smaller suppliers. Another reason for that is that amount of received deliveries per day is moderate compared to the studies with retailing or distribution focus. Compared to the earlier studies where receiving process was highlighted, the biggest potential of direct labour reductions on spare part inventory management is on the inventory audit process, since items have not to be inspected physically and time-saving, especially with items that need to be moved with a forklift is significant. Moving items with a forklift was mentioned to be one of the most time-consuming steps of inventory auditing in empirical research. For the critical items equipped with RFID tag, inventory auditing could be done more frequently to ensure inventory accuracy. Direct labour reductions on picking process are not that significant, but the whole picking process efficiency can be improved with AICD technology, and manual data updating can be avoided when whole processes can be finished during the picking.

However, the main benefits are achieved from inventory inaccuracy reductions because it is a starting point for most of the processes, and it causes a lot of extra work for multiple departments, like mentioned in empirical research. Overall process development is also critical in the spare part environment, and these findings supported by McFarlane et al. (2003), Langer et al. (2007), Banks et al. (2007) & Curtin et al. (2007), who argued that process redesign with technology implementation would lead to maximizing benefits in an inventory management context. In spare part inventory management, stock-outs of a critical component can have severe consequences. A decrease in inventory inaccuracies should be one of the main benefits when counting ROI for RFID implementation. However, it might be hard to determinate monetary value for consequences of stock out situation. Findings in theory part support this founding, Kapoor et al. (2009) mentioned that understanding cost-benefit analysis of RFID implementation is a significant obstacle for counting ROI.

To summarize empirical research findings, the following figures below are represented. Figure 13 identify RFID benefits, obstacles and where RFID can be applied in spare part inventory management.

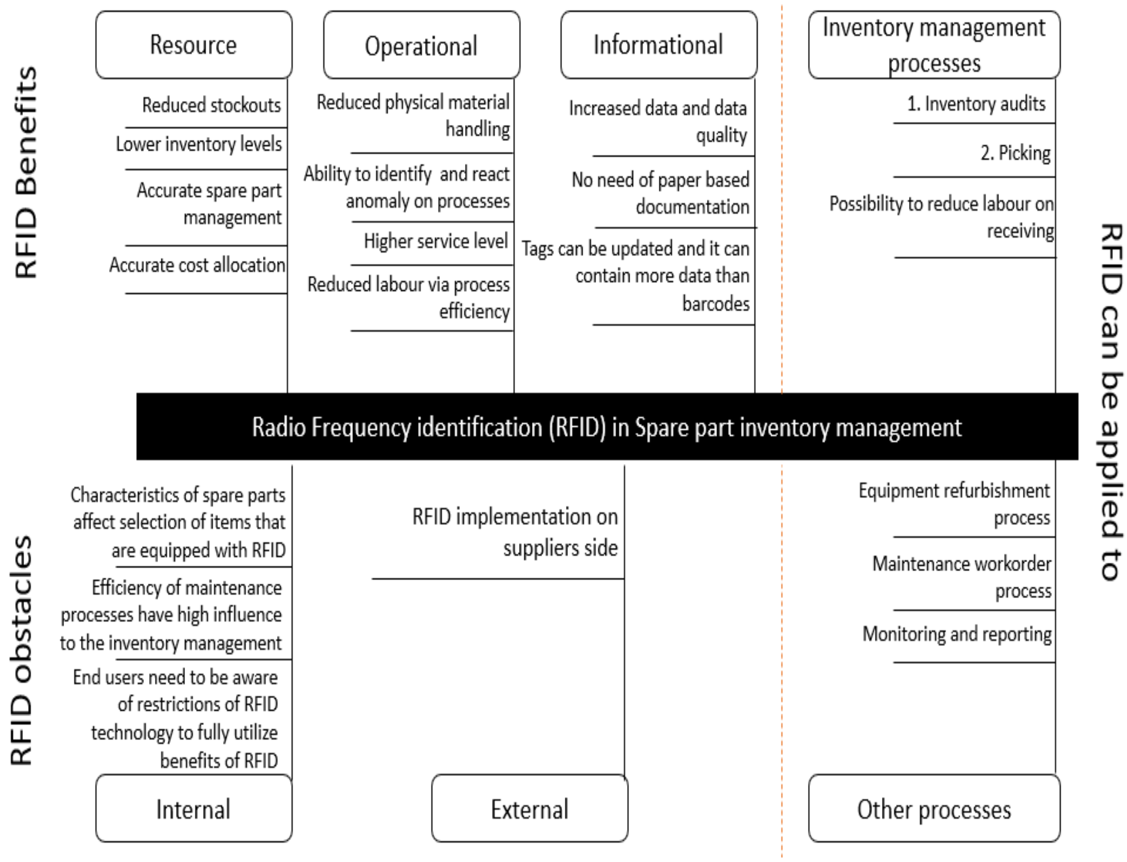

Figure 13 Summary of RFID's benefits, obstacles and where it can be applied

Additional to the empirical findings, the following implementation framework is represented below in figure 14. By following the framework, users should be able to achieve high reading accuracy in a production environment.

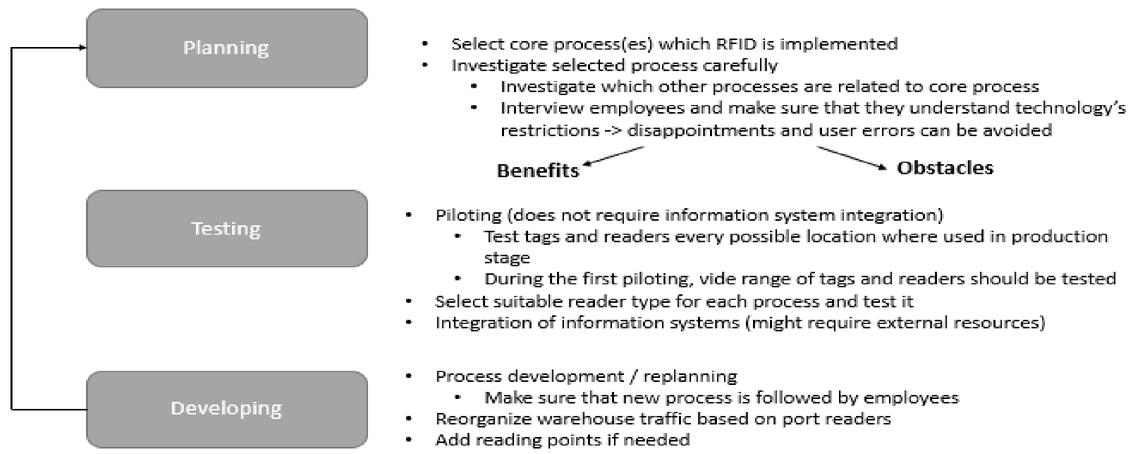

Figure 14 RFID implementation framework

6.2 Recommendations

The result of this study suggest that RFID technology has reached a maturity state, most of the technical issues have been solved, and tag prices have reduced to the achievable level. However, there are still issues in attracting suppliers to implement technology, especially in spare part inventory management, where buyers usually do not have a significant share of the seller's volumes, and negotiation power is smaller than in the retail industry. RFID has a significant benefit in reducing inventory inaccuracies and improving the inventory auditing process. It is crucial to identify processes that are utilising inventory level data when identifying the benefits of RFID implementation. Also, picking process can be streamlined with RFID technology, but the benefits compared to the other AIDC methods are not that significant. Because inventory inaccuracies have such a big effect on the maintenance environment, the suggestion made based on this thesis is to start the AIDC implementation process. Currently, both sites have one warehouse, which layout enables RFID implementation as it is, but other warehouse locations require traffic reorganisation.

RFID is not beneficial for all item stocked at a warehouse. This thesis suggests that hybrid solutions which utilize both RFID and QR-codes should be selected. Items that are equipped with RFID should be based on the characteristics of stocked items. One of the most important factors is the criticality of the spare parts. This research suggests that all the critical spare parts should be equipped with RFID tag to improve the company's capability to monitor stock levels more efficiently with frequent inventory audits and the capability to identify inefficiencies in picking process. A hard RFID tag is a suitable solution for refurbished equipment, which is reusable and can endure an even harsher environment than a regular UHF RFID tag. QR-codes could be utilized items that have high quantity such as O-rings and low price and which are easy to source in case of stockout.

One managerial finding of this thesis was the framework that could be utilized to identify suitable stocking levels and locations for the critical items. The case company could use the suggested matrix as it is or customize it. One thing that needs to be considered is central stocking for the high-cost spare parts with a long response time. It would be a profitable solution for the spare parts which are used other sites in Finland.

One of the findings on the empirical research was that currently, management of contractor's deliveries is lacking. Deliveries that belong to third-party service providers represent about half of the case company's total delivery volumes. Due to missing referral information, warehouse operators are wasting their time investigating which contractor's items are and where they should be delivered. This is something that should be solved right away because it has a major effect on the inventory management process efficiency. However, this is something that cannot be solved with AIDC technology because the root reason for process efficiency needs to be solved first. In the future, RFID technology could be used to improve process efficiency, especially when electronic referrals become more popular, warehouse operators are able to see what is inside of the cargo without inspecting paper document.

6.3 Limitations and suggestions for future research

Even this research was addressed to define the research gap and provide new information about the issue. There is a need for future research due to the limitations of this research. This research was performed as a qualitative study, and it is concerning only one case company and a few external resources, which are mainly answering issues related to the RFID technology. These findings cannot be generalized outside of the case company, excluding technology-related findings that can be generalized. However, this study's purpose was not to provide generalized results but rather gain in-depth insight into the case company about the current state of inventory management and the benefits and potential barriers to RFID implementation. Due to the limitations mentioned above, a suggestion for future research would be to perform a larger study with multiple case company to confirm these findings. By using multiple case companies from different industries, industry-specific findings might occur, and research would offer then industry-specific information.

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